Key Factors in Interdisciplinary Interactive Exhibition Design

Exhibition Design Processes with Museum Professionals and Interaction Design and Technology Experts

Master's thesis in Interaction Design and Technologies

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CHALMERS UNIVERSITY OF TECHNOLOGY
UNIVERSITY OF GOTHENBURG
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Abstract

This paper describes the process of identifying key aspects present in the processes for interactive exhibition design with special regard to the interdisciplinary nature of projects where internal museum professionals and external interaction design and technology experts must collaborate on design aspects. In a case study with one of Sweden's largest science centers, 13 interviews were conducted with participants involved in exhibition development projects and other members of the science center's staff. The interviews were thematically analysed to identify interdisciplinary design challenges and key aspects that affected the perceived outcome of an exhibition, and the observations were validated through a questionnaire sent to interviewed participants and staff at other science centers and museums in Sweden.

Our results describe three phases in the exhibition design process as especially important: *i) understanding of the design space between museum professionals and interaction design and technology experts,(ii) iterative design with museum professionals and interaction design and technology experts* and *(iii) launch, evaluation and long-term maintenance strategies for exhibitions between museum professionals and interaction design and technology experts.*

The primary contribution of this work is additional insight into the less often described design processes for exhibition projects with museum professionals and external contractors and collaborators. It serves to provide an overarching understanding of the exhibition design space and its challenges and should be particularly useful to introduce new participants and actors to these complex interdisciplinary collaborations.

Keywords: Interaction design, exhibition design, museum design, co-design, collaboration, design processes, ideation, prototyping, testing.

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Tora Bodin and Daniel Duvanå
Gothenburg, June 2021

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1
Introduction

Interactive museum environments offer one of the most interesting platforms for experimental interaction design. The desired user experiences are centered around understanding, entertainment, and exploration and allow designers to work with visualization, tangibility, and novel interaction technologies in a way that is rarely possible within other design spaces. Exhibit interactivity is particularly present in museums of science and technology, where a hands-on approach is considered central to experimenting with and teaching scientific concepts. These museums are called science centers.

Simultaneously, museums have a distinct purpose that does not necessarily center around accommodating experimental interaction design. They are crucial institutions for informal education, with heavy requirements on factual and scientific accuracy as well as understanding of informal learning theory. They have a responsibility to make sure that the knowledge they are providing is both correctly conveyed and correctly understood by their visitors.

A well-planned interactive exhibit should contain relevant scientific content, utilize a modern approach to informal learning, accommodate increasing demands on accessibility and inclusivity, and take advantage of technological advancement and the expertise required to implement it when it comes to interactivity and visualization. Together, these aspects work to ensure that exhibits are both educational and entertaining for science center visitors. The different perspectives within interactive exhibit design require different kinds of expertise within a project and place increased demands on the ways exhibit developers do their job [3]. The design process must consider the right aspects at the right times, and allow the developers to bring in different types of expertise in the project when needed.

1.1 Aim and Research Question

The design process for interactive science exhibits is very complex and involves people with different goals and expertise. Scientific content, educational theory and interaction design must be combined. It is not uncommon that discrepancies occur when trying to combine these different perspectives, leading to inadequate interaction quality, complexity levels unfit for certain target groups, or even scientific inaccuracy. The aim of this project was to study the existing processes for developing and designing interactive science exhibits at science centers by working with the following research question:

> Which key factors affect the interdisciplinary design processes of interactive museum exhibitions?

The goal was to identify critical factors and aspects of the interdisciplinary design processes of interactive exhibitions to contribute to existing research of the science center design space. In the end, the results of this project should be able to provide additional insights into the challenges faced in interactive exhibition development today that can aid science centers and museums in their design processes.

We begin this report with presenting science centers from a historical perspective to understand how the use of interactivity and technology has changed in exhibit development over time and which challenges science centers are facing today. We then describe the different aspects present in an interactive exhibit: content, educational theory and interaction design, in more detail. This is followed by an introduction of the different roles often present in an exhibition project, focusing on their responsibilities and how they relate to one another in a process. Finally, we present perspectives on development and design processes from both exhibition design and interaction design to find common ground, ending in a description on how co-design can be applied to interactive exhibition design to promote the involvement of different perspectives in the process.

1.2 Stakeholders

The following stakeholders are involved in the project and affected by its results:

1.2.1 Chalmers University of Technology

Chalmers University of Technology has an academic interest in the project. They provide the requirements and guidelines that need to be fulfilled for this master thesis to be approved. Chalmers also provides an academic supervisor and an examinator that help guide the project and ensure the academic goals are achieved.

1.2.2 Universeum

The science center Universeum will serve as a case study in this project and provides internal exhibition documentation and access to employees for several interviews. They are interested in the result of the project as a way to understand and improve their current development and design processes to be able to create modern interactive exhibitions for their visitors.

1.2.3 Tora Bodin and Daniel Duvanå

As the students behind this master thesis, we are invested in it as a way to explore the academic perspectives in interaction design. By looking at how interaction design is done in interdisciplinary teams, we hope to provide insights that are not only useful for the research community and science centers, but also for ourselves, as a way to understand how our expertise can be integrated in professional contexts outside academia.

2

Background

The following sections describe how and why the first science center, the Exploratorium, was created as a response to the educational needs of the 1960's. Further, we describe how science centers work to keep up with new requirements on educational practises by implementing a visitor-centered approach and utilizing new technology. Finally, we present the Swedish science center Universeum, which will be used as a case study in this report.

2.1 The History of the Science Center

The Exploratorium was not the first museum, nor the first science museum, to offer interactive exhibit material to their visitors. However, it is considered to be the first museum to focus primarily on creating interactive exhibits where visitors can learn science with a hands-on approach [4]. In a time post World War II, the U.S involvement in the Vietnam war and the nuclear tensions and Cold War with the Soviet Union all contributed to complicating the public's perception of the morality of science. The educational system was struggling to update the school curriculum to accommodate the need for a reinvention of the approach to science education within their existing institutions. As a completely new type of organisation, science centers were able to innovate in a way that the school system could not [4]. The Exploratorium opened its doors in 1969 and was founded by Frank Oppenheimer, one of the physicists behind the Manhattan Project and the atomic bomb. As a result of his involvement in the project, and its aftermath, Oppenheimer grew troubled concerning the relationship between scientists and nonscientists. He feared that professional science would run amuck unless the general public gained a stronger comprehension of the basics of science. After being exiled from his university faculty position due to previous affiliations with the Communist Party, he took on the life of a cattle rancher and soon started teaching biology and physics at a local high school. He adopted a hands-on approach even then, locating classes outdoors and at the local junkyard and encouraging his students to explore ideas on their own. When he was allowed to teach at universities again, Oppenheimer continued this approach by creating a "Library of Experiments" for introductory physics courses. This library served as the base for the early Exploratorium exhibits. Today, The Exploratorium has 300 employees and hosts over 650 interactive installations [5].

2.2 Science Centers Today

The Exploratorium is credited with creating the mold for what a science center should be: A museum that is not focused primarily on displaying collections, but on having its visitors interact with scientific phenomena themselves and learn through these interactions. In the five decades that have passed since its founding, science centers have become established institutions. In 2016, ASTC (Association for Science and Technology Centers) reported having 487 member science centers registered as existing or under development across 47 countries [6]. In Sweden, SCC (Swedish Science Centers) currently has 19 registered members [7]. Separate from (or perhaps inspired by) science centers, other fields of museum development are also moving towards a direction with a greater focus on the visitors' experience of museum exhibitions rather than collection curation [8, 9].

The shift from focusing on collections to focusing on visitors has generated a new field of research within museum sciences: Visitor studies, focused on how to "better understand the behaviors, attitudes, interests, motivations, and learning of individuals who visit informal/free-choice educational settings" [10]. Those familiar with the design field will note striking similarities between the notion of visitor studies and the term user research, which describes the process of "understanding user behaviors, needs, and motivations through observation techniques, task analysis, and other feedback methodologies" [11]. Unsurprisingly, the design process for a museum exhibition has quite a lot in common with design processes in general both in terms of methodology and when it comes to working with a user-centered approach. Allen mentions that many of the visitor studies conducted at the Exploratorium suggest that their exhibits would benefit from a more user-centered design methodology, especially in terms of designing for immediate apprehendability, affordances, and techniques for reducing cognitive load [12].

In a landscape where technology and culture is rapidly advancing and evolving, museums of all kinds continuously need to reinvent themselves to remain relevant in the eye of the public [13, 14]. This partially relates to the notion of an increased focus on the visitor and their interests and behaviors. It is also connected to a need for museums to accommodate new ways to present and explain the exhibit content by utilizing both new educational approaches and by adopting new technology. Some examples of technology that has made its way into museums during the past years are virtual reality [15], multi-touch tabletops [16] and tangible digital artefacts [17]. If used correctly, innovative technology has been shown to have a positive effect on the visitor experience [18]. At the same, it places increasing demands on the people involved in developing new exhibitions. They need to be aware of both what technology is available and how it can be implemented in a way that will encourage meaningful interaction [3].

Sweden is currently facing challenges in regard to ensuring skill competency for the next generation within scientific and technology-related fields. A report from 2017 warns that the Swedish workforce will be lacking 70 000 people with IT and technology competency by 2022 [19]. Previous research indicates that the Swedish educational system is struggling to keep youths interested in STEM subjects as they grow older [20, 21]. One of the reasons cited behind this is due to a disconnect between the things taught about science in the school curriculum and the things that the students are interested in. Schools fail to explain the relevance of the curriculum content in relation to society and the students' future careers, making many students who initially expressed an interest in scientific fields select other career paths. In addition, many of the current struggles in society are directly connected to a lack of understanding of scientific concepts by the public. Data harvesting, online misinformation and artificial intelligence generates complex ethical dilemmas that can only be fully understood by understanding the technology behind them. Many doubt the seriousness of global warming and in the midst of a pandemic, many are hesitant to trust the claims around safety and efficiency of vaccines, partly due to not understanding how they work. Similar to how the Exploratorium was able to adopt new teaching methodologies while the formal education system was struggling in the 60's [4], the science centers of today have an opportunity to approach new perspectives on informal education while the school curriculum is slowly adapting to these new challenges.

Universeum, the science center used in this project as a case study, is the national science center of Sweden and has been open since 2001. It is located in Sweden, Gothenburg, and is one of the ten most visited tourist attractions in the country [22]. The building hosts several exhibitions, which they refer to as learning environments, centered around animal life, such as aquariums, a rainforest, and a reptile exhibition, together with several more "traditional" interactive science center exhibitions: a space exhibition, a chemistry lab, and an exhibition focused on new technology. In 2016, they extended their original goal of invoking an interest in science among children and young adults to also explicitly focus on activating critical thinking, encourage more people to study science in higher education, and work toward a sustainable future. Universeum also strives towards incorporating new technologies in their exhibitions as well as the rest of their organisation and is actively working to do so, for example with a new exhibition currently in development called Visualization Lab, where advanced visualisation technology will be used to engage and educate visitors in a range of topics.

3

Theory

In this section we present previous research into interactive exhibition design in science centers and museums, focusing on the interdisciplinary nature of exhibition design and the design processes.

3.1 Aspects of Interactive Exhibition Design

Museums, and science centers in particular, are not only institutions of learning. They are also institutions of entertainment for their visitors. Many science centers work with a budget that is partially dependent on ticket revenue from their visitors and partially built on government funds and financing from private organisations. To keep existing, they must host exhibits that are interesting and entertaining enough to draw visitors, while at the same time keeping them rooted enough in the scientific practises and topics that are required by their other financiers [4]. The combination of content and entertainment value is not only a question of finances, but central to the core of science exhibit development: How does one present content in a way that is both entertaining and enlightening [23]? Here, we present the many aspects to be taken into consideration during the process of designing an interactive science exhibit: perspectives on selecting content, implementing educational theory and utilizing interaction design. In later sections, we will further describe how expertise regarding these aspects can be combined in the development process.

3.1.1 Content

A common way to initiate the development process for a new exhibition is to determine its scientific content; the ideas and phenomena that the visitor should be introduced to. The content should accurately describe the selected topic, must be properly understood by the people working on the project, and deemed relevant to be presented together in an exhibition. In some cases, an exhibition is developed through collaboration with research groups to make their work available to the public [1]. In other cases, exhibitions may be sponsored by external organisations who are interested in making more people interested in their field of work.

There is currently an ongoing debate regarding to what extent science center's exhibitions should adhere to the school curriculum. By presenting material that is similar to what is taught in school, science centers can work closer with the formal educational system. This allows them to be able to host school visits, and obtain government funding. At the same time, some warn that by adhering to the curriculum, science centers lose their role as innovators of new ways to teach science through interdisciplinary means [4].

3.1.2 Educational Theory

A science center is an informal learning environment. In contrast to formal learning environments such as classrooms, visitors make an active choice to visit an exhibit and interact with its content. In schools, education is often quite restricted; teachers have a curriculum to follow and if students are given a task, they are expected to complete it. In an interactive museum, visitors decide what to do based on what appears to be interesting and can do activities for a long as they want, in any order they like. This is a significant challenge when designing a learning experience, sometimes considered to be the greatest constraint underlying exhibit design [12]. Much has been written on how to construct and utilize informal learning environments. Laherto presents a framework for adapting educational research from formal education for informal environments [24] and Schauble and Bartlett describes the complex process of educational research and design behind an exhibition especially developed to suit the way small children learn about science [25]. In general, the hands-on approach present in interactive exhibits has been shown to be an efficient way to encourage scientific understanding [26, 27].

By combining previous educational theory for different target groups, fields and scenarios with knowledge from the science center employees' own experiences, science centers can provide unique opportunities for visitors to comprehend scientific topics. Additionally, the research fields of informal education and science education benefits profoundly from the opportunity to study interactive science exhibits [23, 28].

3.1.3 Interaction Design

If an exhibition contains interactive elements, the field of interaction design immediately becomes relevant. Interactivity can be present in museums in many different ways: Through the museum's web page, through mobile technology for navigation or digital "treasure hunts" or through interactive elements of individual installations. Several useful frameworks exist that can support exhibition designers when designing the interactions used in an exhibition. For example, wideström presents a classification framework for different types of science center interactivity [29].

For individual installations, Allen writes about the importance of developing exhibits with immediate apprehendability to allow visitors to grasp the purpose and properties without conscious effort [12]. She mentions how the Exploratorium has adopted many aspects of user-centered design when working with this approach. Affordances, cognitive load and familiarity are words commonly used during exhibit development. Inadequate usability can make visitors feel stupid for not understanding an exhibit [30]. It can also make them assume that an exhibit is broken, which has been shown to have a negative effect on the overall visitor experience [31]. There are many examples of how to create exhibits and installations from a usability perspective, drawing on knowledge from tangible interaction, information visualisation and interface design [32, 33, 17]. Insights from interaction design can also be used to evaluate and innovate exhibition accessibility and take appropriate steps to accommodate additional needs for some visitors [34].

The interaction design perspective does not only contribute to creating exhibits that are easy to use by visitors. Insight into the many different ways to create an interaction together with knowledge about new and upcoming technology is crucial to innovate around ways to explain scientific phenomena. By implementing modern interactive solutions, museums can remain relevant and interesting as technology and society progresses. This also creates a valuable research opportunity for the interaction design field; new technology that may not be mature or straight-forward enough to use in more formal fields can be explored and evaluated in a less restricted setting [35, 36]. Additionally, much can be learned about designing for public settings in general by looking at how visitors interact with exhibits in museums [37].

3.1.4 Combining Aspects

The different aspects of an interactive exhibition are all crucial to its success. They cannot stand on their own, but must be combined to create an exhibit that is both educational, entertaining and easy to understand. When this balance is achieved, it can result in very interesting exhibits. The project by Schauble and Bartlett used educational theory to interview children about how they understand fossils, and used this knowledge to design an exhibition where the content built on children's earlier conceptions of the topic and interactive activities inspired by scenarios present in children's everyday life [25]. At the Exploratorium, exhibit developers and scientists collaborated to redesign an existing biotechnology platform with a kinect-based user interface [1]. Inspired by collaborative learning between parents and children, Asai, Sugimoto and Billinghurst created an AR exhibit where parents can act as mission commanders and children as astronauts when exploring the surface of the moon [38]. When there is a mismatch between these aspects, or some of them have not been taken into consideration, it can lead to an exhibit that fails to achieve all that it set out to do. Perry describes an exhibit where the intent was to explain how colors can be created by combining different wavelengths of light [39]. The visitors could interact with the exhibit by using their hands to block out some of the lights and see how the colors of their shadows changed. The exhibit was centered around a clear scientific concept, and visitors appeared to enjoy playing around with the exhibit. However, they did not understand what was happening when they played around with the colors and thus, did not gain an understanding of the science behind the interaction. An exhibit can center around a relevant concept and appear to be enjoyable from afar but still fail to fulfill its purpose if interaction design is inadequate or the educational goals are insufficiently evaluated. A useful tool for supporting the interdisciplinary work of exhibition designers have been created by Ocampo-Agudelo, Maya and Roldán [40]. They present the DEX framework, intended to provide project participants with an overview of the different exhibition aspects to support informed decision making in their work.

The people responsible for the development of an interactive exhibit should have at least basic insight into the aspects introduced here but it is unreasonable to expect anyone to be an expert in every field required to build an exhibition. Instead, an exhibition development project involves several people, who are able to contribute to the project from different perspectives. In the next section, we will introduce the different roles commonly present in an exhibit development project and describe how these roles can work together through the development process.

3.2 The Interactive Exhibit Development Process

The aforementioned aspects: content, educational theory and interaction design expertise must all be taken into consideration during the development process along with many other aspects, such as budgeting and time planning. As we mentioned earlier, it is difficult for any single person to have enough expertise, or time, to take every aspect of exhibit development into account by themselves. The development of an exhibition is often done in teams where different persons contribute in different ways. When many people are working together, it becomes particularly relevant to base the work on some sort of framework to avoid conflict and time-consuming communication mishaps [41].

There are many ways to structure a process in regard to the roles present, who is given authority over the project, and the different steps that take place during development. Many emphasize the importance of having models and processes to follow, but mean that it is less relevant which one is actually selected and that the primary value is that the people involved all agree on the same ones and follow them together [42]. In the following sections, we present some perspectives on the development and design processes for an interactive exhibit. We begin by introducing the different roles of responsibility involved when creating an exhibit and how these roles can be organised into a functional team. We then present the overarching development process for an exhibition, and continue with perspectives on how to implement iterative and participatory design in science centers. Most published documentation focusing specifically on interactive exhibition development for science centers is provided by the Exploratorium. To be able to provide less specialised approaches that may be suitable for science centers without the resources available to the Exploratorium, some of the perspectives presented are based on more general exhibition development. We then apply knowledge from other kinds of interaction-focused development to understand how these models can be utilized especially for interactive exhibitions.

3.2.1 Roles

The roles in a process describe the different responsibilities and expertises of the project members. A process role is not necessarily equivalent to a job title, but rather describes the specific tasks that a person is responsible for within the scope of a project. Depending on the projects, a person can have the same role in many projects, or a different role in each one. It is also possible for a person to hold multiple roles within the same project, depending on the scope of the project and that person's expertise, or for several people to be responsible for different aspects of the same role. There is no "correct" way to define these roles but many examples present a similar approach.

Based on previous experience, Kamien [42] defines five roles commonly found in the exhibition development processes at museums. She argues that many of the problems found in exhibit development can be seen as the result of one of these roles not being filled or approached the right way during the process:

Client: The exhibition client is usually part of the upper management at the museum. They have the final approval rights for the exhibition and are responsible for providing the resources required for development. They also ensure that the exhibition is aligned with the goals of the institution.

