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The Design of Tangible Interfaces' volumes and geometry: Effects on discoverability and cognitive load

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Doctoral Dissertation

The Design of Tangible Interfaces' volumes and geometry: Effects on discoverability and cognitive load

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Abstract

In our daily life, it is not considered a challenge to interact with our immediate surroundings that comprises of doors, light switches, coffee cups and any other utilitarian objects. Nobody is really questioning the shapes of a tea mug outside of its aesthetics. All objects that are acted upon obey some underlaying logics that, even if not visible, are communicated via these objects' forms. This is known as affordance, or the capacity for an object to communicate on its potential usability through its design. If users find themselves in the incapacity to properly use a simple object like a door, it is not the fault of the users. If someone attempt to open a door by pushing on it and nothing happens, the only remaining solution is to pull on it. This is sometime frustrating but not impossible to figure out. This school of idea is applicable to any tangible object, but what about the things that are intangible?
In the realm of interaction design, tangible interface is a bespoke artifact created to offer a physical interface to interact with. It has the same purpose as graphical user interface, to communicate on what is available to the user and how it can act upon digital content.

The subject and purpose of this study is at the crossing of these two ideas: If the mechanics of design (affordance) were to be applied to digital content and tangible interface, what shape would such object take? Could that shape help the user connect better with said object, to have a more enjoyable and engaging experience?
Current works on tangible interface focuses on how they render interaction easier and more natural due to direct physical manipulation. This is being explored in varying ways, either by proposing 1) interpretation of a known subject (physically manipulating a landscape) or 2) creating bespoke object with innovative ways to interact with content (manipulating a toy to learn about complex subjects).
Such object is designed to represent its function(s), but its study focuses on the effect of its tangibility and mostly disregard if the design and aesthetics of the object has some effect. It is a study of objects' function over the possibility to study an ensemble of factors.
The study of design shows that good design should be a combination of practicality and enjoyment, simplicity and strong connection with users.
For this study, several experimental tests were ran, in an attempt to understand if there could be some relationship between the shapes of tangible interfaces and how users would perceive those interfaces. Three experiments were performed, each employing dedicated objects aimed at studying two facets of this study: 1) Can the shape of an object affect how participants would move in space, questioning the relationship participant/object/space. 2) Can participants abstract some mental representation out of an object, how does it affect their perception of said object (what is it for, how could they use it).
For the second part, due to relying heavily on how participant would process cognitive load, three age groups were tested, to verify if cognitive development and age would have an effect on how an object would be perceived and interpreted.
Results suggests that some types of shape would have an effect on how user behave, inviting them to move in predetermined ways (forcing them to look closer, to move their head to either side of the object). It also suggests that across all age groups, users are able to abstract the shape of objects and connect it with potential actions and interactions. It also shows that if visual support are applied, user's focus will shift to the images and affect how they would perceived the same object.

This would mean that, if appropriately designed, tangible interfaces could not only allow user to better connect with their object (physical manipulation) but also guide them in how to use or behave with that interface and offer a geometry onto which they could project its potential interaction(s), reduce the necessary connective process (if the object communicates properly on its potential) and allow for a better enjoyment of the interface.

Keywords: Tangible interface; Affordance; Discoverability; Design study; Interaction design.

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Chapter 1

Introduction

The general guideline and motivation of this thesis will be defined in this first chapter, separated in several sections each presenting key starting points for this study. The first section introduces general observation on user interface and user experience in interaction design. The second section extends to the interfaces at play during any interaction processes. The third section presents a brief overview of works related to this study and the choice of potential environment of study. Section four introduces the research objectives, aim and contribution to its respective field of study. Ultimately, this chapter ends with the dissertation roadmap.