Project manager: The project manager is responsible for the overarching process of developing an exhibition. They work to ensure that the exhibition is completed in time and on budget, and that it fulfils the predetermined goals. They plan and organize the ongoing exhibition development process and are primarily responsible for communicating the needs of the project to other in-house departments and external contractors.

Content specialist: The content specialist is primarily responsible for the content of the exhibition. For a science center, this means that they help identify the fundamental, important and interesting aspects of the selected topic that should be represented in the exhibit and make sure it is done accurately. A content specialist can be either an in-house resource, commonly referred to as a curator, or a researcher who is an expert in the field who is collaborating with the exhibition development team.

Designer: The designer is responsible for designing the exhibition aesthetics. This includes working on floor plans and layout, determining visual concepts, scenography and other atmospheric aspects and providing the proper blueprints and concept sketches required to build the exhibition in full. It is not uncommon that an external architect or design bureau is responsible for this role.

Content interpreter (developer, interpretive planner, educator): The main responsibility of the content interpreter is to ensure that the topics selected for the exhibition are presented in a way that makes the knowledge accessible to the target audience. They help define a desired visitor experience for the exhibit and identify which content should be presented to achieve this, and how the presentation should be done.

Museums Victoria presents a list of roles that is quite similar to Kamien's model, but adds a few other examples to the list [43]:

Publicist: The publicist is responsible for making the public aware that the new exhibition exists. They work with the museum's social media and other types of marketing such as local newspapers to promote the new exhibitions arrival. They are also responsible for organising the exhibition opening.

Further, they separate the role of content interpreter into two separate roles:

Audience Advocate: The audience advocate is responsible for ensuring the exhibit adheres to the goals and needs of the intended target groups, in terms of both exhibition comprehensibility and accessibility. They are familiar with how learning in informal environments occurs and work to ensure that the exhibition is adapted to this approach.

Public Programs officer: The public programs officer works together with the audience interpreter with identifying and creating material to suit different audiences. During development, they pay special attention to how to enhance the visitor experience in an exhibit. They develop specific programs to complement the exhibit, such as guided tours, talks with “experts”, or special activities for very small children.

It is mentioned that there are many present in the development process who may not be part of the core team responsible for the exhibition but still valuable contributors to specific parts of the process: *Specialists*, such as lightning technicians, health and safety advisors and software developers, amongst others [44]. An emphasis is also placed on involving the so-called *Spectators*, museum staff that are not explicitly involved in the development process, for constructive feedback and advice. This could refer to other exhibition developers who are working on other projects, or other stakeholders in the exhibitions, such as maintenance staff or the employees who man the exhibition floor. At the Exploratorium, high school students, called Explainers, are hired to interact with, guide and assist visitors in the exhibitions [45]. Many other science centers recruit volunteers to fill this role.

It should be noted that these are the roles commonly present in museums on a greater scale, and not specific to science center development or to interactive exhibitions. For interactive exhibits, it may be appropriate to assign someone with explicit interaction design expertise to work with exhibit usability and technological solutions, aspects that often fall under the of the content interpreter's responsibilities. It is possible that we will be able to offer more concrete advice on how to implement this role closer towards the end of the project. It could potentially be done either by inviting an interaction designer as a project specialist when needed, or by having a museum educator and an interaction designer share the content interpreter role.

3.2.2 Team Organisation Models

In an interview-based study held during the development of an interdisciplinary project meant to connect school activities with those in a science museum, science center employees, designers from an external bureau and university researchers were interviewed with the intention of determining different priorities in the project based on their backgrounds [46]. While all involved agreed that every aspect of an educational, interactive experience is important, participants from different backgrounds tended to emphasize different aspects of the project as most important. Those who come from a background in educational research prioritized the learning aspect of the project, museum professionals focused on the visitor experience, and the involved architecture firm emphasized the need for emotional involvement. Unsurprisingly, people with different roles and previous experiences will commonly put more emphasis on the aspect of the project that is most relevant to their own responsibilities and expertise.

As the person who is given the main responsibility for a project is commonly the one trusted with major decision-making, the aspects they emphasize may have an outsized impact on the direction of the project. For exhibition design, it becomes relevant to understand how the priorities and background of the lead visionnaire will shape the final outcome of an exhibition. Traditionally, the curator or content specialist has often had the main responsibility for both the content and creative vision of an exhibition. While not always the case, this model can create a scenario where the curator selects exhibition content based on their own expertise and interests. This can create an exhibit that is out of tune with visitor needs and the content is prioritised above the visitor experience. If an exhibition is developed externally, a content specialist may not be available to the project. In these cases the responsibility for both content and creative vision is often given to the lead designer on the project which may cause the exhibition to instead be too focused on design aspects while failing to hold together conceptually [42].

Kamien finds the developer model, in which a senior content interpreter has main responsibility for an exhibition, to be most successful [42]. The content interpreter is supported by a large group of specialists from several different fields (a project manager, curators, designers, evaluators etc.). Where a designer or curator focuses on content and presentation, content interpreters focus on the visitor's interpretation of the exhibition, making this the main vision of the project. As all team models, this one can instantiate internal conflicts if team members do not support the authority of the one in charge. It also tends to take a huge toll on the lead developer. It is also possible to work with exhibition development with a team approach. Here, a content specialist, a designer and a content interpreter share equal responsibility for the vision and outcome of the project. While it serves to ensure that no single aspect is given primary control over the exhibition, the different roles may strive to drag the project in different directions. By appointing a person to have head authority, they can create a common vision for the project. If several different visions exist amongst the people in charge, it can cause them to each prioritize their own points of interest, leading to a fragmented result that is uneven to the visitors.

Every model or approach has its advantages and disadvantages in how it affects the development process and final exhibition. It is important to understand how different perspectives can shape an exhibition and utilize this knowledge when determining the team organisation. However, the most important thing is that everyone involved in the project agrees on the structure, and respects the project vision.

3.2.3 The Development Process

The development of an interactive exhibition typically includes a multitude of people and stakeholders who contribute to the project in varying ways. Depending on the project, the actual process can be structured in quite different ways. Due to being the first, and probably most well-documented science center in the world, the Exploratorium is often referenced to as a representation of science centers everywhere. There, exhibit development is conducted primarily in-house. The science center sports its own workshop and makerspace and has full-time employees with the competency to construct exhibits in its entirety. It is common that the same people are responsible for both concept, design, and actual construction [47]. Most science centers and museums do not have the luxury of in-house workshops and staff capable of using them. It is not unusual for a museum to develop exhibits together with bureaus that specialize in exhibition design, or to order an exhibit in its entirety from an external contractor. Additionally, the Exploratorium model is for the most part centered around individual, stand-alone exhibits that explore individual phenomena [48]. Many science centers and museums, including Universeum, are working with exhibit design from a more holistic approach; An exhibition can typically fill an entire room with thematically connected installations that are all developed in parallel. This requires a development process that will cover both the development of the exhibition in its entirety and the individual installations.

The Franklin Institute uses a process with seven phases during exhibition development [42]:

1. *Initial Concept:* The topic is thoroughly researched and the project's conceptual framework is described.
2. *Concept Development:* More focused research is done. Formative evaluation through prototyping and interviews take place. An exhibition outline, schedule and budget is created.
3. *Final Concept:* The design is finalised through refinement of exhibition elements.
4. *Construction Documents:* Documents and sketches are created to describe how the exhibition should be constructed.
5. *Fabrication:* The exhibition is constructed with in-house means and collaboration with external companies
6. *Opening and Punch List:* Immediate issues are resolved. Project members start preparing for evaluation and final documentation.
7. *Revisions and Documentation:*A summative evaluation is performed on the

exhibition. All exhibition documentation is gathered and archived.

At the Exploratorium, similar steps are used to develop individual exhibits (Fig.3.1)[1]:

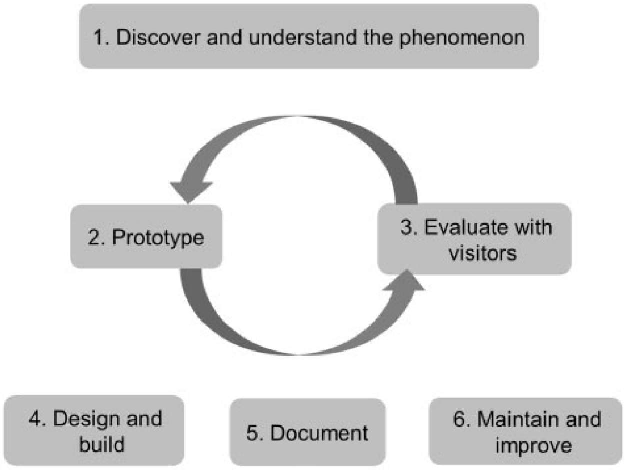

Figure 3.1: The exhibit development model at the Exploratorium [1].

1. *Discover and understand the phenomenon:* Potential exhibit ideas are researched and assessed based on how interesting the topic will be to the visitor and how well it will translate into an interactive exhibit.
2. *Prototype:* Mock-ups and low-fidelity prototypes are developed to explore the phenomenon further and examine different approaches.
3. *Evaluate with visitors:* The prototypes are evaluated with visitors to refine the design and identify potential usability issues and misinterpretations early on in the process. They are then updated according to the findings and evaluated further.
4. *Design and build:* After several iterations, the final design is reworked from a prototype to an installation that is sturdy enough to withstand repeated use by visitors.
5. *Document:* Finished exhibits are extensively documented, from early prototypes to contact information to vendors involved.
6. *Maintain and improve:* If the resources are present, exhibits can be improved over time if deemed necessary.

3.2.4 The Design Process

When summarizing a study where museum professionals at over 60 museums were interviewed, Doering says that “in our interviews with museum staff inside and outside the Smithsonian, the design phase of exhibition development has the most struggles and conflicts” [49]. This should be cause for concern at any museum or science center and is the motivation behind this project. The design phase refers to steps after the general concept of an exhibition has been determined; the day-to-day design decisions that take the exhibition from a concept to a finalised design. In this report, the design phase is referred to as the exhibition's design process.

Many aspects of exhibition development are strictly constrained by budget concerns, deadlines and formal requirements. This is something that is necessary to ensure that an exhibition is finished on time and fulfils its intended purpose. The development process exists to provide structure to a project, and ensure that the project is continuously moving forward toward completion. The design process in exhibition development is typically less well defined in formal documents, as the steps taken can vary a lot from project to project, depending one the people involved and the goals of the exhibition. Some activities often present here are target group research, idea generation, prototyping and formative evaluation. A framework from user experience design can be used to define steps commonly present in this process. An example of this could be the Google Design Sprint Kit, an iterative frameworks with six steps per sprint, as seen in figure 3.2 [2]. The steps of one sprint is described as following:

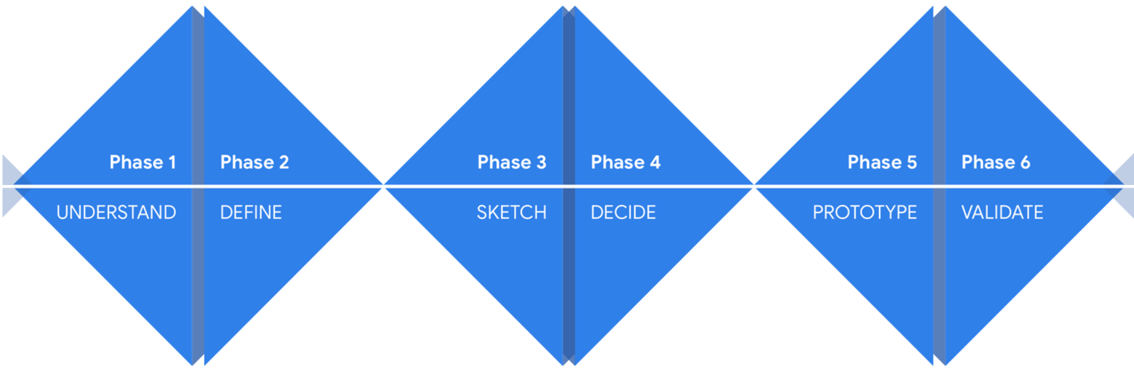

Figure 3.2: The six step model used in google's design sprint kit [2].

1. *Understand:* Here, project participants create a shared knowledge of the problem at hand to look at the issue from different perspectives.
2. *Define:*The knowledge shared in the understand phase is evaluated to establish a more specific project focus. A specific context for the design is defined and goals and success metrics are established.
3. *Sketch:* In the sketch phase, participants produce different solutions for the problem through sketching techniques, resulting in several solution sketches for different ideas.
4. *Decide:* The team selects one of the solution sketches to move forward with.
5. *Prototype:* A quick prototype is created to validate the selected idea. Prototypes can have very low fidelity and should represent the steps of the sketched experience that the team wants to test.

6. *Validate:* In the validation phase, the created prototype is evaluated with users, stakeholders or technical experts, depending on the purpose of the prototype.

In the following design sprint, the takeaways from the previous one is used to rethink the concept or continue to refine the idea. The advantage of an iterative process is that it provides opportunity to evaluate the developed product in many different stages of development. Through formative evaluation of low-fidelity prototypes, issues and opportunities present in an idea can be discovered early on in the process [50]. This allows designers to make changes to improve usability and other aspects at very low cost, as low-fidelity prototypes are easy to produce. Projects without formative evaluation or room for iteration must trust that their product works without validation, something that can result in resource demanding changes if usability issues have not yet been discovered when a project moves to production [51].

The Google Design Sprint is one of many different models used for iterative design processes and not necessarily the one best suited for exhibition design. Iterative design is clearly already present in the exhibit design field, as seen in the prototype/design loop present in the developer model used at the Exploratorium (figure 3.1). We choose to include a framework from interaction design primarily to facilitate knowledge transfer between interaction design and exhibition design and do not mean to propose the Google Design Sprint Kit as superior. In fact, many of the design process structures present in interaction design are based on the concept of design thinking [52], a methodology that is often criticized for valuing an external designer's problem solving skills higher than the experience and knowledge of experts and project stakeholders [53]. As the aim of this project is explicitly to look at ways of combining expertise from different fields, prioritization of a model with an acknowledged bias to one field would serve directly against our purpose.

4
Methodology

In the following section, the methods used during the project are presented. Some methods of working that could have been useful for the project but were not selected are also described and discussed.

4.1 Design Research

Ludvigsen [54] describes research in interaction design to typically fall into one of three categories: Research on design, focusing on studying the results and consequences of usage of a design product, Research in design, focused on examining design processes, practice and methodology, and Research through design, which refers to utilizing design methodology and perspectives to examine an area of interest. This project will primarily utilize a research-in-design perspective, as the purpose is to examine current design methodology in exhibition development and attempt to suggest new methodology and solutions that can be used in the field. New methodology can refer to methods for ideation, evaluation or co-design, as well as more overarching perspectives on design processes.

Additionally, design methodology and design thinking can be used to achieve results through an iterative process, as described in the definition of research-through-design [54]. The aim of this project is not to produce a design artefact, meaning that the context is slightly different from what is commonly used with the research-through-design term. However, we can choose to approach the conclusions of this thesis as an iteratively developed product, where each methodological activity within the project serves to examine and refine the current conclusions to create a picture of the current design processes that is as closely aligned to reality as possible. By continuously striving to examine and improve our insights, a design perspective could be utilised in our research.

4.2 Qualitative Interviews

Interviews are a useful tool to gather information about participants' experiences and gain an overarching understanding of a topic. There are many frameworks for thinking about different types of interviews in qualitative studies [55]. McNamara defines four types of interviews: Informal, conversational interviews, the general interview guide approach, standardized open-ended interviews and closed, fixed response interviews [56].

Informal, conversational interviews are held without predetermined questions. Instead, the researcher attempts to be as open-minded as possible, to allow the topics of the interview to follow the topics brought up by the interviewee and "go with the flow". Interviews held with the general interview guide approach are used when the intention of the researcher is to gather information from the same general area from all participants. A set of questions are created to ensure the interview stays on the same track, but some degrees of freedom are still present to allow the researcher to ask follow-up questions and personalize the interview to suit the knowledge of the participant. This approach is also known as semi-structured interviews [55]. When using the standardized open-ended approach, all interviewees are asked the same open-ended questions and can choose to answer them in any way they like. In fixed response interviews, participants are presented with response options, and can typically choose from a list of alternatives when answering a question.

An interview does not need to only consist of questions that are asked and answered verbally, it can also include other ways of spurring conversation and help researchers and participants to better communicate. For example, interviewers can provide participants with pen and paper and ask them to draw something in response to a question such as "can you draw a map of who's involved in the design process and what they do?" [57]. Another technique is to have the participants use, sort and group cards with a word or a picture on them to visually convey their thinking [58]. An example when this might be useful is when trying to understand what a participant thinks is most important among many alternatives. In order to help participants answer that question, the researcher can ask the participant to rank cards that represent those alternatives in order of importance. Using visual and tactile aids in an interview can help the participant to formulate their thoughts more clearly as well as help the researchers better understand what participants are communicating and ask more specific follow-up questions. However, doing so over video chat can be challenging and prove more distracting than helpful. Participants may either need to use some digital tool that they may or may not be familiar with or if physical aids such as pen and paper are used, it may be difficult for researchers to see what the participant is drawing as easily as if the interview is conducted face-to-face.

4.3 Thematic Analysis

Thematic analysis is a method commonly used to code qualitative data and discover patterns in qualitative data, e.g. interview transcripts. There are many different variations and types of thematic analysis. Braun et al group these into three broad types: coding reliability approaches, reflexive approaches and code book approaches [59].

Coding reliability approaches are characterized by blending qualitative and quantitative methods by testing the reliability and replicability of how the data is coded by letting multiple coders, all working with the same list of codes (often with definitions and examples from data), analyse and code the data independently [**source**].

The results that the coders come up with are then compared according to different methods, often using algorithms, to determine how much agreement there is. Higher levels of agreement are supposed to indicate less bias in how the researchers have coded the data and that the themes are a more accurate summarization of the data and vice versa. Braun et al argue that this approach incentivizes making codes that will lead to more agreement, which could mean that the codes are more high-level summaries of themes rather than codes that require more in-depth analysis and engagement and that it is not testing researcher bias but rather if the coders have been trained to code data in the same way [59]. They also argue it does away with a more open, flexible and exploratory analytic process and that this is problematic.

Reflexive approaches are described by Braun et al as “a fully qualitative approach” where “researcher subjectivity [is] not just valid but a resource” [59]. Codes and themes are derived from deep and exploratory analysis of the data, with codes being iteratively changed to reflect changes in the researchers’ understanding as they go along. If a coding reliability approach is more about minimizing and summarising the data, a reflexive approach is more about coming up with an interpretation of the data, meaning the researchers are actively using their own perspectives to understand the data and tell a story based on it.

Code book approaches are thematic analysis variations where the themes or codes are decided upon in an early stage, before the data have been rigorously analysed. The codes are formulated with descriptions, for example in some sort of “code book”, hence the name. Template analysis [60] and matrix analysis [61] are examples of this. Braun et al describe this approach as something existing between a reflexive and a coding reliability approach as it is using a more structured way of working with codes, but does not utilise qualitative methods to calculate coding agreement and also embraces more of the qualitative way of working [59].

In this thesis project, the aim is not to just collect and summarize the experiences of the people involved in interdisciplinary design processes of interactive exhibitions and their perceived challenges, but also to interpret their experiences through a lens of interaction design to identify challenges that may go beyond (or even run counter to) those self-reported and try to answer the question of how the design process should be altered to better handle those challenges. Because this project is highly exploratory in nature, with little preexisting knowledge about the specific context and design processes and no predetermined themes, it also lends itself more to an iterative approach to identifying and developing themes. As such, a reflexive approach is best suited for our purposes.

4.4 Questionnaire

Questionnaires and surveys are useful ways to quickly gather information from a larger group of participants. Responses can be both quantitative, such as multiple choice questions or likert scales, or qualitative, in the shape of more open-ended text responses [55]. One advantage of questionnaires over interviews is that they make it somewhat simpler to recruit participants, as there is no need to schedule meetings. The primary disadvantage of questionnaires is that researchers do not get the chance to clear up ambiguous responses or as follow-up questions, unless the questionnaires are used as a pre-study to inform later interviews [55]. Unlike interviews where the interviewee can ask for clarification of a question, and the interviewer can not only use their words but also tone of voice and body language to convey information, questionnaires does not offer these possibilities, which means that they demand more effort in the wording of questions to minimize misunderstanding and to think through what tone the wording of the questions might strike for the person reading them. When writing a questionnaire it is also important to think about what types of response options to provide for the participant. Opting for open-ended text responses, where the participant may write whatever they like, can provide a richer and more valuable answer but takes more time and effort on part of both the respondent to write and the researchers to analyse. If the choice is made to only provide predefined answers that the participant have to choose from, it is crucial that a good range of answers are given including options such as “I don’t know”, “I have no opinion”, “None of the above” to not force participants to answer in a way that is not true to what they think, which can cause frustration as well as make the collected data less accurate.

The research in this project will mainly focus on one organization and a smaller number of people who work there. It is also mainly an exploratory project, searching for challenges and issues in the design process of exhibitions and installations without having a predetermined expectation of what to find. This means that for most of the work, questionnaires will not be a great fit because of their limited ability to capture responses outside the defined structure of them, more open-ended interviews would be a better fit. However, questionnaires can be very useful in the later stages of the project to assess how well our findings at the science center that serves as a case for this study align with opinions and experiences of staff at other science centers and museums.

4.5 Diary Studies

There are a number of research methods where the researchers themselves are not directly involved in collecting the data, but instead gives the users or other people already involved in the context that’s being studied tools to document their own experience and context. These methods can be labeled as “diary studies” and are usually carried out in the actual space and context being researched, as opposed to something more akin to a “laboratory” setting that methods where researchers themselves are directly involved often are [62]. Rieman argues that the results of research that take place in a laboratory type setting instead of the place in the actual space that is being researched (e.g. a workspace) may give a very limited insight into the behaviors of people in the real context they operate in, and perhaps even lead to faulty conclusions, but that methods carried out both in the real context, and ones that are not, can complement each other and lead to greater insights [62].

In diary studies, the participants collect qualitative (or sometimes quantitative) data about their own behaviors, activities and experiences, often over an extended period of time [63]. This can be done in many different ways, using actual diary books, photos, sound or video recordings, etc. You can also have participants not just document their own experience, but those of their peers [64], handing the role of researcher over to someone who people may already know and be comfortable around and thus may be more willing to share a more accurate picture of their experience.

In a project such as this one, where the goal is to understand how a particular workspace actually works, the processes and challenges that exists and look for ways to potentially improve, methods that can collect data over longer periods of time may prove much more valuable than a few interviews or questionnaires that may only capture a snapshot representation. Data collected by the people working in the workspace themselves may provide insights that are hard, or perhaps impossible, to access through methods where external researchers are directly involved with collecting the data. However, diary studies can be very burdensome for the participants who are tasked with documenting, making it hard to justify in some workplaces where workers may not be able to comfortably set aside the time or resources needed. Also, the data collection of diary studies are often stretched out over long periods of time, often weeks or even months [63], and the amount of data produced can end up being very large and in need of significant analysis from researchers before value can be extracted from it. As such, this method may not be well suited for a project like this one, where the people whose workplace is being researched can't be asked to designate the time and resources that would be needed and the timeline and resources of the project itself are too limited to handle the data collection and analysis.

4.6 Case Studies

Case study is a research methodology that involves close examination of one or a few case(s), usually within its own context and environment, as opposed to a lab environment [65]. Ridder [65] says that case selection in case studies are typically non-random by design, that is to say, unlike in much of qualitative methodology where you want to avoid selection bias, here researchers actively select cases based on what they want to achieve. It is common to choose a case that is believed to be representative of a larger number of whatever is being studied, but cases can also be chosen precisely for the opposite reason; that they stand out and are uniquite in some way.

Case study design has many different aspects, and one the most important aspects is whether the study is a “within-case analyses” or “across-case analyses” study, according to Ridder [65]. Within-case analysis means that each case is being studied only in relation to itself and researchers search for patterns and insights within that case, as opposed to across-case analyses where researchers compare patterns and data across different cases. However, Riddler [65] also stresses that such aspects are not binary choices and that it is common to combine different methods and designs.

Case studies are commonly associated with collecting qualitative data such as interviews, documentation and observations but can also include collecting quantitative data [65].

In this project, we only chose one case to examine in depth, mainly using a within-case analysis. Some incorporation of aspects of across-case analysis still occurred through the collection of data from additional science centers close to the end of the project.

5

Planning

The project plan was constructed as a design process consisting of three main phases, that can be summarised as (i) understanding, (ii) iteration, and (iii) evaluation.

5.1 Phase 1: Understanding

The plan of the first phase was to familiarize ourselves with the science center used as a case study, gather data on their experiences of exhibition and installation design and development in order to find what areas to focus further interviews on, as well as develop a basic understanding of their overall organisation structure and processes. The reason we planned to not only focus on the design process itself but also to a certain degree on the overall organisation structure and development processes, was that we believed it to be helpful to know how the design process fits into the overall development processes (which include activities that are not directly related to design, e.g. evaluating risk and cost, securing funding or some aspects of organising in projects).

The aim of this planned work was largely preparatory to achieve a more thematically focused round of interviews in the second phase, but it was also planned to start the identification of critical factors and challenges that could be iterated upon in the next phase. The planned outcome of the preparatory work in this phase was understanding where and how to search for possible challenges and critical factors for success. In other words: whom to interview, what to focus questions on and which exhibitions and installations to analyse in more detail.

This was to be achieved by conducting semi-structured interviews with persons directly involved in the design and development of exhibitions and installations at the science center. We planned to talk to people with different roles such as project managers, content specialists and educators.

Once the data had been gathered through interviews, the planned conclusion of the first phase was a thematic analysis to start the process of identifying critical factors and challenges in exhibition and installation design, where the result could be iterated upon in the second phase.

5.2 Phase 2: Iteration

The second phase was planned to be an iteration upon the results from the first phase, mainly through more semi-structured interviews with the science center staff and more thematic analysis. The results of the first phase were planned to inform the work of the second phase in two ways.

Firstly, the preparatory work of the first phase (identifying areas of interest such as exhibitions and installations to further research) was planned to be used as the basis for selecting whom to interview in the second phase, as we wanted to interview people with direct experience of these projects and areas of interest. Secondly, the first iteration of themes regarding critical factors and challenges in exhibition and installation design was planned to be used in part to inform what questions to ask of interviewees in the second phase, as we planned to delve deeper and gain a better understanding of themes that would come up during the first phase. However, we did not want to limit ourselves to only ask about preliminary insights from early on in the project, so we planned the second round of interviews to also probe for more critical factors and challenges, for example by planning to ask participants about their experiences and thoughts about what makes an exhibition or installation successful or not more broadly.

Through more semi-structured interviews and a more extensive thematic analysis, our plan was that the result of phase 2 would be a collection of somewhat well defined and specific critical factors for success and challenges in exhibition and installation design that could be evaluated in the final phase.

5.3 Phase 3: Evaluation

Once we would have a collection of insights to attempt to answer our research question, we planned to also evaluate those insights by asking science center staff, both interview participants and others, to weigh in on how well the critical factors and challenges identified by us would match with their own experiences and thoughts. The reason for doing this is twofold: firstly, as Wadsworth suggests [66], letting interviewees weigh in on the researcher's interpretation of their words lets the researchers check if their understanding of what the interviewees said is fair and gives the interviewees an opportunity to provide clarification or even pushback. Secondly, by also asking science center professionals from other organisations than the one where we would conduct our interviews, we could begin to assess if our conclusions could apply to science centers more generally, as opposed to only being applicable to the once science center used as a case study in this project.

The planned method for achieving this was through constructing a questionnaire where our preliminary findings would be presented and respondents asked how well these match their own thoughts and experiences within their organisations with multiple choice questions and optional text responses. We planned to use the results from the questionnaire to assess the validity of our findings as well as use it as an opportunity for iteration and further specifying our insights with the help of potential clarifying comments from respondents.

5.4 Ethical Considerations

When analyzing previous projects and conducting interviews with people involved with the expressed purpose of probing for critical factors and challenges present during exhibition development, there was a risk for encountering interpersonal conflicts between employees or other sensitive information about the organisation. It was not immediately clear how to handle such issues and information but steps should be taken to ensure that neither individual employees or the science center itself were harmed by anything presented in this report. Questions around what information to include in a report or make available to other people (e.g. other interviewees) may be of ethical concern, especially since the interviewed participants would be recruited from a small group of employees, meaning that identifying the person behind a piece of anonymized data (e.g. a quote from an interview) is not impossible. This also extends to data gathering in general in the project, where the handling of potentially sensitive material needs to be handled responsibly and with consent.

It was also possible that we, because of a lack of contextual knowledge in regard to the culture and history of the team at the science center, could miss the significance or misinterpret something an interviewee said, and thereby unintentionally misconstrue the information when presenting it. This could potentially lead to participants and other members of the staff feeling misrepresented themselves, or that we were misrepresenting their organisation and their work as a whole. This could in part be counteracted by giving participants an opportunity to give feedback to our interpretation of their words.

Another ethical concern was bias. We are interaction designers ourselves, and this project was in large part about examining the role of interaction design in the science center exhibit development processes, where an interaction designer would be but one of several important stakeholders. Due to our profession, we may be prone to bias in our assessments of issues and processes e.g. by overestimating the importance of the interaction designer's role or disregarding useful knowledge from the fields of expertise of other stakeholders.

Bias could also come from the fact that one of the students behind this report was working part-time at the science center that was studied in this project. Additionally, the thesis supervisor was working as an interaction designer in an ongoing exhibition development project with the organisation. As such, there is a risk that the opinions held by us or by our supervisor when going into this research project could have led to blind spots and confirmation bias during analysis.

The aim of this project was to provide support to interactive exhibit developers and designers with regard to avoiding and solving issues in the design process. This guidance could in part be opinions on how to structure the design process, what roles should and should not exist and how these roles should interact. If such guidance were to be adopted, it could considerably alter the way design work is done, potentially leading to a shift in prioritization of roles and thus who is employed and who is not. It could also impact the focus and direction of interactive exhibits in a way that changes the visitors' experiences and ultimately affect the way science centers fulfill their mission statements and affect society by educating the public.

5.5 Time Plan

The time plan for this project can be seen in figure 5.1.

Month	Dates	Aim
January	18 - 22 Jan	Start gathering and reading articles on background, theory and methodology. Establish contact with Universeum and supervisor.
	25 - 29 Jan	Narrow down scope and approach to methodology. Start writing the planning report.
February	1 - 5 Feb	Book first round of interviews. Write the Planning report.
	8 - 12 Feb	Finish Planning report **Planning report seminar**
	15 - 19 Feb	**Planning report hand-in** Examine exhibition documentation. Identify overarching processes. Identify unclear areas (things to ask about in interviews). Conduct introductory interviews.
	22 - 26 Feb	Introductory interviews. Produce high-level process map.
March	1 - 5 Mar	Select cases and identify people involved in these projects. Book interviews.
	8 - 12 Mar	Look at case documentation in detail. Produce interview scripts.
	15 - 19 Mar	Interviews + transcription. Possibly begin categorizing/coding
	22 - 26 Mar	Interviews + transcription. Code data.
April	29 Mar - 1 Apr	Analyze data. Describe challenges and observations.
	6 - 9 Apr	Send out questionnaire with findings. Ask people if they have experienced observed challenges and how serious they are. Document guidelines.
	12 - 16 Apr	Plan workshop(s).
	19 - 23 Apr	Conduct and evaluate workshop(s).
	26 - 30 Apr	Report writing.
May	3 - 7 May	Report writing.
	10 - 12 May	Report writing .
	17 - 21 May	Report writing.
	24 - 28 May	**Project presentation**
June	31 May - 4 Jun	**Project presentation**
	7 - 11 Jun	Final post-opposition editing.
	14-15 Jun	**Final submission deadline.**

Figure 5.1: The time plan constructed at the beginning of this project.

6
Execution

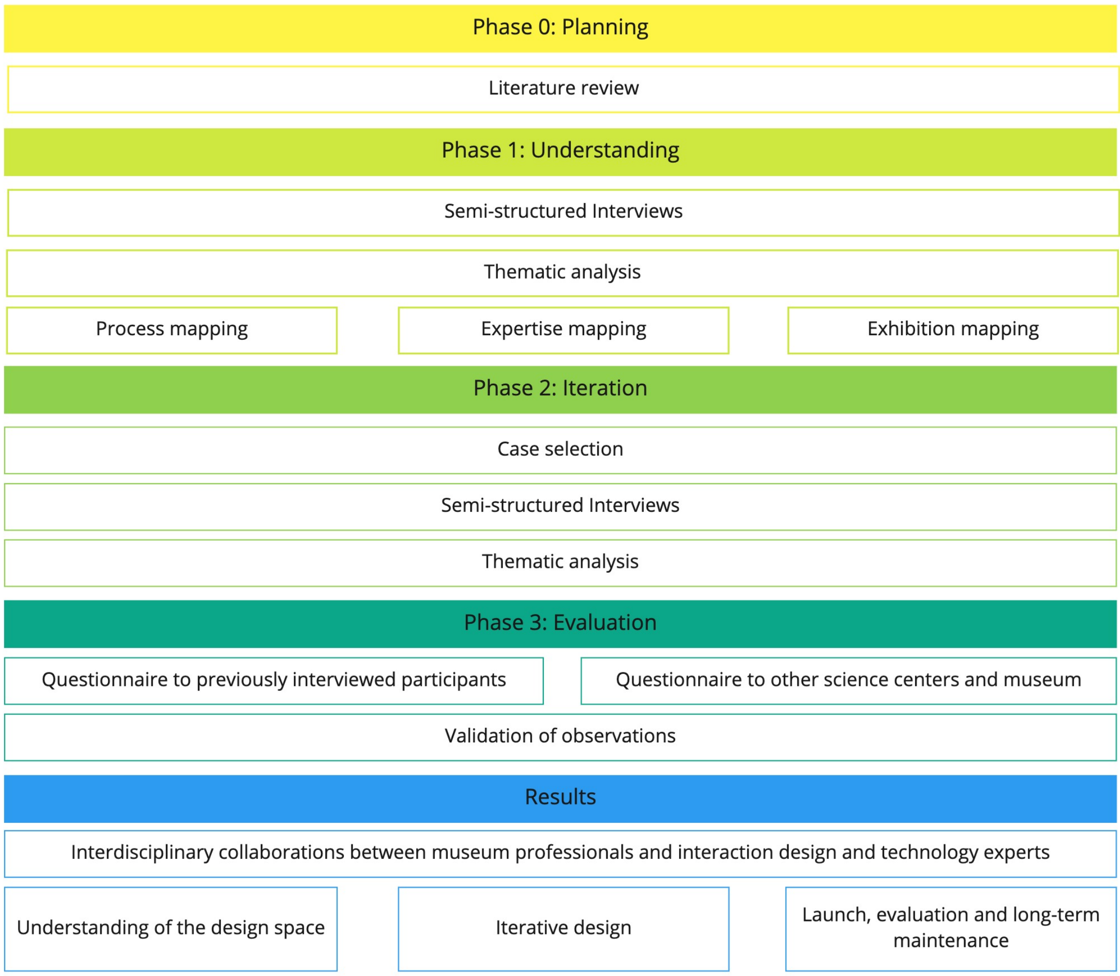

Figure 6.1: An overview of the phases and activities undertaken in the execution of this project and their results.

This project was conducted through a research process in four phases, as seen in figure 6.1. In Phase 0, the plan for the project was drafted through an examination of previous literature on exhibition and installation design processes. In Phase 1, semi-structured interviews were used to establish an initial understanding of the science center's design space and current development processes, identify interesting projects and preliminary themes to be further explored in later phases. In Phase 2, the insights from Phase one were used to guide another round of interviews. A thematic analysis of all interviews were then used to identify design challenges and critical moments in the design processes. In Phase 3, the observations from Phase 2 were summarised in a list of statements about exhibition design that was sent out to both previously interviewed participants and staff at other science centers and museums to evaluate the validity and accuracy of the observations. For a more detailed description of the work conducted in this project, see the Gantt chart in appendix A.

6.1 Phase 0: Initial Theory

During initial planning of this project, existing literature was consulted to establish an initial understanding of the exhibition design space at both science centers and museums. The insights from the literature were used to construct the Introduction, Background, Theory and Methodology sections of this report and served to guide the construction of interview questions and identification of themes that are described in sections 6.2 and 6.3. We will not go into too much detail on the execution of this literature overview, as it was not a formal literature review but rather a general attempt to gain an initial understanding of the design space. Although much of the reading from this phase was not utilized explicitly during this project, it is worth to note that our reference system held over 170 instances of examples, research and perspectives on design theory, interaction design, exhibition design, science education and different types of research methodology by the time Phase 1 (Section 6.2) was initiated.

The references that served to most prominently influence the direction of this project can be credited to Kamien and the Victoria Museum's overviews of roles types of expertise within exhibition development projects [42, 43]. These frameworks served to establish the exhibition design space's interdisciplinary nature from a general museum context and encouraged us to decide to examine how these frameworks could be applied in more interaction design and technology-focused projects, as present in the science center field.

In addition, the many publications from the Exploratorium served to aid us in establishing an initial understanding of the specific requirements placed on science center and interactive exhibition design. The contributions of Allen, with regard to research opportunities within the science center field and King et. al, with regard to collaborative design processes for installation design were considered to be especially useful for establishing the scope of the project as well as for determining codes during initial data analysis [12, 1]. In particular, they were exceptionally useful for understanding how the challenges and opportunities present in the design space differed in organisations that had less internal design resources compared to the Exploratorium.

6.2 Phase 1: Understanding

The first phase of the execution of this project focused on gaining an initial overview of the design processes and organisational structure at Universeum. This was done through a brief analysis of existing documentation from different exhibition projects, and six semi-structured interviews. The interviews were transcribed and thematically analysed and resulted in a mapping of the organisation's processes, the placement of different types of expertise, and five indicators for interesting exhibition projects to analyse further in later phases.

6.2.1 Documentation analysis

As part of working to understand the exhibition development and design process and the different roles and expertise involved at Universeum, we were granted access to many internal documents from exhibitions currently under development. The documents consisted of meeting notes, planning documents, organisational overviews, idea documents, design sketches and similar. These were analysed to in part inform our questions regarding organisational structure and design and development process with specific examples to ensure that the time with participants were used as efficiently as possible in later interviews.

6.2.2 Interviews

In the first round of interviews, six semi-structured interviews were conducted with science center personnel with the goal of gaining an overview of current practises, processes and exhibition development projects at the science center. The participants were recruited with advice from our thesis supervisor and the science center's CEO to ensure that they had insight into relevant exhibition development processes in a way that would be useful for the project. One of the participants held a project manager role, two were educators, one was a scientific content expert, one was working with the science center's more strategic vision work and partner collaborations, and one was an interaction designer from partner university who was often brought in for consultation during interactive exhibition development projects.