1.1. The design of an interface

"How do I access information? How will information be displayed?" These are not really questions most users of smartphones, tablet pc and computers are asking themselves, yet it is a group of actions they perform on a daily basis. One of the main feature of those devices is to make an action feel seamless and effortless, the users not being expected to ask themselves how are things working underneath their phone's skin of glass and metal. This effortlessness to perform a given task is what's attractive about those devices. In the field of design, what look effortless tends to be misunderstood. Simplicity and clarity tends to be mistaken for a lack of originality and laziness. When an object like the iPhone™ entered the life of millions of users, the general consensus after a period of acclimation went from "This will never catch on" to "of course a smartphone has to look like this, why wouldn't it?". Yes, why wouldn't it? An object that performs as designed and communicates well on its functions can be considered to have a good design. In general, if a user is not able to figure out the correct way to use an object (a door, a tea kettle or any relatively simple object), chances are the designers did 1) not do the best interpretation of what actions were necessary to be performed by the user, 2) design the object and its interaction process without enough clear indication given to the user on how to perform properly.

This particular notion, that an object can communicate its function purely through its shape is known as **affordance** [1]. Affordance represents the interaction potential of an object, what can be done with it and how. An object communicates this via its form (its design).

"How do I access information? How will information be displayed?", in the field of interaction design, those two questions are key elements around which all design are created. They are defined by the following fields of work: **User interfaces** (known as UI) are what users sees and interact with on a given device and **user experience** (known as UX) is the set of actions that defines the interaction process the user is taking part in. User interfaces usually rely on imagery, known as **graphic user interface.** It is the sets of buttons, images and visual support that users receive information from on how to use the interface.

How do I access information, with which devices, or which processes? How will information be displayed, communicated or visually shown via imagery? This study as for purpose the exploration of those questions.

In the field of design, inspiration and creativity represent a reasonable part of the creative process and I personally have an interest in product design and thus have always been intrigued by **tangible interfaces** [2]. Tangible interfaces are custom made artifacts responding to the same principles as a graphic user interface, they have to communicate with the user and allow for practical interaction. They only differ in the type of manipulation being performed by the user, one based on a visual medium, the other on the physical manipulation of an object.

This very idea, that interacting with digital data is not necessarily bounded to a limited set of tools like a screen, keyboards and mouse opens the scope of potential interaction to solutions that could be precisely tailored for specific interaction needs, and potentially be more meaningful.

A second subject of interest for myself are educational environments, such as schools and museums. The breadth and specificity of the subjects being studied there lands themselves as suitable environments to apply and create dedicated physical interfaces that allow for direct manipulation and self discovery. Self discovery is the capacity to explore and discover elements of knowledge (how to use an object) without the need of explanation or external help. For this study I will not apply the findings to educational environments. Instead I will use the findings of different studies on this subject to see how to enrich the design of potential tangible interfaces aimed at promoting discoverability.

1.2. Interaction design and artifacts

This capacity to design an artifact with any given shape than can perform any imaginable task has motivated the creation of novel ways of interacting with digital contents. It could be considered that there are as many types of tangible interfaces as there are problems or original ways to interact with an interface.
The concept of a tangible interface was introduced in the previous section as a stand alone object through which users can manipulate or control digital information. The goal is not exactly to remove any sort of display and work uniquely through direct manipulation, but to broaden the selection of interactive processes and communication aids to a wider scope of mediums and ideas.

That very basic idea can result in combining a tabletop display (a table with its upper surface being a screen) with tangible interfaces allowing for a back and forth communication between both elements, for example the manipulation of architectural content [3].
A tangible interface being an artifact custom made for a given interactive system, it can take any shapes and can also be the result of the combination of smaller interfaces, in the end resulting in a system that allows users to assemble each elements in accordance to their actions [4].
The freedom of creation for those interfaces can lend itself to more artistic ways of interpreting a subject and thus creating an interface that perform in original and specific ways [5].
This freedom of shaping the interface and the interaction process can be adapted to the digital content as well as to the environment in which it is being used. Tabletop type interaction can also be reproduced in a more nomad way and integrated in public space like in a museum. This types of system could allow user for a direct choice/manipulation of the content by replicating the behavior of large table top system on smaller devices like a tablet Pc [6], where they can also place and move tangible interfaces.
The interface itself does not need to be passive and can also be related to contextual information (IOT, internet of things) and perform in a way that is aware of the users' environment [7].
The purpose for those enabled interfaces is to remove the need of a "display only" interface and increase what the display can communicate by allowing for contextual interaction.