Participants were told that the purpose of the interviews was to inform an overarching comprehension of Universeum's design processes, perceived challenges and existing exhibition projects. They were informed ahead of time that the interviews were voluntary, that they would be recorded. Furthermore, emphasis was put on the fact that and that they would not be referred to by name in our report but that citations could be used, and that because of the nature of the project, with focus on processes and roles within the science center's organisation, we could not ensure complete anonymity. The participants were reminded of this again at the start of the interview. All participants agreed to the presented conditions.

6.2.2.1 Interview Questions

The semi-structured interview questions asked to participants varied depending on the participant's role in the organisation and the type of expertise that they provided during exhibition development. The interviews were initiated with questions that served to establish the participant's role in exhibition development:

- How would you describe your role and your tasks [at the science center]?
- When are you involved in exhibition development projects? What is your contribution?
- Describe the exhibition and installation development process [at the science center] from your perspective.
- What does the ideation process look like and who gets to contribute?
- Are you working with prototyping and formative evaluation in exhibition development, and if so, what does this process look like?
- How are external actors, such as partners and contractors, involved in exhibition development?

Depending on the participant's responses, the next section of questioning was adjusted to focus on the aspects of exhibition design that the participant would have sufficient insight into. Those who held a role with a stronger focus on content and educational aspects of design were encouraged to elaborate on their experiences in that area and those participants who had more insight into overarching process structures and collaborations with external actors were asked to elaborate on those aspects instead.

All participants were asked to name projects where they felt particularly satisfied or unsatisfied with either the development process or the final exhibition result. They were further asked to motivate their answers and reflect on why they felt that way about the project. Additionally, all participants were asked to describe both the easiest and most complex challenges they felt existed in exhibition development, as well as what they believed the science center should be doing differently to face these challenges:

- Which exhibition(s) are you most satisfied with the end result of and why?
- Which exhibition(s) are you least satisfied with the end result of and why?
- Which exhibition(s) are you most satisfied with the design and development process and why?
- Which exhibition(s) are you least satisfied with the design and development process and why?
- Which are the greatest challenges present during exhibition development?
- What do you think your science center should do during exhibition development that is not done today?

All participants were also asked for advice on persons to include in the next round of interviews. This was done in an attempt to prevent selection bias into which members of the science center staff were included in the participant selection to ensure that as many perspectives as possible could be taken into account. All interviews were conducted in Swedish. The interview questions have thus translated to English for this report.

6.2.3 Thematic analysis

The interviews were conducted over video call using Zoom, recorded and later transcribed. Each interview lasted for one hour, resulting in six hours of recordings and approximately 46 000 words of transcribed material. The transcribed interviews were then processed in the qualitative analysis tool ATLAS.ti, and coded for a thematic analysis to identify themes that related to key factors and challenges in the exhibition design process. The codes in the thematic analysis evolved over time through searching for repeated patterns in the participants' experiences that could be connected to existing literature or the design processes in relation to different process phases and different types of expertise. 289 quotations were identified that related to 36 different codes. The most significant codes and identified themes are presented here. For examples of quotes connected to these codes, see appendix B. All interviews were conducted in Swedish. Quotations have thus been translated to English for this report.

- Ideation
- Concept development
- External partnerships and contractors
- Testing and evaluation
- Roles and expertise
- Scientific knowledge
- Interactivity perspectives
- Educational knowledge
- Target groups
- Exhibition environment requirements
- Satisfied with
- Unsatisfied with

The themes identified through thematic analysis were used to create three different mappings of the different design processes. We will begin by introducing a process mapping (section 6.2.3.1), that was primarily informed by the codes *Ideation, Concept Development, External partnerships and contractors* and *Testing and evaluation.* In section 6.2.3.2, we describe an overview of the different types of expertise present in exhibition development, based primarily on insights from the codes *External partnerships and contractors, Roles and Expertise, Scientific knowledge, Interactivity perspectives* and *Educational knowledge.* Finally, in section 6.2.3.3, we present some identified important factors for exhibition success, based on the codes *Scientific knowledge, Interactivity perspectives, Educational Knowledge, Exhibition environment requirements, Satisfied with* and *Unsatisfied with.*

6.2.3.1 Process Mapping

In order to create better understanding of the science center's design process and prepare for the second phase, participants were asked about the overall organisation structure and development processes not directly related to design.The overarching development process, with special attention to the design process for individual installations, was defined by the science center with the following steps, as depicted in figure 6.2.

1. *Idea*: The initial pitch that leads to the initiation of an exhibition project.
2. *Exploration*: The overarching themes of the exhibition in relation to scientific concepts, learning goals and target group are determined.
3. *Concept Development*: Individual exhibition elements such as activities, installations and scenography are determined. External actors are sometimes consulted for advice on technology solutions.
4. *Production*: Installations are developed by external actors under supervision from museum staff.
5. *Launch*: Installations are installed in the exhibition environment and the exhibition opens to the public. Final corrections and fine-tuning is done if possible.

One of the most prominent themes identified was the science center's reliance on contractors for developing exhibitions, especially for the development of individual installations. Most of the technical expertise for suggesting technological solutions and ability to estimate development costs and complexity was considered to be placed with these contractors, making them crucial to the success of an exhibition. Several participants emphasised the importance of having a good relationship with these contractors to successfully communicate the science center's needs and requirements during development. An often described cause to an exhibition, installation or activity being less successful was when contractors, partners or collaborators were given too much influence over the design process and the outcome of a project. Participants often emphasised the importance of their own experience with science center design and insight into visitor's user patterns as one of the most critical aspects for making a successful design.

Another central theme was identified in the design processes for conducting iterative design at the science center. When asked about processes for prototyping and formative testing, participants described it to be in rather low priority. The reasoning behind this was considered to be a combination of it being deprioritized due to lacking project resources, and difficulties in working with prototypes and evaluation when most development was done by contractors, and the science center itself did not have the workshop environments or expertise internally to conduct parts of this process on their own. The thematic analysis did provide indicators that some earlier projects could have benefited from more formative testing. In some cases, installations were described to have issues that related to usability concerns, such as visitors having difficulty understanding how to use certain installation functionality without the assistance of science center staff.

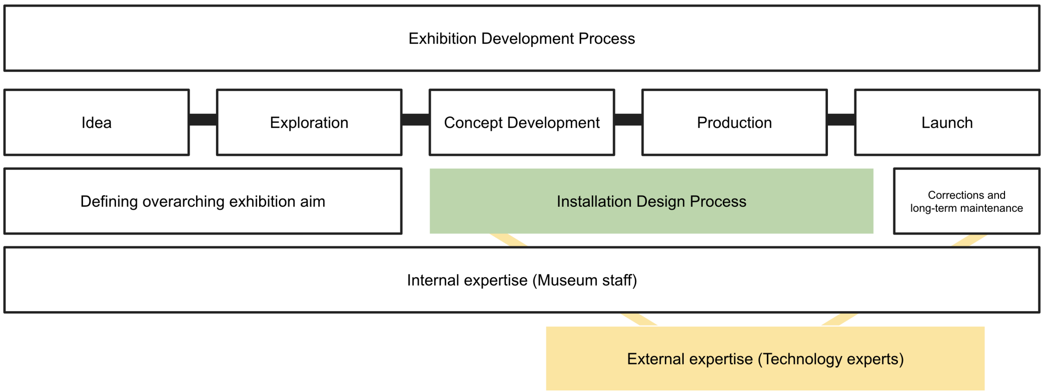

Figure 6.2: An overview of the science center's development process with emphasis on the processes for installation design in relation to the introduction to external software developers.

6.2.3.2 Expertise mapping

The insight about the importance of external actors such as contractors and collaborators described in section 6.2.3.1 inspired a mapping of the different types of expertise that were described to be present in relation to their position as internal science center staff or as an external contractor or consultant, as seen in table 6.1. In general, external actors of different types were seen to contribute during the entire process in different ways. The most important aspect to be highlighted here is that interaction design and technology expertise, which was found to be placed almost completely externally while content and educational expertise mostly existed internally.

6.2.3.3 Exhibition Mapping

Through thematic analysis, several interesting factors were identified that participants considered to be contributing to higher or lower exhibition success, as presented in table 6.2.

The exhibitions where participants were most content with the results were described to cover scientific topics where the participants felt comfortable in their domain knowledge, such as biology and physics. Exhibitions with several different types of interactivity that appealed to different senses were also considered to have a positive effect. Another important aspect was found in an exhibition's ability to interest a magnitude of different visitors from different target groups at once, by having installations and presenting information that would interest both children and adults. Additionally, exhibitions that covered topics that visitors were already interested in, such as space or dinosaurs, were considered to be both more successful and easier to design.

Type of expertise	**Internal science center expertise**	**External actor expertise**
Educational expertise - Knowledge about pedagogy.	Science center educators typically held teaching degrees in STEM subjects and contributed in the design processes for both activities and installations. They were described to be very knowledgeable in doing so.	In some scenarios, additional educational expertise were consulted to gain insight into more specific topics, such as designing for educational play for very young children.
Content expertise - Knowledge about specific scientific topics.	The science center staff was described to be very knowledgeable in many different topics, such as biology, chemistry and physics. They did a lot of internal research to gain insight into new topics.	External collaborators, professionals and researchers in the field, often contributed with additional expertise related to specific exhibition topics.
Interaction design expertise - Knowledge about interactivity alternatives, interface design guidelines and user testing.	The science center had no internal interaction designers. The internal staff was described to have a lot of experience with what types of interactivity that was successful in their exhibitions and which types where not.	Interaction designers were often present at the external organisations that built the exhibition installations. In some cases, additional interaction design experts were explicitly consulted to aid in communication and planning with external actors.
Technology development expertise - Knowledge about technology development and resource estimates for different solutions.	The science center staff was described to in general have low internal knowledge about this aspect and were very rarely responsible for technology development	External actors were typically completely responsible for software development and overall installation manufacturing.

Table 6.1: An overview of different types of exhibition design expertise and the placement of this expertise.

Aspect	Successful exhibitions...	Less successful exhibitions...
Target groups	Provided content for many different target groups	Did not provide content for many different target groups
Interactions	Had a variety of different types of interactions elements, and a lot of tangible elements	Had less variety in types of interactions, and many touch screens
Topic	Covered topics that visitors were immediately interested in (e.g. dinosaurs and space)	Covered topics that visitors were less interested in (e.g. math and technology)
Experience	Covered topics that museum staff had extensive knowledge and experience with (e.g. biology and physics)	Covered topics that museum staff had less previous knowledge and experience with (e.g. technology and visualisation)
Self explanatory	Had installations and activities that visitors could interact with without support from museum staff	Had installations and activities where visitors were dependent on instruction from museum staff

Table 6.2: Some aspects of exhibition design that were identified to affect to an exhibition's overall success.

When participants described exhibitions and projects that they felt less satisfied with, the opposite themes were identified. Participants described feeling less happy with the results of the exhibition projects that focused on new technology, AI, and visualisation techniques, topics that they had less prior experience with. For interactive components, exhibitions that primarily contained touch screens and had a lower variation in other types of interactivity were considered to be less successful with visitors. When discussing target groups, participants described how some projects had ended up with a too narrow target group, resulting in some of the visitors being uninterested in an exhibition. Exhibitions that covered topics that were less approachable to visitors, such as mathematics, were considered to be more challenging to design.

The presented aspects were some of many that affected exhibition success and should not be considered as identified design guidelines or validated predictors for exhibition success. In this project, these indicators were primarily used to select exhibition projects for further analysis, focusing on exhibitions that were described to have one or more of the identified themes, and to exemplify situations with important design challenges.

6.3 Phase 2: Iteration

Based on the insights from Phase 1, a more narrow scope was selected for the second phase. The goal was to gain further insights into the identified themes and was as such to focus on the following aspects:

- Different types of exhibition interactivity, such as using different types of tangible and touch-based interfaces.
- Exploring the differences in presenting scientific themes that the science center staff felt comfortable in presenting, such as biology, physics and chemistry, with themes they expressed feeling less comfortable in, such as technology and visualisation.
- The observation that some exhibition topics were described to be naturally more interesting to visitors than others and its implications on experience design.
- The implications of selecting specific versus more general target groups for an exhibition or individual installation and how it was observed to affect the experiences of all science center visitors.
- The importance of creating a strong base of understanding in the relationships with contractors to ensure that both the science center staff's experience with exhibition design and the external actors knowledge about interaction design and software development was taken into consideration during a project.
- The challenges present that hindered the science center's ability to work with testing and formative evaluation during development.

6.3.1 Documentation Analysis: Cases

As with the previous phase, we again analysed internal documentation on exhibitions that we were granted access to by Universeum. In this phase the aim of the documentation analysis was to identify what specific exhibitions and installations to focus our attention on in the second round of interviews. Exhibitions and installations were analysed through the perspective of the identified themes at the end of the previous phase as well as some more practical considerations:

- **How interactive is the exhibit?** Since our focus was on interactive exhibit design, we were not interested in non-interactive exhibits.

- **How old is the exhibit?** If the exhibit was too old it may not reflect the current design processes used, or it may be too hard to find documentation and/or people participating in the making of the exhibit with a detailed memory of the process.

- **How much documentation of the exhibit development and design exists?** Exhibits with a larger set of documentation of the development and design may be easier to analyze. However, projects with little or no documentation should not be immediately dismissed as doing so may result in a selection bias that negatively impacts the usefulness of our work.

This resulted in the selection of five exhibition cases, and the selection of a few specific installations within each exhibition to focus on in the second round of interviews. This supported the selection of participants to interview in the second round of interviews and informed the construction of questions to ask in order to further examine and understand the previously identified themes, as well as explore potential additional ones.

6.3.2 Interviews

In the second round, seven interviews were conducted with eight different participants (two participants were interviewed together). The participants were recruited based on suggestions from participants in the first round of interviews and based on their participation in different exhibition development projects, previous or current, that had been described to hold examples of the themes identified in the previous thematic analysis. Four of the participants were project managers or coordinators, one was a science center educator, one was an interaction designer from an external organisation who were involved in a large technology-focused exhibition project, and two were science center guides who had worked in the exhibitions with instructing and educating the science center's visitors. The two guides were interviewed together as they expressed that it would help them feel more comfortable during the interview.

Participants were informed that the purpose of the interviews was to gain more in-depth knowledge of design processes and perceived challenges in existing exhibition projects. They were informed ahead of time that the interviews were voluntary, that they would be recorded. Furthermore, emphasis was put on the fact that and that they would not be referred to by name in our report but that citations could be used, and that because of the nature of the project, with focus on processes and roles within the science center's organisation, we could not ensure complete anonymity. The participants were reminded of this again at the start of the interview. All participants agreed to the presented conditions.

6.3.2.1 Interview Questions

The exhibitions and themes that were identified as particularly interesting at the end of the first phase informed the construction of the questions asked in phase two. The interviewees in the Phase 2 who were not interviewed in Phase 1 were asked some additional questions that were used in Phase 1, such as:

- How would you describe your role and your tasks?
- What do you think your science center should do during exhibition development that is not done today?

The interviews were structured to have sections for each exhibition that the interviewee had participated in that had been identified as interesting, with some questions being repeated for each exhibition:

- Was there any specific role or expertise that was missing in this project that you would have been useful in your opinion? If so, which one and why?
- What are some lessons learned from this exhibition's design and development that you think your organisation should take advantage of in future projects?
- What were the most challenging parts of this project and why?
- What were the least challenging parts of this project and why?

Many questions were also specific to one or a few exhibition(s) or installation(s), and not posed to all participants:

- Are you planning on using VR/AR or visualisation techniques in this project? If so, how?
- How did the content and design of this installation change when it went from first idea to final product? Why did this happen?
- To what extent was your team involved with the design of the digital interface of this installation, compared to the contractors who developed it?
- How detailed were the plans that you presented to the contractor when you first got them involved?

As one of the most significant themes identified in the first phase related to the relationship and collaboration with contractors, the interviews focused in particular on this area with many questions and follow-up questions that explored the collaboration with contractors for different exhibitions and specific installations:

- When and how did you involve collaborators and/or contractors in this project?
- What did the collaborators/contractors contribute to in terms of content, interactivity and technology in this project?

Additional questions about participants' thoughts on different types of interactivity and specific installations were also asked. These questions varied a lot from participant to participant and were sometimes as a result of us deliberately picking out questions in advance to suit the participants role, but very often simply as a result of where the participant naturally led the discussion into relevant themes. When planning the questions throughout this phase, and trying to estimate the time it would take, we made an effort to also leave room for participants to lead the discussion in directions we might not have predicted. This led to both more varied and deeper interviews compared to those of the first phase.All interviews but one were conducted in Swedish. Interview questions have thus been translated to English for this report.

6.3.3 Thematic analysis

The interviews were conducted over video call using Zoom, recorded and later transcribed. Each interview lasted for one hour, resulting in seven hours of recordings and approximately 56 000 words of transcribed material. The transcribed interviews were then processed in the qualitative analysis tool ATLAS.ti, together with the material from the previous round of interviews in Phase 1. In total, thirteen hours of recordings, which resulted in approximately 102 000 words of transcribed material, were analysed. The thematic codes were selected based on the the themes identified during the first round of interviews and expanded into additional subcategories when necessary. In total, 697 quotations were identified that related to 63 different codes. The most important identified themes that related to the exhibition design process are presented here. For examples of quotes connected to each code see appendix C. All interviews but one were in Swedish. Most quotations have thus been translated to English for this report.

- Interactivity: Different types of interfaces
- Interactivity: Self-explanatory aspects
- Target groups: Accommodating everyone
- Target groups: Parent-child learning
- Understanding: How to present something educationally
- Understanding: What is possible to develop
- Understanding: Science center requirements
- Testing: Prototyping and formative evaluation
- Testing: Summative evaluation

The second thematic analysis allowed the themes identified in the first phase of the project to be explored in more detail. This contributed to the identification of more concrete aspects of the challenges presented and generated additional insight into why they occurred and which difficulties were present when trying to find alternative solutions. The analysis is presented in two parts. The first part describes some specific design related challenges that were noted to be present in exhibition and installation design. The second part describes the challenges present in the collaborative design processes between the science center and external actors.

Many of the observations should be viewed in part as consequences of exhibition projects rarely having enough resources to prioritise finding solutions to them during development; Interviewees frequently brought up lack of time and money as contributing factors to these challenges. The science center used as a case in this project is currently part-way through redefining their processes to accommodate for an increased focus on technology in exhibition design, a process that requires a reexamination of resource management strategies in many dimensions. The design-related challenges presented should be seen in a context where an institution is going through a learning process. In this light, the observations can offer some useful insights into the benefits of allocating resources to prioritize some aspects of exhibition design further in future projects.

6.3.3.1 Design Challenges for Exhibitions and Installations

The data from the thematic analysis helped to further describe some specific challenges related to interaction design that were critical to development: The importance of having different types of interactivity in an exhibition, the need to create installations that would be self-explanatory, the difficulties present when determining a target group for an exhibition or individual installations, and the ever-present challenge of creating installations that would both educate and entertain the science center visitors.

Different Types of Interactivity
A multitude of installations that allow visitors to learn about science through different types of interactivity is an important contributing factor to exhibition success. Many of the interviewed expressed a preference for installations with tangible interfaces compared to those that were completely touch-based but additionally described that it could be difficult to create meaningful tangible interactions that would work in the science center environment. Fragile, expensive technology such as VR headsets could only be made available to visitors when supervised by science center personnel and tangible, loose components were avoided as they would otherwise break or disappear and require replacement.

Many of the interviewed expressed a desire to create installations with more complex and experimental interactive elements but explained the durability requirements present in the science center environment severely limited the possibilities for doing so. This resulted in many installations being designed with simpler types of interactions, such as touch interfaces or physical buttons, that could be constructed in a way that would ensure that the installation would remain functioning for longer periods of time without intervention.

Designing Self-Explanatory Installations
A critical interaction design aspect for science center installations can be found in an installation's ability to be self-explanatory. For most installations, visitors should be able to walk up to an interface and immediately be able to understand what the purpose of the installation was and how to use it without instruction from science center personnel. Additionally, the interaction should ideally enable visitors to learn something about the scientific concept that the installation was intended to communicate.

The self-explanatory aspects of interactive installations were considered to be more challenging to achieve for installations where visitors were supposed to interact with interfaces for longer periods of time to gain insight into more complex scientific concepts. This was often the case for installations where visitors were to explore data visualisation and make their own realisations about the material. These installations often contained more complex interactive patterns that required visitors to go through several steps of interaction with the different types of functionality in the interface. Two primary challenges can be identified in the design of these interfaces. One is an increased necessity for interface usability to make it possible to present the datasets and multiple functionalities in a comprehensible way. The other is an increased need to maintain the visitors' attention for longer durations, to give them enough to notice and explore the more complex installation functionality.

Designing for Multiple Target Groups

One recurring theme when discussing exhibition development is the difficulties present when determining the primary target group for both entire exhibitions and individual installations. A science center has visitors of all kinds, from families with young children, to teenagers, adults and senior citizens and should accommodate for different disabilities and special needs as well as provide activities suited for both the public and school visits. This goal presented several challenges in relation to determining the primary target group for both entire exhibitions and individual installations.

A majority of the science center's visitors were described to be groups, most commonly families with children in different ages. Many of the interviewed participants stressed the importance of ensuring that the exhibitions had something to offer for every member of such a group and described the consequences of not succeeding in this approach. An illustrating example of this is found in a situation where a family visited an exhibition that was designed primarily for older children. The younger sibling in the family ended up being uninterested in the exhibition content, resulting in the entire family leaving the exhibition before an older sibling got the opportunity to interact with the installations to the extent they may have liked. Attempting to design visitor experiences that would suit a magnitude of target groups at the same time was described to create several challenges. It was considered difficult to create installations that would present scientific concepts with a level of complexity that would fit the knowledge level of both young children and adults simultaneously. A similar challenge could be found in determining the physical height of installation screens and activity tables. Attempts to design installations, or entire exhibitions, that would suit every type of visitor was often considered to end in a compromised design that did not work particularly well for anyone.

An additional aspect of this was found in the science center's desire to interest target groups that were typically less common amongst visitors: teenagers, especially teenage girls, and groups of adults who were visiting without younger children. Historically, science centers have primarily focused on providing content that would accommodate the interests of children. The extension to additional target groups complicates the process of determining primary target groups further and serves to additionally highlight the importance of exploring the best ways to do so. Many of the interviewed expressed an interest in finding ways to incorporate more target group analysis and understanding into their design processes. Some challenges in doing this were identified. These were primarily related to accidentally being too accommodating to the target group's wishes instead of trusting their own knowledge of exhibition design, and to a fear that the inclusion of target groups would create too high expectations on the final exhibition result.

Designing for Education and Entertainment

A few of the identified challenges relate to the science center's goal of both educating and entertaining its visitors, and can partially be connected to which scientific topics an exhibition was meant to present. Exhibitions about topics that were considered to be less approachable by science center visitors, such as mathematics and technology, were considered more difficult to design compared to exhibitions that focused on subjects that the visitors were already fascinated by, such as dinosaurs or space. Some participants additionally expressed feeling less certain about finding a suitable approach to exhibitions that were focused on technology; Many had little previous knowledge about the topic and no previous experience in creating exhibitions that were intended to explain it.

Another challenge in exhibition design can be found in the importance of finding strategic ways to evaluate the learning goals and educational aspects of installations. Evaluating entertainment aspects is quite easy to do, as all it requires is that visitors are having fun during their visit, which can easily be established by observation and simple questioning. The process for understanding what visitors are actually learning from the interactions is more complex. For this, methods for gathering insight into both the visitors' previous understanding of a subject and into the way an interaction caused this knowledge to evolve are required.

6.3.3.2 Interaction Design Processes With External Actors

The science center used as a case in this study does not have the internal resources present for conducting exhibition development on their own. This means that their exhibition development is always done together with external contractors or collaborators. The relationship to these external actors are central to the design process and the final exhibition result and presents several interesting challenges to the design process. One of the most crucial challenges is the initial process of ensuring that the science center and the external developers have established a common understanding of the goal, possibilities and requirements present during exhibition development. Another is related to difficulties in establishing the iterative processes that allow for prototyping and testing during when the science center's installations are developed externally.

Understanding Exhibition Goals and Installation Requirements
The thematic analysis indicates that the science center has good knowledge and well established processes for defining the scientific content and the educational aspects for an exhibition. These aspects of exhibition design are primarily handled by science center staff, with additional external expertise occasionally being brought in as advisors on the scientific content and specific pedagogical methodology when necessary. This is usually what creates the base for an exhibition project and serves to define its goals, and are typically established internally by the science center before external contractors are invited into the design process.

Once the overarching direction for a project has been established, exhibition development becomes more focused on defining the purpose and design of individual elements within the exhibition. Some of these elements are informational wall text and video clips, others are the interactive installations that are the primary focus of study in this project. It is difficult to present the exact processes present at the science center when exploring installation alternatives, as it was described to vary a lot from project to project. In general, it can be summarized to be a two-step process where the first step consists of workshops held internally where science center staff brainstorm different installation alternatives and the second one is centered around bringing in external contractors to provide the technical expertise required to determine which ideas are possible to build with the existing project resources and suggest suitable technical solutions.

The interviewed participants described this initial phase of collaboration with external actors to be the most challenging part of the design process. The challenges were described to be primarily related to getting contractors that were inexperienced with science center design to understand the requirements the science center had for its installations. These requirements related partially to the importance of creating installations that were very durable, both in terms of physical durability to accommodate for the rough treatment provided by science center visitors, and in terms of software durability, in that installations should ideally never crash, and that it should be possible to restart them quickly if it ever were to occur. Another important aspect that contractors needed to understand was the design requirements present when creating installations for public places. While the science center was typically closely involved in the design of installations, the contractors were the ones primarily responsible for designing the actual installation interfaces. If the contractor did not have insight into the specific interaction requirements for such an installation, it could lead to a long and expensive design process that required extensive feedback from the science center before the installation could be completed.

One of the exhibition projects used for analysis in this project presents an interesting deviation to the relationship between science center and contractors. In an ongoing project focused on visualisation techniques for education, the primary purpose was not to present specific scientific concepts, but rather to explore how digital techniques can be used in a science center environment by creating visualisations based on existing data sets. As such, the exhibition goals did not originate primarily in the educational aspects but rather from the available data and technology. Additionally, this exhibition was created through a collaboration with a partner organisation that were experts in visualisation techniques instead of through the more common contractor relationship that were previously described. Many of the interviewed described how the design and development processes for this project had been a very different experience compared to other exhibition projects created at the science center. Due to both organisations having decision making rights and stakes in the project, there were sometimes difficulties in determining project priorities; For the science center, the installation content and the visitors' educational experiences was considered to be most important, while the other organisation was described to be more interested in furthering their own research and exploring advanced visualisation techniques.

It is clear that one critical aspect during exhibition development with external actors is that the initial design phase is able to ensure that all project participants are sufficiently aware of the exhibition's educational goals and the requirements placed on an interactive installation. A consequence of this challenge can be seen in participants describing that the science center preferred to work with recurring contractors for most of their exhibition projects. This allowed them to focus more on the actual development and less on the initial communication. At the same time, the science center was a bit concerned with becoming too dependent on this contractor and emphasised a need to develop successful relationships with others as well to allow for more innovation in the types of installations they were creating. For new collaborations, the communication process required to achieve this can be quite strenuous. Yet, it is necessary to allow science centers to continue to develop installations with varying types of interactivity and be innovative in the experiences they create for their visitors.

Iterative Design Processes

Several interesting challenges were identified when examining the science center's opportunities for working with prototyping and formative evaluation during interactive installation development. One of the most important aspects can be found in the processes for working with low and high fidelity prototyping. As the science center did not have any workshop environments or development expertise internally, the opportunities for working with low fidelity prototyping in the early phases of the design process were limited. Initial installation ideas were often described with brief concept sketches before the decision was made to begin the production phase and develop the installation software, which made it difficult to evaluate the ideas and identify potential challenges before development began.

While installations were in development, it was challenging to conduct user testing that could aid the project members in identifying usability concerns and similar aspects. Evaluation of half-finished software typically became more focused on identifying bugs and other high-fidelity concerns rather than on exploring the usability aspects of the design. As such, the possibilities for conducting usability testing were only present close to the end of an installation's development. At this time, it was often too late to modify the installation to accommodate for identified issues; The corrections would have required more development time from the contractors building the installation and the cost for this could not be covered by the project budget. To be able to use user testing efficiently during installation development, science centers must find ways to evaluate usability aspects of installation early on in the design process so that the takeaways from the evaluation can be used to improve the installation design.

With development being done externally, the opportunities for testing were also dependent on finding ways to conduct strategic testing that would actually provide useful results. The science center environment was described to be very unique, and testing done elsewhere could not always catch the interaction challenges that would be present when the installations were made available to the public. Formative testing must not only be adapted into early process stages, but must also be conducted in settings where aspects of design for public spaces, such as immediate apprehendability, can be sufficiently explored.

Another important aspect of the iterative design process can be found in the long-term maintenance of installation software. Digital installations were described to often benefit from getting software updates and other types of fine-tuning to stay relevant over time. When an installation was developed externally, this type of upkeep would require long-term contracts with contractors, which was considered to be an expensive and quite complicated process.

6.4 Phase 3: Evaluation

In the last phase of this project, the aim was to evaluate the accuracy and importance of the critical factors for success and challenges that we had identified in the previous phases. The findings were evaluated for two things: firstly, to see to what extent interview participants would agree with our findings, and secondly, through asking professionals at other science centers to what degree they agreed with the findings in the context of their own organisation and experiences. In other words, we wanted to make sure that we had not misinterpreted and misrepresented the views of the interviewees, and we also wanted to find out if and to what extent these findings could apply to other science centers.

This was accomplished by constructing a list of statements presenting critical factors for success and challenges in exhibition and installation design and development that we had potentially identified. This list was presented in a questionnaire where, after each statement, the respondent was asked to answer the following multiple choice questions (only one answer could be chosen):

What best fits this statement?
A: I completely agree
B: I partly agree
C: I do not agree at all
D: I have no opinion

If the respondent chose one of the options A or B, indicating that they agree with the statement, a follow-up multiple choice question would be shown, asking "how serious are the consequences of the statement?". Respondents could answer on a scale from 1 - 5 where 1 was "not serious at all" and 5 was "very serious".

The respondents were also encouraged to leave an optional written comment with the prompt: "Leave a comment on this statement (optional)". Additionally, after completing these questions for all statements, the questionnaire ended with a final and optional question that respondents could leave a written response for: "Is there anything you want to add, or do you have any observation of your own that you think is missing from this list?".

The formulation of the statements sent to the people who had been interviewed in this project differed slightly from the formulation sent to other science center professionals. The reason for this was that the statements sent to interview participants

	Statement	Purpose
A	We sometimes have difficulties estimating how resource demanding development of digital installations are, and what is possible to build.	To understand whether internal museum staff was considered to have adequate understanding of technology development.
B	External contractors and partners have a hard time understanding our organisation's requirements and needs.	To understand whether external actors involved in exhibition development were considered to have adequate understanding of museum environment design requirements.
C	Our development processes are not currently structured to allow prototyping and testing. This makes it difficult to discover usability problems and figure out solutions to these problems.	To understand whether processes for prototyping and testing existed and if a lack of testing was considered to have negative consequences.
D	Our organization rarely conducts final evaluations of installations, which makes it difficult to determine what visitors are learning, and how the installation could have been improved.	To understand whether processes for summative evaluation existed and if a lack of evaluation was considered to have negative consequences.
E	It is difficult to determine a specific target group for an installation, or whether an installation should even have a specific target group.	To understand the accuracy of the target-group related observations in previous phases.
F	Some installations and activities are reliant on guides in order for visitors to understand what they are supposed to do and to learn from it, even though they were planned to work well on their own, without guidance.	To understand the accuracy of the self-explanatory related observations in previous phases.
G	Our organization currently does not have the ability internally to do maintenance on, update or adjust software in our installations.	To understand whether science centers have internal expertise and access to make changes to software that a contractor has delivered, without involving the contractor.

Table 6.3: Statements from the questionnaire where science center professionals were asked how much they agreed with the statements and the purpose behind presenting each statement.

included references to some things only relevant to their specific work and organisation which was removed in the version sent to other respondents, as we wanted other respondents to think about the statement in the context of their own organisation. Each statement consisted of a one sentence summary as well as a one or two paragraphs long description with more details and context surrounding the statement. The statement summaries are presented in Table 6.3, along with a motivation as to why they were relevant to examine. underlying reason for asking participants how much they agreed with them. Three statements that were in the questionnaires related to overarching aspects of museum organisation and fundraising and have been omitted from this report due to being deemed as too far removed from the aim of the project. For a complete list of the statements with their longer, explanatory description, see appendix D.

6.4.1 Results From Questionnaire

In total 6 interview participants (out of the 7 it was sent to) and 13 employees from 5 other Swedish science centers and museums responded to the questionnaires, for a total of 19 respondents from 6 different institutions. A summary of the responses can be seen in figure 6.3.

For every one of the statements, a majority of respondents said that they agreed completely or agreed partially. The questionnaire results could not be used to draw any statistical conclusions, but indicates that the described themes described here managed to successfully catch critical factors for exhibition design as experienced by interviewed participants, and that other science centers and museums in Sweden that work with interactive exhibitions are experiencing similar challenges.

Statement A, C and D were the only ones where more participants replied *Partially agree* instead of *Completely agree*. The additional text replies provided explanations as to why that was. For statement A it was noted that this was most often solved by having external actors consult on resource estimations and that this made it possible to do this even when the knowledge did not exist internally. For statement C, many noted that the primary reason for not working with prototyping and testing was due to a lack of resources, both time, budget, expertise and workshop environments in the project. For statement D, it was noted that final evaluations were similarly not prioritised, partially due to resource constraints. For both statement C and D, some replied noted that both testing and final evaluations were starting to become more prioritised, but that they were still working with the processes for doing so.

Statement F and G were ranked to have the most serious consequences by the respondents. From a design perspective, the replies to statement F are of particular interest. The described challenges that relate to self-explanatory design are closely related to usability design. As such, it is particularly interesting to note that this aspect is considered to commonly be complicated, while many respondents at the same time thought it slightly less important to work with prototyping and testing methodology. This emphasises a need to work more with finding ways to highlight the value of working with iterative design when facing these challenges.

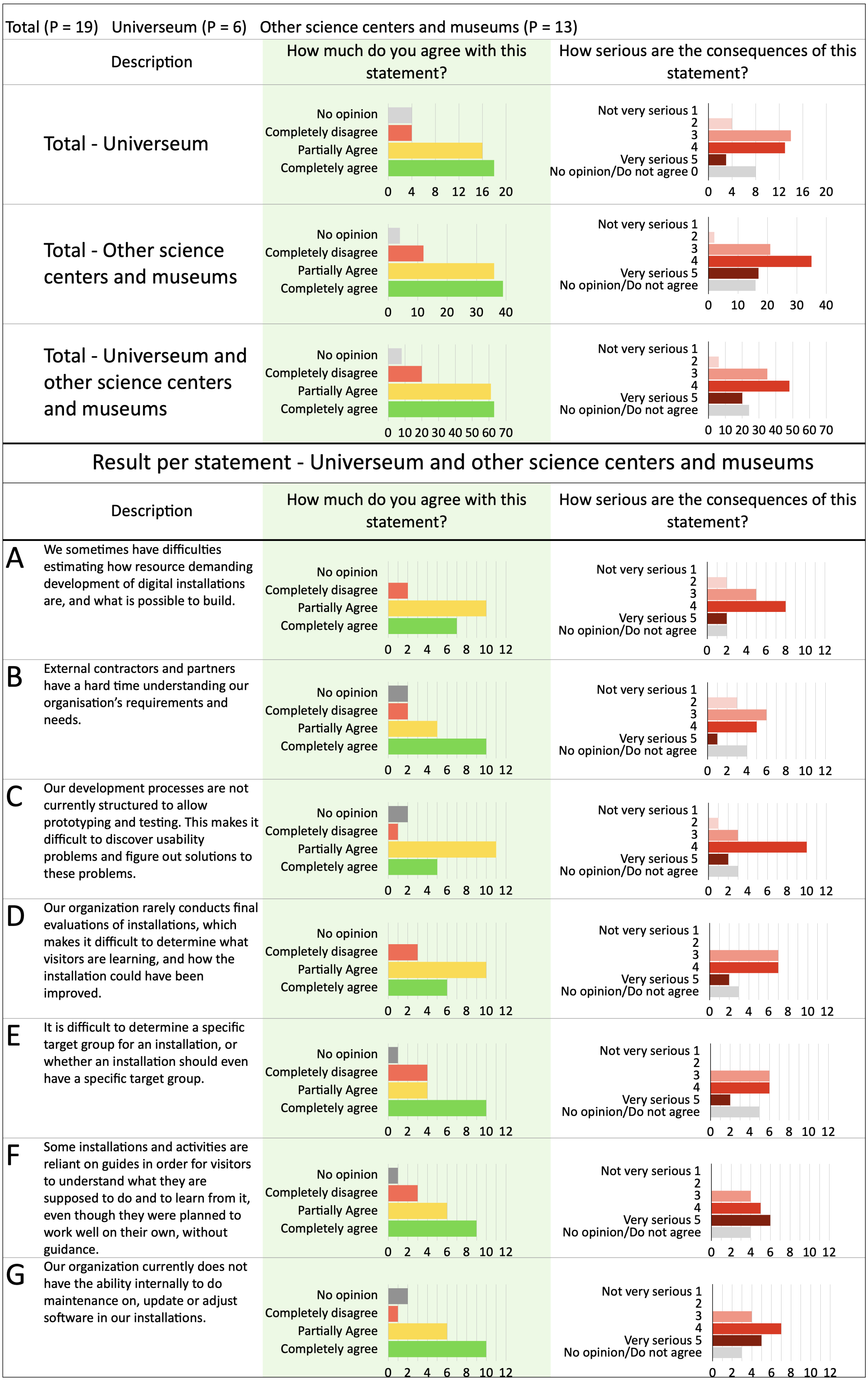

Figure 6.3: A summary of the responses sent out to Universeum and other science centers and museums in Sweden.

7
Results

The purpose of this project was to answer the following research question:

Which key factors affect the interdisciplinary design processes of interactive museum exhibitions?