Interacting with something does not have to be representative of anything, it can also be the interpretation of user imagination and abstract ideas. Using common basic knowledge as a base of interaction can allow for the creation of innovative interactive processes. For example it is commonly known that pinching or knotting a water hose will stop the flow of water traveling inside it, so pinching or knotting an electrical cable could be interpreted in the same way to limit or control the flux of electricity passing through that one cable [8]. It is this sort of interpretation that can lead to original and meaningful ways of perceiving and connecting with digital content.

Previous studies have been focusing on the creation of novel artifact to either solve a problem or create a different narrative or way to interact. The experimental project Topobo is a prime example of this principle, starting with the goal of teaching basic concepts (in this case kinematics) to students. It ended up as a tangible interface that would allow students to experiment in an effortless way with the class subject [9], learning the subject by directly manipulating a toy representing the subject being studied.
Interacting with an object does not limits itself to the user acting on it and enabling an object to be animated can open the scope of interaction. In this case both user and object are active and help create a more dynamic interaction process, resolve a key problem or enable innovative representation. As an example, allowing memo notes to move around on their own in the work space might enables the creation of novel ways to interact with it [10], for enjoyment purpose or efficiency.

That aspect of pervasive technologies, accessible everywhere but not visible is not a brand new idea [11] and it allows for an ever-present interaction with digital data, not only in the form of a device like a phone, but the data embedded in your transportation pass, your fitness training bracelet or your car. This ubiquitous ballet of data simplifies what was once a multistep process, "You can take a picture with your camera, send it from your phone, store it on your iPod" [12 p.97] and this without having to do or wait much. The ever growing presence of these communicating objects also promote "the refashioning of physical space as we cohabit and co-occupy space with things" [13].
That constant ballet of recording data, communicating data and integrating data lands itself to novel ways of interacting with it, interpreting it and understanding it. An example could be that the advent of future technologies could allow for a seamless integration of the life span of the object/interface in its environment, from its creation to recycling [14]. This concept is some years away in the future, but the constant access to information and integration of objects in the everyday data communications is now part of our reality. The way we process information is becoming paramount to keep a relative comfort of use, the object being able to adapt to its and the user's context.
Strictly speaking, these are things not observable by the users as they are located "under" the skin of any digitally augmented object. In the realm of physically designing and shaping interfaces, if the shape of an object help communicate its function, then an object that can take an infinite amount of shapes could communicate an equally infinite amount of functions. The advent of shape display is a step toward that creation of shape shifting interface although it is limited as of right now in 2.5 dimension [15].

1.3. Brief overview

The concept of affordance is one of the keystones of good design, may it be product design or user interface design. It defines the way an entity communicates its functions and how to use it through its shape. The general idea behind this study is to question how affordance could be applied to tangible interfaces, not only from a design perspective, but also in term of **cognitive load** processing. Cognitive load represents the effort applied to a user prefrontal cortex when performing an action or perceiving an object (or environment). It is usually linked to cognitive overload, when user's brain can't process properly the amount of information given to it (either in too much quantity or complexity).

The ways users process information can be categorized as based on contextual clues and direction called **situated cognition** which has an effect on mental processing during the completion of tasks. Situated cognition represents the information someone perceives in different contexts. That person won't be aware of the same set of contextual clues in a kitchen or in a class room to help achieve specific tasks.
In her study [17], Bonawitz, E. discovers that children who have received no explanation on how to perform a task will be more prone at experimenting and testing. Mitra, S. demonstrated that student could organize themselves around a given task and find ways to solve a given problem, even if the subject was considered as advanced [18]. This way of teaching might not be suitable for all type of subjects and concepts, especially for younger students. Applied to this study, their proposition is to broaden the scope of ways to present and teach educational content, thus broadening the scope of potential tangible interfaces at the same time.

Figure 1.1. Representation of the concept of conservation of numbers, an exercise where young children experiment cognitive shortcuts where (left) two lines with equal spacing will be perceived as identical, but (right) spacing the bottom line will confuse them into thinking the bottom line has more elements than the top one.