The results from extensive thematic analysis of interviews, input from questionnaire respondents and existing literature on exhibition and interaction design serves to identify the collaboration between internal museum professionals and external interaction design and technology experts to be the most important factor that affects the design process for interactive exhibitions. In almost every observed situation, the expertise of museum professionals was held by internal museum staff while the interaction design and technology expertise was held by external contractors and collaborators. This highlights the importance of focusing on the relationship between internal and external actors to succeed in exhibition and installation design. The importance of this relationship becomes particularly clear in three specific phases the design process:

1. *(i) understanding of the design space between museum professionals and interaction design and technology experts*
2. *(ii) iterative design with museum professionals and interaction design and technology experts*
3. *(iii) launch, evaluation and long-term maintenance strategies for exhibitions between museum professionals and interaction design and technology experts*

Out of these, the execution of (i) *understanding* and (ii) *iteration* are considered to be most key to the execution of the actual design process while (iii) *launch, evaluation and maintenance* is slightly less so from a design perspective. However, it was ranked to have serious consequences in the questionnaire, indicating that it is still very valuable from a process perspective. A simplified model of these phases in relation to the exhibition design process found at Universeum and the different types of involved expertise can be seen in 7.1. The details and specific challenges present in these phases are further described in the following sections.

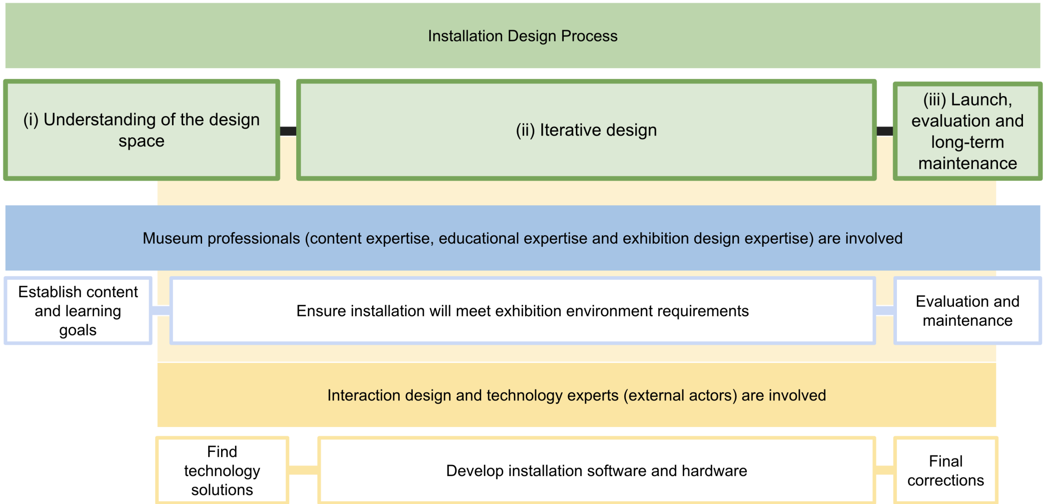

Figure 7.1: An overview of the design process for individual installations in relation to the contribution of museum professionals and external interaction design and technology experts.
https://www.overleaf.com/project/60abaa9d03d1343daa46201c

7.1 Understanding of the design space between museum professionals and interaction design and technology experts

Many of the design challenges described in the thematic analysis in 6.3.3.1 can be seen as a direct result of interactive exhibition design's interdisciplinary nature, the different aspects of exhibition expertise and where this expertise is located. This serves to highlight the importance of building a common understanding of a design space and sharing knowledge between project participants. The interviews and questionnaire responses indicate that for many science centers and museums in Sweden, the internal staff typically hold internal expertise about relevant scientific content, educational aspects and general experience from the exhibition environments, while external actors contribute to development primarily through expertise in interaction design and technology. A result of this division is a shared responsibility for the identified design challenges, as presented in table 7.1, which emphasises the need for finding efficient ways to establish knowledge-sharing during early stages of development if these challenges are to be met.

An often described consequence of this communication not being sufficient could be seen in cases when interaction design and technology experts that had little or no experience with the science center environment designed installations that were too complex to be self-explanatory to visitors. Another often described case related to contractors underestimating how robust an installation had to be and because of this suggesting interactive elements that would not be feasible in the environment.

Design Challenge	**Primarily internal expertise (museum professionals)**	**Primarily external expertise (interaction design and technology experts)**
Exhibitions should have variety Exhibitions should host a multitude of types of interactive installations but the requirements created by the science center environment limits the opportunities for doing so.	Knowledge of the requirements of the exhibition environment, both in relation to visitor behavior and interaction patterns, and to durability requirements. Ability to preliminarily determine possibility for installation success.	Knowledge of alternative interaction solutions, their complexity, requirements and development costs. Ability to evaluate possibilities for adapting existing technology to suit the exhibition environment.
Installations should be self-explanatory In general, visitors should be able to understand the purpose of an installation, be able to use it, and learn something from it without instruction from museum staff.	Knowledge of visitor behavior and suitable complexity levels for educational concepts.	Knowledge of interface design, and guidelines for usability and information visualisation.
Exhibition should be relevant for all target groups Exhibitions should have content to suit all target groups but designing installations that can do this is very difficult.	Knowledge of appropriate installation content for different target groups and of group behavior in exhibition environments. Insight into the educational aspects of collaborative learning.	Knowledge of design guidelines for different target groups as well as for interfaces designed for collaborative interactivity.
Exhibitions should be both educational and entertaining Exhibitions should both educate and entertain. Some exhibition topics, such as mathematics, are more difficult to make available to visitors compared to others.	Educational expertise. Knowledge of which parts of a subject are relevant to present to visitors and of how to present this in a fascinating way.	Entertainment expertise. Knowledge of how to use gamification and other interaction design techniques to affect and enhance user experiences.

Table 7.1: An overview of identified design challenges that require both internal and external expertise to solve.

From the opposite perspective, museum professionals were described to often have a limited understanding of which technical solutions alternatives were possible to develop and how complex they were to implement, resulting in them sometimes having too high expectations of the outcome of a project in relation to the resources they had allocated to it. Particularly during new collaborations, the overlap of shared knowledge and experience between these parties could be quite small, which caused tedious initial communication phases in these projects. During collaborations with external interaction design and technology experts who were already experienced with exhibition design, it was seen to be a lot easier to facilitate, resulting in more successful final results. This was seen to decrease museums' and science centers' willingness to initiate collaborations with new contractors, which limits the possibilities for innovation when exploring alternative technology that can be used in exhibition design.

To successfully combine the different types of necessary expertise that are required to face these design challenges, interactive exhibition projects require process methodology that can allow them to efficiently and strategically map the requirements and expert insights that different project participants are able to provide.

7.2 Iterative design with museum professionals and interaction design and technology experts

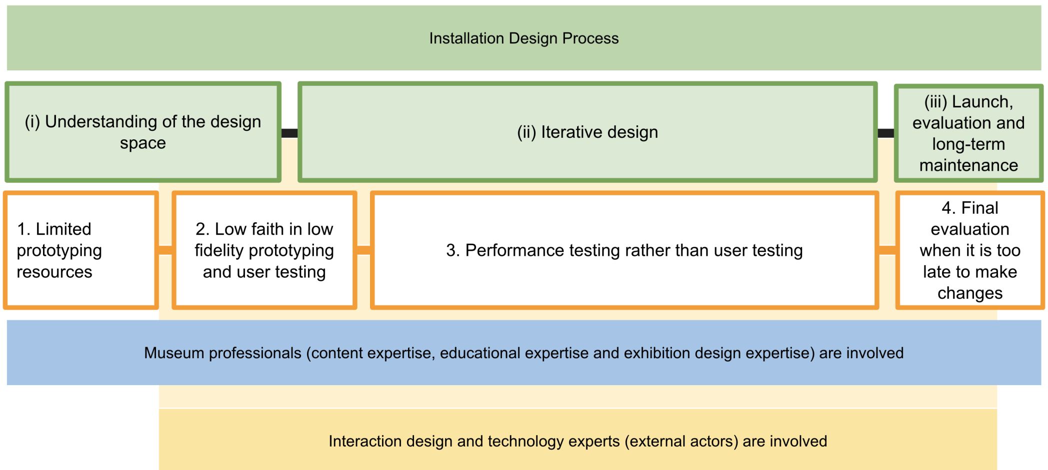

Figure 7.2: An overview of the challenges present that prevent successful prototyping, testing and iteration during installation design and development.

The combined expertise of museum professionals and external interaction design and technology experts does not on its own guarantee successful installation design. The successful application of the design challenges described in table 7.1 can only be evaluated and explored through user testing with exhibition visitors. Iterative design processes with prototyping and testing are always crucial to understand a user's experience of an interface. Exhibition and installation design is not an exception to this rule. Our findings indicate that the design processes at the science centers and museums examined in this project were rarely very iterative in nature. There are likely many reasons for this, with one often mentioned by participants being a lack of resources dedicated to activities such as prototyping and user testing. Four specific challenges related to iterative design methodology were identified during the project. These are presented in relation to the installation design process phases in figure 7.2 and highlights the importance of two things: The importance of finding ways to cost-effiencly work with prototyping and testing during the entire design process, with both high and low fidelity prototypes, and the importance of encouraging everyone involved in an exhibition project to see the value of working with iterative methodology in this process. The four identified specific challenges are:

1. Limited prototyping resources
In early stages of the design process, museum professionals often conduct initial ideation and brainstorm installation ideas internally, without including external actors in the process. In this stage, many organisations were observed to not have internal expertise in design prototyping, or adequate workshop environments to support the creation of such prototypes. This leads to staff often finding themselves limited in ways of evaluating and exploring interactive installation alternatives.

2. Low faith in low fidelity prototyping and user testing
In addition to not having sufficient resources to work with low-fidelity prototyping, doing so is also often considered inadequate in its ability to successfully evaluate a design idea. The reason behind this was described to be that these prototypes would not be able to create a real enough representation of how the installation would work in the exhibition environment, partially in regard do durability requirements, but primarily in relation to evaluating an installations self-explanatory aspects.

3. Performance testing instead of user testing
When external interaction design and technology experts start to become more involved in development, the project is often somewhat rushed for time, and software development is prioritised above prototyping. Some testing is present during this part of the process, but as it is often done on installations that are still under development, it often becomes focused on performance and bug tests rather than on user testing.

4. Final evaluation when it is too late to make changes
Once an installation is installed in the exhibition space and opened to the public, project participants can see how visitors are interacting with it in full, in the actual exhibition environment. At this point, final fine-tuning and corrections can sometimes be done, but it is often too late and too resource demanding to do larger adjustments or redesigns if the installation is observed to work differently

than expected. In some cases, the contract with the external software developers is concluded at this point, and no changes can be done.

7.3 Launch, evaluation and long-term maintenance for exhibitions between museum professionals and interaction design and technology experts

Related to the observations about summative evaluation and final corrections described in section 7.2, it is important to describe an installations life cycle after the formal design and development processes have been concluded with the installation's launch. In most cases, external interaction design and technology experts do not have long-term agreements about software and design maintenance, meaning that once the installation is installed in the exhibition, and sometimes fine-tuned a little, the delivery is complete and the project is over. As previously discussed, museum professionals rarely have sufficient technology expertise to work with continued development themselves. Additionally, they are often unable to access the source code themselves even if they would be able to make changes. This means that it is very difficult to maintain and change installations over time, in relation to both potentially adjusting interfaces and updating datasets and factual information. This can cause technology installations to age more quickly than if this would have been possible.

Another important aspect of the post-launch process for an installation relates to the final summative evaluation that happens once the installation is placed in the exhibition environment and final insights about the design and its impact on visitors can be gathered. Although it is often too late to apply this knowledge to the current installation, these insights are very useful to build experience with exhibition development that can be used in future projects. The results from the questionnaire (Statement D) tells us that while exhibitions are sometimes evaluated in full at the end of projects, focus is rarely placed on the impact of individual installations. This means that most of the participants' experiences from interactive installation design are not documented. While this experience can still be useful to individual participants in future project, it can in some cases lead to situations where new project participants are not aware of previous insights, which can cause them to repeat mistakes discovered in previous projects if the challenges described in section 7.1 are not successfully communicated.

8 Discussion

In this research project, science center employees and other project participants involved in interactive exhibition development have been interviewed with the purpose of gaining insight into their perspectives on the design process. Through thematic analysis of the interviews, several critical factors and recurring challenges present in the design process for interactive exhibitions and installations were identified. With a questionnaire, the accuracy of the identified key factors was successfully validated with both interviewed participants and staff from other Swedish science centers and museums. The final results of this work are presented as concrete exhibition design process challenges from an interdisciplinary perspective in relation to expertise held by internal museum professionals with insight into content, pedagogy and exhibtion environmnet requirements, and external actors with expertise in interaction design and technology. The findings highlight the importance of three phases in the design process:

1. *(i) understanding of the design space between museum professionals and interaction design and technology experts*
2. *(ii) iterative design with museum professionals and interaction design and technology experts*
3. *(iii) launch, evaluation and long-term maintenance strategies for exhibitions between museum professionals and interaction design and technology experts*

The results serves to help emphasise the importance of finding methodology that can support project participants in successfully utilising the different expertises that exists in an exhibition project when working with the identified design challenges.

These results should not be seen as a presentation of Universeum's current design processes, as the conclusions are made based on observations based on experiences that have occurred during several years, in many different projects. It is also very important for us to emphasise that the goal of this project was in no way to criticize existing development processes nor the expertise of the staff at any science center, museum, external partner or contractor organisation. Instead, we strive to highlight the challenges that can be present in the exhibition design process, in the hope that this work will provide additional understanding of these challenges in a way that will help the organisations in future design work. By showing that many of these challenges are common across several science centers and museums, we hope to help organisations feel less alone in these questions and encourage them to work together to find solutions. In the questionnaire responses, one respondent wrote that they were already planning to use the list of questionnaire statements as a basis for discussion within their organisation. This is in itself a promising indication of the applicability of our work.

In the following sections, the identified challenges and key factors will be reflected upon in relation to previous literature on exhibition and interaction design. Methodology alternatives and existing interaction design guidelines will be presented to provide support to exhibition designers in their work. Hopefully, this can assist both science centers and museums and the external actors that wish to work together with these institutions in their future development of interactive exhibitions.

8.1 Understanding in Interdisciplinary Exhibition Projects

Kamien defined the role of the content interpreter as the one responsible for making the knowledge and themes that are to be presented in an exhibition available and understandable to the museum visitors [42]. This role holds knowledge of how to present information in a museum setting based on pedagogical expertise and previous experience with exhibition design and visitor behavior. The content interpreter role is often successfully filled by museum staff. For digital installations, the responsibilities of this role additionally requires an understanding of usability and UX guidelines, interface design for both touch and tangible interactivity, and several similar areas of expertise that can typically be found in an interaction designer's toolkit. In interactive exhibition design, museum professionals can generally be assumed to have a basic understanding of these aspects of installation design through previous experience, but it is quite unfair to expect that they should hold a 'full' interaction design skill set in addition to often holding teacher's degrees and having extensive knowledge of museum pedagogy, as well as a good understanding of several scientific fields. Similarly, interaction design and technology experts can sometimes hold expertise on exhibition-specific design and its different aspects, but as seen in our results, this is not always the case.

Gurian reluctantly recognised that the superstar developer who can take responsibility for every aspect of exhibition design exists, but continued to argue that a team approach with several supporting roles was the most realistic way to go [67]. While exhibition design projects can hope to find project participants who are already familiar with the full digital installation design space, there is no guarantee that this will always be possible. For some institutions, it may be advisable to consider the advantages of narrowing the gap between museum specific expertise and interaction design understanding by adding additional personnel to their internal expertise pool that can become experts within both knowledge domains by working with nothing but interaction design for exhibitions. In other cases, an external contractor may decide to specialise their offers toward the science center and museum sector, thus shrinking the differences in expertise from the other direction. However, there are many cases where the advantages of being in touch with additional contractors will still be present. As long as new types of technology come into existence, there will always be a need to start up new collaborations with individuals who are yet to explore the interdisciplinary design space in full. Because of this, the key aspects and challenges presented in this work can be presumed to always be present in exhibition projects to some extent.

Within interaction design, most design process models begin with an introductory step where the aim is to generate a common knowledge base of understanding for a design space and select a smaller design domain to focus on as the project progresses. In the google design sprint model, this is referred to as the Understand and Define stages [2] and in the double-diamond framework, it is described as the Discover phase [68]. There will always be a need to find methods for understanding a design space. Especially in interdisciplinary projects. In the following sections, we will discuss different ways of doing so, focusing on methodology for co-design and the application of existing exhibition design research to lower the threshold for understanding.

8.1.1 Process Methodology to Support Knowledge Sharing in Interdisciplinary Teams

In interaction design, the term co-design, sometimes called participatory design, is often used to describe design processes where designers bring in non-designers into the design team, instead of merely consulting their experience during initial user studies and later user testing [69]. Co-design is a concept that usually refers to designer-led projects, where designers are still primarily responsible for facilitating the interdisciplinary process. As discussed in the previous section, there is a risk for designer-led projects losing track of some of its educational aspects. This should be taken into consideration, while still utilising the experiences that exist from previous attempts at exhibition co-design.

Many research projects in exhibition design use the term co-design to explore techniques for encouraging collaboration between different fields of expertise. Through workshops with different museum roles present, Olesen, Holdgaard and Løvlie developed a co-design tool to strengthen the ideation phase when designing digital experiences with the explicit purpose of creating a tool that was targeted towards museum professionals rather than design researchers [70]. The resulting co-design tool ASAP was considered to be applicable by museum professionals when facilitating interdisciplinary ideation. However, the researchers noted that it was possible that it was not the tool itself, but rather the attempt to encourage project participants to explore the possibilities with co-design that had the greatest effect on the overall organisation.

Bringing stakeholders and people with different expertise and perspectives together does not automatically lead to a great outcome. In interdisciplinary projects where participants have different goals, priorities and expectations, it is especially important to ensure that everyone is on the same page in regard to the priority of different types of contribution. Hornecker noted that it was especially important to establish roles and agreed areas of expertise between participants in co-design projects, to ensure that the knowledge of those with specific domain expertise is prioritized over common consensus [37].

8.1.2 Design Guidelines and Existing Research Frameworks for Interactive Exhibition Design

The work done in this report resulted in the identification of several design challenges that can typically require the input from multiple fields of expertise to be tackled sufficiently, with the most prominent being achieving interactive installation variety in exhibitions, making sure installations are self-explanatory, designing for multiple target groups within an exhibition, and the ever-present challenge of designing installations that will both educate and entertain the exhibition visitors. These challenges are well established in the museum research community and have frequently been discussed in literature. Allen presents an extensive overview of this field and its different aspects, focusing on immediate apprehendability, physical interactivity, conceptual coherence, and diversity of learning modes [32]. Most of these challenges should be considered as wicked problems, meaning there is no ultimate, optional solution, but rather stronger and weaker strategies and solution alternatives [71].

To avoid repeating already discovered pitfalls in installation design, insights from previous research on the topic can and should be consulted. Doing this is useful to effectively gather knowledge about both the entire exhibition design space and narrower more specific installation domains and can serve to both introduce new project participants to exhibition design and to help strengthen the knowledge base of already established professionals. Within the exhibition design research community, essentially all installation design is done based on already established design theory. Many exhibition projects, especially within science center design, are partially commercial and are prioritising other aspects above design research that may cause them to partially separate themselves from the research community and its insights. A common strategy for bridging the gap between interaction design theory and practise is through interaction design frameworks that serve to synthesise existing research into clear and comprehensible guidelines. These guidelines can then be consulted for design decisions and save designers the work of going through extensive research sessions on their own. Within interactive installation and exhibition design, the list of previous research and available frameworks is quite substantial, and serves to provide insight and advice for many of the situations identified in this work.

For successfully creating exhibitions with a variety of interactive elements, an understanding of how to implement these varied types of interactions is required. Allen and Gutwill present an enlightening review of the pitfalls present when designing tangible installations with multiple interactions [12] and the EDGE (Exhibit Design for Girls' Engagement) framework provides many concrete guidelines for making installations more appealing to teenage girls [72]. Tangibility opportunities are often restricted by durability requirements in the exhibition environment. Some interesting examples of potential solutions for finding workarounds have already been explored: Horn, Solovey and Jacob introduce the notion of passive tangibles to explore ways to make loose installation components reliable and cost-efficient to replace [17] and Rehnberg, Alford, Roberts et al. describe the challenges present when trying to implement VR activities in a museum setting [15].

On the topic of self-explanatory installations, Allen coined the term *immediate apprehendability* and concluded that much knowledge can be derived from user-centered design when working with these challenges [12]. One of the most important methodological approaches to successfully utilise user-centered design is through repeated user testing during development. We will return to the different aspects of iterative design to explore the challenges present there further in the next section of this discussion.

The target group dilemma, of how to target individual types of visitor groups while still designing things to be accessible and appropriate for “everyone”, is also commonly discussed in the larger scope of exhibition design. Targeting every type of individual within the same installation may not always be possible. Still, there are strategies that can be used to make the possibilities for reaching additional, less common groups of science center visitors. When evaluating the results of the EDGE (Exhibit Design for Girls’ Engagements) framework, researchers found that explicitly designing for teenage girls made the exhibition work equally good or even better for all teenagers [72]. Designing for groups that are typically more difficult to reach may be an efficient way to ensure that as many as possible are included in an installation target group [73].

The challenges in making education entertaining while still actually being educating have also been well discussed by others. From a design perspective, many useful design guidelines for these types of interactions can be drawn from frameworks in gamification techniques and perspectives on user experience design [74, 75].

8.2 Iterative Design in Interdisciplinary Exhibition Projects

As described in our results, iterative design with cycles of prototyping and testing is often deprioritised in design processes with the intent of saving time and other resources. While iteration workflows may initially present as more resource demanding compared to linear approaches, they have also been shown to save project resources in the long run; Discovering design problems earlier in the development process can help with adjusting designs while it is still easy to do so, as well as help creators decide whether it is appropriate to continue with an idea or if it ought to be discarded to make room for something else [50]. There are many examples to be found in literature that describe the advantages of an iterative design process and formative testing, both within the general design field and specifically within the museum and science center community.

For exhibition design, many design challenges are directly related to aspects of usability and user-centered design. Some of the examples identified in this work related to installations being self-explanatory, having multiple target groups and varied types of interactivity. As described in our results, a good collaboration between museum professionals and interaction design and technology experts can go a long way in finding solutions to usability challenges. However, these collaborations will rarely be able to utilise the full potential of a project without also taking feedback from the exhibition target groups. The visitors are the experts on their own experience and the only way to fully understand what that experience will be like is to conduct user testing on installations and adapt their design based on derived new insights. Dancu, Gutwill and Hido describe the discoveries made during the iterative development of a "geometry playground" [76]. In the project, qualitative data from interviews with visitors and systematic observations of visitors' interactions with several installations were used to adjust the installation design to make it more educational, as well as easier to use. The team presents several questions used during evaluation that would quickly evaluate an installation's most critical aspects:

- Are visitors interested in the exhibit concept?
- Can visitors quickly figure out how to interact with the exhibit to produce interesting effects?
- Are visitors motivated to continue (i.e., focusing on process over completing something specific)?
- Does the exhibit spark any new areas of inquiry for the visitor?
- Are visitors practicing the skills we have designed for?
- Are visitors frustrated or confused?

Other studies describe formative testing methodology with a more quantitative approach in addition to qualitative methods. Some of the data collected for for quantitative evaluation includes: measuring the time visitors spend using an installation, noting down demographics such as age and gender, and comparing different alternatives of information presentation within an installation, such as changing the information on signs and switching tangible interfaces for completely touch-based ones [77, 78].

For interdisciplinary projects with internal museum expertise and external technology expertise, some challenges that restrict the opportunities for testing were identified in this project. During early phases of a design process, design was done primarily by museum staff that had limited possibilities for building prototypes in workshop environments or doing their own scripting, and relatively little experience in different types of low-fidelity prototyping techniques. During later phases, prototyping was placed in lower priority compared to actual software development, which resulted in situations where testing became focused on detecting software bugs rather than on usability testing. During final evaluation sessions, anything but smaller corrections and fine-tuning was often too expensive to change. From this, we can note that the challenges relate to both finding strategic ways to work with iterative methodology in exhibition design, and in finding ways to highlight the value of iterative methodology to ensure that sufficient resources are allocated to enable using it in practise.

8.2.1 Low and high fidelity prototyping

The dilemma of high and low fidelity prototyping and its advantages and challenges is well documented within interaction design: Low fidelity prototypes are quick to build and easy to adjust but have lower detail and are less representative of the final design while high fidelity prototypes are more detailed and more likely to reveal real user behaviors, with the risks of users assuming that the prototype represents a final product and larger changes being a lot more resource demanding [79]. This is a common challenge in interaction design processes. Many frameworks for solutions and workarounds have already been established, tried and evaluated, both in interaction design in general and specifically for exhibition design. Strategies for low and high fidelity prototyping and testing for exhibition design are further discussed in the following sections.

Low fidelity prototyping refers to the part of an interaction process where simple representations of design ideas are used to explore alternate solutions and identify potential challenges without yet committing fully to any aspects of a design. Through a combination of using simple materials such as paper or cardboard together with resource effective methods for testing and evaluating such as Wizard of Oz [55] (where software interactivity is simulated by a person behind the scenes), low fidelity prototyping can help guide and inform the design process from a very early stage.

For installation design that is primarily screen-based, paper prototypes and wireframe tools are both effective ways to begin a design process. When researching how computer prototypes and paper prototypes compared as tools for evaluation and collecting feedback for improvement, Sefelin, Tscheligi, and Giller [80] found that paper prototypes could generate almost the same amount of feedback and potential insights from users as their computer-based low-fidelity counterparts could, showing that insight into advanced graphical prototyping and programming tools is not necessary during early development.

Installations at science centers often include some tangible elements that may be harder to represent on paper than something such as software on a screen might be. However, Wiethoff, Schneider, Rohs, Buts, and Greenberg [81] demonstrated that many tangible interactions can be prototyped with cardboard and other low fidelity materials and methods, all without the need for any significant resources or technical expertise in software, electronics or mechanical engineering.

While low fidelity prototyping can provide a lot of valuable insights with a small amount of resources, high fidelity prototyping can have some significant benefits without being much more resource intensive [82]. Building a high fidelity prototype does not have to mean building a fully functioning system or installation. For example, if the aim is to prototype a digital installation where the user interacts with a touch screen, an interactive wire-frame can be built that can have the same graphical look and feel as well as the same response speed as the eventual end product, but without the need to code the full interactive capabilities. High fidelity prototypes can provide interactivity, allow for easier testing of workflows and let's the researcher focus on observing the users interactions instead of how to perform the test itself by faking the interactivity themselves [82]. It also provides an experience to the user that is much closer to a real interactive installation, thus having the potential to provide even more valuable and specific insights than a low fidelity prototype.

8.2.2 User testing in exhibition environments

The largest obstacle standing in the way of iterative user testing at science centers and museums is the fact that much of the development is done elsewhere, by other people. We often refer to the Exploratorium and their perspectives on installation development in this paper, but it is important to once again note that the work there is done by an organisation that has the internal resources, workshop environments and expertises necessary to create an installation, place it in their exhibition environments and then explore and iterate on the design mostly without leaving the building [83]. When development is conducted elsewhere, it places restraints on what is possible during these processes and limits the opportunities for user testing in realistic exhibition environments.

The difficulties in conducting formative evaluation sessions in the real exhibition environment was seen to result in the first proper evaluation of exhibition installation often being summative rather than formative. User testing can be used as a type of summative evaluation to guide smaller design adjustments that are still possible to do and to gather useful insights for future design projects. However, noting problems and new insights with a design without creating opportunities to adjust it comes with additional implications. When describing their own interactive design approach, Dancu, Gutwill and Hido reflect on the challenges of introducing evaluation aspects into design [76]. When beginning to introduce evaluation methodology to a new exhibtion process, they found it useful to begin by working with formative testing, rather than summative. This is because summative testing can create scenarios where the exhibition designers feel like the evaluation is examining their performance in the project rather than the final product. By initially implementing formative testing, installation developers can instead be encouraged to instead see testing methodology as a useful tool that can support the design process and make the designers' work easier.

8.3 Methodology Reflection

The conclusions from this report are primarily based on qualitative data collected through semi-structured interviews with both museum professionals and external project participants. The gathered data was analysed with consideration to processes, different types of expertise and important aspects that were described to affect exhibition success. The identified challenges were validated for accuracy through questionnaire responses from both previous interviewees and with employees at other science centers and museums across Sweden. Together, these methods have been used to present perspectives on exhibition design that recounts already well established design challenges and observations from the fields of interaction design, visitor studies and exhibition design while providing additional insight into the collaborative aspects of such projects.

The exhibition design space is inherently complex solely based on the multiple target groups and other design challenges that must be taken into account during development. The interdisciplinary nature of the collaboration between museums and technology experts complicates the process of understanding the many aspects of the design processes in context even further. Many of the aspects that were seen to affect the outcome of an exhibition were described in the context of specific project resources, collaborations and decision making structures. To ensure the anonymity of project participants and focus this work on presenting insights from an interaction design perspective rather than an organisational one, the full analysis of the exhibition projects and processes examined in this work have been excluded from this report. The same reasoning also serves to explain why some statements from the questionnaire used in Phase 3 have been omitted, and why the results from the questionnaire sent to interviewed participants and staff from other institutions are merged instead of presented separately.

The aim at the start of this project was to conclude our work with a workshop or co-design session together with Universeum to explore methodology based on the results from our work as well as facilitate conversation and potentially gain more valuable insights to present. However, due to the ongoing Covid-19 pandemic, physical meetings have not been possible and while it is possible to conduct workshops via online video conferencing and other tools, we deemed that to not be a good option. We believed that an online workshop would simply be to constrained in what would possible, and that the restrictions would potentially give participants a negative view on co-design instead of encouraging them to continue working with that type of methodology. With difficulties to divide the group into smaller groups, to work together with hands-on materials and generally having a lower quality of communication compared to physical meetings, it was decided to be best to save it for potential future projects.

8.4 Future Work

The aim of this study has been to identify key aspects of interactive exhibition design processes. Many of the observations and conclusions presented align with previous work in the field, and serve to highlight that there are many interesting aspects of design principles and process methodology that will continue to require further research.

Future research in exhibition development methodology should strive to examine the collaborative aspects of how museum professionals work with external technology experts further. In this project, data was gathered primarily through interviews with project participants and will as such mirror the individual perspectives and opinions of these participants. In similar future studies, an action research approach where the researchers are themselves part of the design process to some extent might be appropriate to gain additional insight into the knowledge exchange processes that occur in interdisciplinary collaborations.

To support exhibition developers in creating processes that support iterativity and prototype-test cycles, more effort should be put into finding suitable methodology for conducting user testing during this development. The focus of this work should be placed on examining rapid low-fidelity prototyping techniques that can help museum professionals to explore interaction alternatives before involving external actors in the process. Explorations in regard to finding effective methodology for estimating an installation's functionality in real exhibition environments before deployment in such is another recommended area of research.

Although both internal museum professionals and external interaction design and technology experts were interviewed in this project, the majority of the interviewed were internal museum staff. As such, their perspectives have been represented with more weight in this work. Future projects should strive to examine the perspectives of external expertise in more detail to gain more insight into how exhibition development is perceived from an interaction design and technology expert perspective.

8.5 On the Implications of Increased Use of Technology in Education

An ongoing debate in the science center and museum field relates to these institutions' need for becoming more digitized and entertainment focused to be able to compete for visitor attention with other types of entertainment that exists in the world [3, 14]. This brings with several new challenges to the exhibition design space, that in their turn creates additional implications, both in relation to why technology is required in educational spaces, and why it is often implemented the way it is.

We have previously provided some example on how interaction design perspectives on gamification and user experience design can assist in these attempts, but are yet to talk about if this is the best way to move forward. In many scenarios, applying additional entertainment aspects to encourage interest in learning is expected. However, many gamification techniques are to a great extent design methods that are utilizing the human brain's reward system to trick us into becoming invested in interactive activities [84]. While gamification in educational contexts can be useful to help users visualise their learning progression [85], adapting it as a standard methodology for educational design has troublesome implications that relate to society's view of science and knowledge in a larger perspective. Humans are evolutionary wired to be curious and seek out knowledge about the world around us [86]. If gamification techniques such as progression badges and point systems are starting to become some of the primary design guidelines for ensuring that children are developing an interest in mathematics and technology, by essentially tricking them to find it enjoyable, there may be larger challenges ahead than finding additional techniques to support interactivity.

Similarly, attempts to create more complex interactive solutions for information visualisation in exhibition environments may not necessarily lead to more successful solutions. Historically, science center exhibitions have to a large extent managed to convey a lot of scientific knowledge through rather simple means. While flashier, modern interactive technology such as VR and holographic visualisation techniques may be able to present information in alternate ways and visualise more complex relationships, there is no guarantee that this approach is inherently more comprehensible or educational than the more classic solutions. Especially as we have noted that the demand on technology in exhibition environments is increasing, it is not impossible that many attempts to create more technologically complex exhibition components serve a much larger commercial value compared to the educational aspects that exist at the core of science center design. This creates a scenario in which it is exceptionally important to ensure that methodology for interaction design and technology is incorporated into these projects. Technology development is very resource demanding, and science centers and museums are often low on resources. As such, it is crucial that the technology projects they are spending resources on become as successful as possible, once again emphasising the importance of finding ways to work with usability testing and other types of methodology as efficiently and strategically as possible.

9

Conclusion

The purpose of this project was to answer the following research question:

> Which key factors affect the interdisciplinary design processes of interactive museum exhibitions?

Through interviews with science center staff, external exhibition project participants, and questionnaire responses from additional science centers and museums, we have presented an extensive overview of different perspectives on interactive exhibition design. We have found that the most important factor that affects the outcome of an interactive exhibition project is the collaboration between museum professionals and the external actors that are responsible for technology development. The possibilities for solving many important design challenges in the exhibition design space are directly related to these interdisciplinary relationships.

Our results described three phases in the exhibition design process as especially important in these collaborations:

1. *(i) understanding of the design space between museum professionals and interaction design and technology experts*
2. *(ii) iterative design with museum professionals and interaction design and technology experts*
3. *(iii) launch, evaluation and long-term maintenance strategies for exhibitions between museum professionals and interaction design and technology experts*

We have continued to discuss the challenges present in these phases from a theoretical perspective, showing that there are many examples to find in existing design methodology that can help meet these challenges and suggesting areas that relate to this that should be studied further in the future.

Our work highlights the importance to continue work with improving the collaborations between museum professionals and external interaction design and technology experts to an even higher degree. Many existing models for museum exhibition design, such as the one presented by Kaminen [42] are not focused on exhibitions with a strong technology focus, meaning that many of these models cannot be translated directly to interactive exhibition design. By exploring the collaboration between museum staff and interaction designers, hope to have provided a valuable contribution to the initial understanding of the necessary roles and types of expertise in more technology-focused projects.

Much of the existing literature in the field of exhibition design stems from either research created by science centers and museums with the expertise and resources to design and develop exhibitions and installations mostly in-house (e.g. The Exploratorium.) or from primarily designer-led research projects where museum professionals are primarily involved as expert consultants, if involved at all. However, many science centers and museums have an exhibition development model where they rely heavily on contractors and other external collaborators in interaction design and technology and these institutions seem underrepresented in the literature on exhibition design. This is why we believe that one of the most important contributions this report offers to the field of exhibition design is shining a light on the challenges of exhibition design in science centers and museums where exhibitions are not primarily designed and developed in-house, as practices that works well in institutions that do design and develop in-house does not always translate well to institutions that do not. While many established participants in interactive exhibition design projects may already have experience and insight into these factors, there will always be new participants who do not. As such, these results are particularly useful for science centers and museums who are currently starting their journey into creating more technologically advanced exhibitions. This report can also be used as a quick guide to technology contractors who have not done development for exhibition environment before, as well as for aspiring exhibition interaction designers who want to gain an initial understanding of the design space and its processes and challenges.

The implementation of processes for greater overlap in understanding and a shared iterative design process is crucial for ensuring that typical design challenges in the exhibition design space are adequately met. With science centers and museums often having very restricted resources for development, it becomes especially important to ensure that these are spent as efficiently as possible when beginning more expensive technology development, to ensure that the already extensive amount of work being placed in these projects is translated to as successful final results as possible. Finding effective ways to work with these challenges will enable museums and science centers to continue to consult external interaction design and technology experts that have less experience with exhibition design in addition to more experienced contractors. This exchange will allow these collaborations to continue to innovate on the possibilities of using interactive technology to educate their visitors in new ways in the future.

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A

An overview of time spent in the project

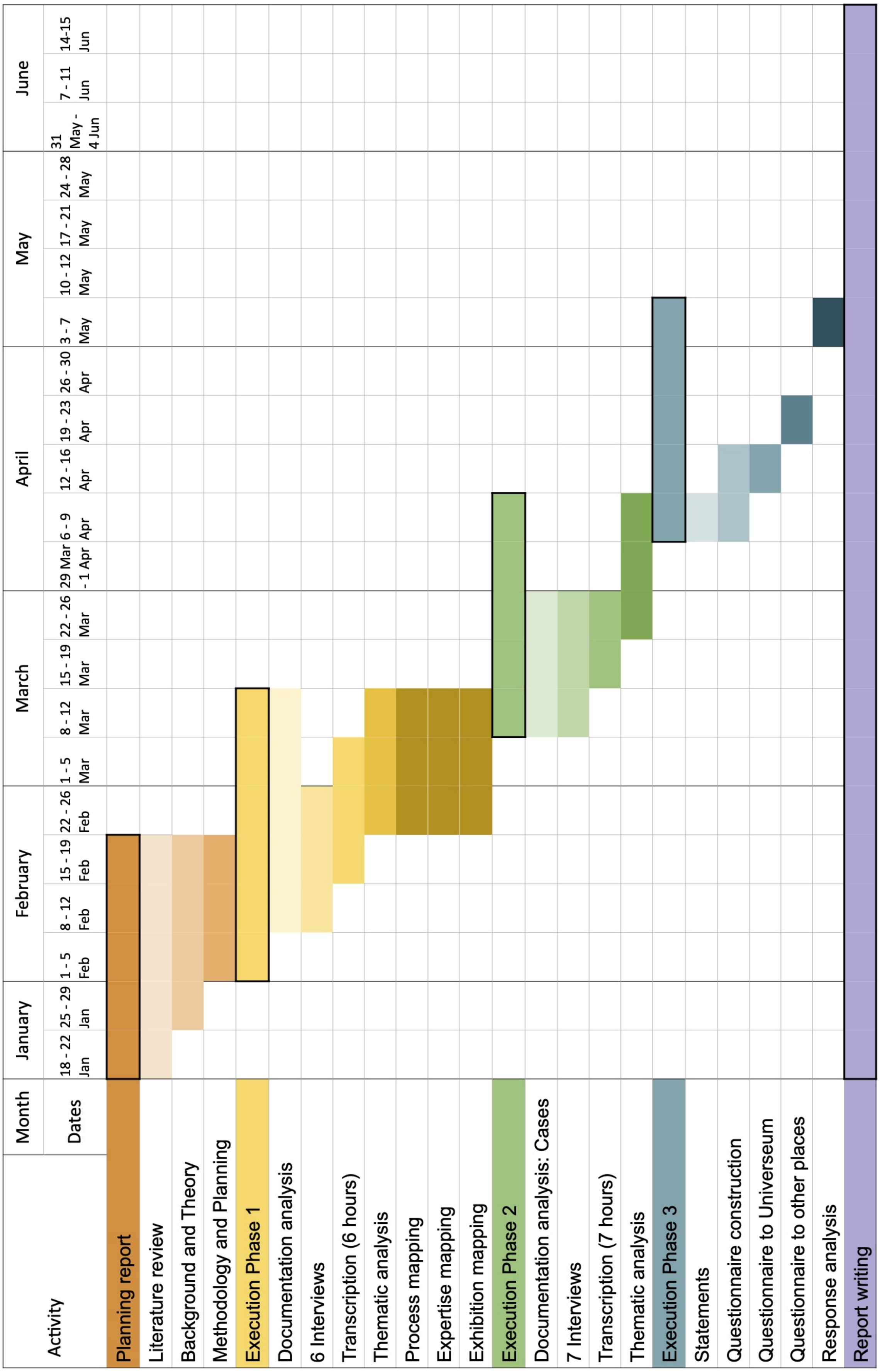

Figure A.1: An overview of the phases and activities undertaken in the execution of this project in relation to time spent

B

Thematic analysis from Phase 1

Theme	Example Quotation
Ideation	"They [ideas] come from different... staff from [the science center] who are involved. If you look at [exhibition], we were many educators who joined early and then the ideas come from the educators in that case. But it is far from everything that can be done. So in the beginning, it's just a brainstorm of different ideas."
Concept Development	"Depends on what stage you are in the project because in the early stage then it is very broad then it really is: no idea is too crazy. It can be high and low and completely crazy. Then you have to start landing in something that should be a little more concretizable and practically feasible and put within the constraints of time, money and what room you have. In the beginning it is extremely wide and wild and everything is allowed and then it is that it is slowed down towards the end when time and money are a very limiting factor."
External Partnerships and Contractors	"Understanding what you mean and understanding what the other person means and trying to express what you think and think... it is very difficult and it lands a bit in what I said before: that is why it tends to... there is a security to work with actors you have worked with before because then you can skip some of the communication difficulties that exist because then you know how to interpret each other. So communication is among the most difficult things there is."
Testing and evaluation	"We don't build prototypes because it's too costly, we never have that kind of financing, plus we don't have our own workshop [to build prototypes in]. Which means that prototyping is really difficult to work with."
Roles and Expertise	"What is perhaps a little special about the educator role is that we are usually involved not only early on, but in the whole process because the input we have is relevant, I would say, from start to finish." "On the other hand, I think it's good when you bring in different expertise early in the development work in a way that you might not have done 10 years ago. So it is still good that everyone is involved from the beginning and can wear different glasses when developing."

Scientific knowledge	"I get to read a lot, it's very fun, you have to like learning yourself too. Because when we go into a new subject then I have to read a lot myself so I can understand what is important in this subject area and can talk to experts in the right way and stuff like that. I get to learn a lot."
Interactivity perspectives	"It's about learning about science by discovering science, I would say. If you can interact with it, if you can, then it will be something other than just reading" "[Interactivity] is absolutely crucial, because we have an idea of how one would like to experience [something] and what to learn and those who know this technology can present solutions to what is physically possible."
Educational knowledge	"The biggest challenge is learning. To get people to actually learn something. It's very difficult. How to do this. We want people to have learned something when they leave here, that they carry something with them. Then you have won something. To think about it in every situation, not everyone can learn everything, of course, but even if you only visit one installation or see one animal or part of the rainforest or something like that, it is good if you learn something, so to speak."
Target Groups	"We have all grown up: children do not do as you say, children do as you do. So if we can find a way to influence adults, we can do a great good. Then come simple questions like: what is it that would make a parent go into the [science center] after work when you are tired and so on? So we have to find these factors that make people stay after work and go to some kind of after work or something like that." "The big challenges are precisely that everyone should… it is difficult to choose a target group because it means that you opt out of some other target group. At [our science center], we have huge problems with it being for everyone and I think it's very difficult to develop an interactive product for everyone because it means that no one really feels that this was really great for me."

Exhibition environment requirements	"They [an external collaborator] have a completely different set-up and a completely different level regarding if it is okay that an installation does not work: yes, for them it is okay, you just put up a sign and then a technician can go there when they feel like tinkering with it. For them it's okay, for us it's nowhere near okay. There is a huge cultural difference." "[Installations] must withstand that people use [them a lot]. It almost means pounding on them and it should still work and it should be easy to start and everyone who works here should be able to start it and do troubleshooting and the like. We have very practical use."
Satisfied With	"[In this exhibition] we thought of a broad target group quite simply. So there is something for the very youngest and there is something for the oldest and you have also thought about whether you are wheelchair bound or if you have… So there is something for everyone. So therefore I think [this exhibition] is good."
Unsatisfied With	"There is a lot [of good stuff] in [this exhibition] but it... It requires a lot of staff for it to be able to give our visitors something [good] I think." "It would be [this exhibition]. We had external people involved and it did not go well."

Table B.1: Examples of quotations coded for the most important themes identifies as part of the thematic analysis in phase 1.

C

Thematic analysis from Phase 2

Beginning of Table	
	Themes and Example quotations
Interactivity: Different types of interfaces	"I think it is important for a science center to have a wide range. So that you include different types of interaction. [...] I think that having a wide range of interactivity has its own value. To achieve different experiences and reach different types of learning." "[A touch screen with text] is not interactivity, it is exhibition communication. Just because there is a screen, it does not mean it is interactive. There is nothing to do but swipe. That is not interactivity." "There are only screens where you are working with real data so the interactivity is just pointing there and there and selecting things. But the interactivity is really low and it is purely digital interactivity. There is no tactility or analogue components. It is a lab." "[The] first generation of [installation] had physical cards. You can put on things and move around. And you can see tangible things in the virtual world. But then, [the science center] had problems. They would lose a set of cards every day. We cannot manage it. We have to make it virtual."

Continuation of Table C.1	
	Themes and Example quotations
Interactivity: Self-explanatory aspects	"... many find it to be fascinating and fun but we really want as many as possible to understand that there is more to do and that they can bring it home in another way. I would say there is a threshold to it. If none of us are there for what we call guided learning, few are able to understand that you can get your own screen recording in your phone or computer from home as it is right now." "[The exhibition] is a lot more dependent on us having people in there. Of there being a guide or educator nearby for it to not feel dead. But if we have one or two guides or educators in there, it feels like there is quite a lot happening". "I would say the pedagogy-based usability aspect. It needs more development. Especially the 'walk-up-and-use' has to be clear enough for [visitors] to understand what to do. It is difficult in that installation to understand the bookmarks and how to record the movie and such. We know that there is a threshold for understanding. It is easy for visitors to sort of give up and leave. I think it would have needed adjustment, pedagogy-wise" "It was too difficult for our guests, so we had to scratch it. We had it for a while, but only if a guide or educator were standing there and introducing guests to it. But it is not economically sustainable to always have a guide standing there. It is the same with VR, you could only do it if a guide is there."

Continuation of Table C.1	
	Themes and Example quotations
Target groups: Accommodating everyone	“Before, it was children and youths, but now it is lifelong learning. From birth ‘til death, there should be something at [the science center] for everyone” “[...] many parents said: my 10 year old loves being in here, but it is difficult to be in here because I have a 5-year old as well, and he leaves and does not think it is fun, and you have to be able to be together. Which is completely right.” “...it is difficult to pick a target group because it means excluding [another] target group. At [our organisation] we have huge problems with the fact that it [exhibitions] should be for everyone and I find it difficult to develop an interactive product for everyone because it leads to no one feeling that it is actually made for them.” “You wanted to put everything into these installations. And that is physically impossible. To attract everyone in such an environment. So somewhere you have to limit yourself, and [the science center] had a hard time doing that.” “So it is, I think, the scope of the user. That is the biggest challenge. Whenever making it too complicated, I’ll say ‘please, think [that] I’m a six year old. I don’t understand what they are talking about.’ [And on the other hand,] when we show the project to the most intelligent people in the country, they will say ‘Oh that is too childish. It’s too simple. You didn’t deliver the depths of science’. Okay. Then, you have to deliver all of them in one product.”
Target groups: Parent-child learning	“One thing we need to do better with is adults. It’s also a way to get to the children. If parents are interested then the children will become interested. “When we selected photosynthesis as a good thing to show, we brought it up with the advisory board and he who is good at play and interaction between children and adults told us to think that when you are creating for example a distance between mechanical elements so that you have to be three or that you understand that you have to be three”

Continuation of Table C.1	
	Themes and Example quotations
Understanding: How to present something educationally	“For [the partner organisation] that is working with the technology, the content does not really matter, but rather the functionality. So sometimes there was some collision. Because they wanted the low hanging fruit somehow. To deliver the data. So that they could focus on the technical functionality. And we were more… The content is most important. So even if there is a dataset that is great, it is not for us. Is there no content to be built on it? So that was a bit unclear actually I would say. But also really difficult. I don’t think anyone had understood how difficult this is.” “...mathematics gives me a stomach ache as well: We know that we need to make it well, but the initial conditions are completely reversed compared to dinosaurs”
Understanding: What is possible to develop	“I felt that I did not have enough… I should have had some more experience in visualisation than I have. [...] I did not have the strength or feel secure in knowing in which direction we were headed, as no one else did either.” “So if I were to determine whether it was possible to build or not, then you would have needed someone with programming skills. To help. To help us make better orders. And also to do maintenance over time.” “You feel a frustration over feeling like something should be easy to develop technically even if it’s quite complex, but as an educator when you say it, it feels simple. So sometimes you feel frustration because you do not really understand the developer.” “It is what it is. But.. Spend more time on this so that you… End up with a realistic goal, and all the advantages with that goal. So that it does not become too fuzzy or too big. And then it just becomes that. It’s kind of like.. Otherwise you will feel that a lot of things are missing, even if they were not intended to be there in the beginning.”

Continuation of Table C.1	
	Themes and Example quotations
Understanding: Science center requirements	“We like to work with external contractors that we have been happy with [before], it will be easy to work with them again because they know what our requirements are, because we know that if you have a completely new contractor, no matter how much you describe what the requirements are, if we would make it and they manufacture it… we know that it will last no more than two days at best, it will be a total breakdown, we know from experience. In other words, there is an inertia in the fact that we like to work with those we know have delivered well before because they know exactly what wacky stuff we have in our house” “So very clear specifications [are needed] if they have not worked with us before. When I work with an architect or someone new who will build [something for the science center], I know that we always say: "it must be robust!" but people do not understand what being robust means so one really needs to also specify what robust means. Basically what weight it should withstand.” “We are faithful to our contractors for better or for worse. Which makes us a bit comfortable, because you know people, and then it is easier. At the same time, it can make the exhibitions too similar.” “Our dream contractors are those who know our organisation very well who can be part of the process in early stages and help with both general brainstorming and then also set guidelines for what is appropriate or technically doable and such.” “It’s great if someone is an expert on the subject. But I think that even the experts have to understand who the target group is. To ask ‘Who will be using this?’ and ‘What are your experiences in attracting someone to…?’ [...] We cannot design it on our own. That is why it was… It is so good that they have someone who does it. But, we should have been more [included] in the process. And not just be given a GUI that… Because the person who is designing has never done it for public environments. It is someone who has designed user interfaces for… other stuff. But never public installations. That is something completely different.”

Continuation of Table C.1	
	Themes and Example quotations
Testing: Prototyping and formative evaluation	“Many projects have had a short development time. Even if you know it is important to do these steps [testing], they are very time consuming. So you remove them and save a lot of time even if the final result could have been much better if you had used them.” “You have external partners and you have a budget and we decide that we should have these installations and then you exhibit them. That is how it is done. And in there, you cannot really... There is no time or room in that process to create prototypes and do testing along the way. That is not how it has been done, at all, during the years here. Rather, you notice when it is being exhibited that this thing did not work, but this thing turned out great. And you’ve built up. You’ve built up a really great experience, that is partially dependent on individuals I guess because some people remember what it was like 10 years ago... ” “[The installation] was finished very late. So the first prototype we at [the science center] got to see... It took almost a year before we could see what it would become. And that was the first time we could test towards our colleagues and make a small test group and such. And there was a lot of feedback. But we were way too far along in the development so it could not be adjusted.” “... it is a situation where some kind of testing along the way could have balanced and adjusted it a little and made it good. An installation can fall completely on being too simple or too difficult. You want to achieve the level where it is challenging but not impossible, or it won’t be interesting. User testing like that could have contributed lots of course. It is not just about testing whether an idea is good or bad but it can also be to fine tune. Testing could contribute a lot, I think.” ”What could have been caught potentially... Is more user studies [where] you could have discovered when it did not turn out great in earlier stages. If that would have led to us moving on and getting it working better, or seen that ‘no, we might not do this after all’, I don’t know. So I would have to say that the only way to... discover it earlier would be with more extensive user studies. But it was done, I’ll say, during development there were user studies but not when it was finished.”

Continuation of Table C.1	
	Themes and Example quotations
Testing: Prototyping and formative evaluation	"At least, I think that the first one or two or three tests should be internal. With engineers. Focusing on the performance. [...] And then we can do user tests with internal people. Including [with the science center], also internal people. Then we test it and see whether it's some product you want delivered to the user. I think at least we should do one or two rounds of internal testing. Then we can start to book external users. But not super-external. Because we are not ready. Because I would say external users are really precious resources to give an opinion. Don't waste their time on things that are not ready. So I would say, after we are pretty sure that this is what we're going to put out. Then we can start to do external tests." "If you were to invite the target groups to think freely we are. . . We were a bit scared that this would lead to too high expectations on things that we cannot deliver the way we are currently working." "Reference groups and target analysis is great to get inspiration and understand who you are developing a product for. But often, they don't know what is best for them, or what is best." "I would say to involve the experts more. For testing, involving target groups a lot lot lot lot more. They are the ones who will give... The new users. To spend time and money on letting them test early on and give feedback. You have that with you, like all the way to the end. To not think that you are always sitting with the answers, but that the target group has them, I think. Especially in new environments where you don't have any experience yourself."
Testing: Summative evaluation	"You can have given something a lot of thought, and had test groups, but it is first when it is for real that you see it. Sometimes, it only takes working for an afternoon to see things for what they really are." "... I think it is important to not leave an exhibition when it is 'finished', because it is not finished when it is open. Rather, there is a window of one or a few months where you can tweak some things, where you can see the exhibition with fresh eyes because after a while you become used to it" "Of course, we can see if people think it is fun and interesting, but when it comes to learning, it is more difficult to measure. You'll have to go in more specifically, almost like a test: 'What have you learned?' We haven't quite reached that point yet."

Table C.1: Examples of quotations coded for the most important themes identifies as part of the thematic analysis in phase 2.

D

Questionnaire statements from Phase 3

Beginning of Table

	Statements
A	**We sometimes have difficulties estimating how resource demanding development of digital installations are, and what is possible to build.** It can be difficult for our project participants to estimate the development time, cost and what result can be expected for the installations they want to build. This is especially relevant when it comes to areas where my organization has less experience, such as software development and the use of technologies such as VR, AR and visualization. One consequence of this is that we sometimes propose ideas to our suppliers that cannot be implemented with the resources they have available. Sometimes it results in the supplier instead proposing a simpler solution that is adapted to our budget, which can result in disappointment. In some cases, this also leads to the suppliers gaining great influence during the concept development phase to concretize ideas, which can lead to parts of our vision being lost. An uncertainty about what technical alternatives are available can also contribute to projects missing certain technical solutions that could have improved the result.
B	**External contractors and partners have a hard time understanding our organization's requirements and needs.** We have high demands on durability, usability and content in our installations. External partners often have difficulty understanding these requirements on their own and require a lot of information to be able to come up with solution proposals that meet the requirements. Things that are developed for us without much help or feedback from staff are rarely considered successful. Conveying our needs requires a great deal of communication at the beginning of the process, especially when we work with new contractors. If this communication is lacking, it can lead to what is delivered not living up to our needs and requirements. Due to this, we are happy to continue to hire contractors we have had a good collaboration with before. This is not necessarily negative but may make it more difficult to test new solutions that the "regular" contractors do not have experience in.

Continuation of Table D.1	
C	**The development processes at our organization are not currently structured to allow prototyping and testing of installations. This makes it difficult to discover usability problems and determine if an installation will work well for visitors if we haven't done something similar before.** At present, our processes are not structured to create conditions where project participants can work with prototyping and testing of installations to evaluate and improve concepts we have not used before. The organization also does not have the opportunity to develop things internally, which requires strong collaboration with contractors to get evaluation opportunities. Ideas and concepts for installations that are under development are therefore evaluated mainly on the basis of gut feeling that has emerged from previous experiences. If our experience is not sufficient, it can lead to installations that are difficult to use, do not interest visitors or that too much resources are invested in developing functionality that turns out to not work as well as expected. It can also lead to us partially limiting our ideas and concepts for installations to things that we have seen work well before instead of testing something new.
D	**Our organization rarely conducts final evaluations of installations, which makes it difficult to determine what visitors are learning, and how the installation could have been improved.** Currently, there are no structured processes for evaluating learning objectives and how well the interactive experience works for visitors in specific installations. It is also unusual that lessons we learned from installation development are documented. Valuable insights on how interactive installations are best designed to engage and educate visitors can therefore be lost because they are not discovered or documented. This can make it difficult to know which installations are actually successful and why. It also makes it difficult for people who were not participants in a project to access and use insights from the project.

Continuation of Table D.1	
E	**It's difficult to decide on a specific target group for an installation, or whether an installation should even have a specific target group.** In our organisation we have different opinions regarding whether the installations that are developed should work for all target groups or only certain specific ones. When a new installation is developed, some believe that one should work to make it work for all types of visitors, at different ages and with different needs. Others believe that an installation must have a more concrete target group in order to be able to design something as good as possible. There are pros and cons to both mindsets: Designing for everyone at the same time can result in something that can be used by most people, but which is not specifically successful for anyone. Designing for a specific target group can make an installation extra good for them, but other target groups are less interested.
F	**Some installations and activities are reliant on guides in order for visitors to understand what they are supposed to do and to learn from it, even though they were planned to work well on their own, without guidance.** In my organization, the goal is usually to create installations that can stand on their own and engage and educate visitors without help from our staff. Sometimes after opening it turns out that visitors nevertheless find it difficult to absorb the material on their own. In order for an installation to be able to stand on its own, it must be so easy to understand that visitors at once know what to do and quickly understand the underlying pedagogical point. A typical example of when this is lacking is when visitors have to read longer instructional texts to familiarize themselves with a task, or when the pedagogical point must be presented in text form as a supplement to a simpler activity.

Continuation of Table D.1	
G	**Our organization currently does not have the ability internally to do maintenance on, update or adjust software in our installations.** In order to be able to improve exhibitions and installations over time, make adjustments and ensure that technical installations continue to function, it is required that it is possible to internally continue to work with the installations when they are in operation. When this possibility does not exist, exhibitions age at a faster rate than necessary. Small bugs are not fixed, datasets are not updated and there is no possibility to improve user-friendliness based on insights from when the exhibition has been in use. At present, my organization does not have the opportunity to do this internally. It can also be difficult to even access the software in the first place in existing installations. Instead, we have to rely on contractors for this type of work. This becomes both complicated and costly as this need arises after the original project has been completed, which leads to it rarely being done.

Table D.1: Statements from the questionnaire sent to science centers and museums other than the science center used as a case study. Statements were originally in Swedish and have been translated for this report.