Education also has a grounding in cognition regarding cognitive mistakes young students can make if not enough time is given to analyze a situation and answer a problem. For example, a classic cognitive mistake can be observed on young children [19] when they are given the simple task to determine how many items they are given to calculate, see figure 1.1. In this context, if you ask them first if both lines are identical, then proceed to space the bottom row and ask once again which line of dots contain the most elements, children will tend to point toward the line that looks the biggest, their brain not processing the cognitive load and not recognizing the difference between numerical quantity and physical spacing (conservation of numbers).

Prior to presenting the organization of this study, my general thoughts can be summarized as follow:
A key point in the study of design creation revolves around key problems or observation to which innovative solutions can be applied to. As a base to start from, I am looking into educational environment, primarily due to the broad range of subjects and ways of accessing the subjects (individual discovery, group discovery, museum visit with a family, study in the classroom, large age range).
This broad array of ways to access and process the information can land itself to the creation and understanding of novel interfaces.
The general goal of this study is to propose interfaces that could motivate the discovery of new content and enable students to reach new achievements. "In simplest terms, "achievement" implies "the accomplishment of something." In education, that "something" generally refers to articulated learning goals." [20 p.3].

1.4. Research objective and contributions

This study belongs both in the fields of design study and knowledge science. The following section introduces the key elements this research will be looking into and its expected outcomes.

1.4.1. Research question

This study proposes to analyze how user understanding of a tangible interface might be affected by the design of such artifact. Surrounding this statement, several questions can be elaborated on:
1) How the interface's affordance could alleviate the cognitive load required to achieve a given task?
2) How the interface's affordance could motivate discoverability (what sort of signifiers)?
3) Could the interface's geometry have a broader effect on user involvement with the task (not only manipulation but movement in space)?

1.4.2. Research objective

To answer the research questions stated in the previous sub-section, the experimental test described in later chapters will follow these main objectives:

1) Understanding the relationship between the design of a tangible interface and its effects on the way users perceive the interface.
2) Finding basic principles that can create a guideline applicable to the design of various interfaces.
3) Understanding if the geometry of an interface can affect the way its users are performing and interacting with it. How are the users moving, are they using the integrality of the interface or just a local area. Did they understand how to use correctly the interface and if not how could the interface's geometry be changed to simplify that interaction.

The principal aim of this study is to determine the potential relationship between the perception of a tangible interface, its interpretation, the efficiency with which it could be used by the user and the potential emotional response from the user while using that tangible interface.
This is also related to questioning if the volume of an interface could be promoting discoverability, by either its form or **signifiers** [1]. Signifiers are the visual cues that help understand object's function, for example the handle on a tea cup indicating where to grasp it.

The scope of this study could encompass all potential situations where someone is interacting with a tangible interface. For practicality and precision reason, this particular study will focus mainly on the interaction potential of abstract objects and their representation, in an attempt to grasp what could be basic sets of rules and behaviors determining the relationship user/object/space. A large array of participants where tested while attempting to answer the research questions and objectives. With potential disparity in the cognitive process from different persons with age variation, we ran tests with populations spanning three age groups: Children (primary school), young adults (undergraduate students) and adults (active workers). With in mind the potential integration of this research to promote discoverability, preliminary studies of museums content where integrated in the definition of two research hypothesis presented in chapter three. Also integrated in the hypothesis definition were the study of key tangible interface concepts (study in chapter two). These were used as a base to identify key features to be tested, enabling the creation of basic test objects (simple enough so participant could focus on the objects themselves, not on their aesthetics or mechanism)
The first hypothesis was used as a base for experimentation one (Chapter four) and two (Chapter five) while the second hypothesis served as a base for experimentation three (Chapter six). All three experimentations were divided in two smaller sub-tests to properly identify participants behaviors and the potential origin of these changes (the size of the object, the shape, the tasks given to perform, etc.)

1.4.3. Contribution to interaction design

As describe in the previous sub-section, this research and its results are aimed at defining general paths and ideas that could support the creation of simplified interfaces, or help discover new path to follow for not only interfaces, but the ways in which the users will approach them.

Novelty: Approaching this subject with in mind the clear goal of defining underlying properties and relationships between an interface, its geometry and the user's behavior. It is also considering the approach that, with ever increasing complexity of interaction processes, how could interfaces be designed to both accurately represent their content and connect meaningfully with users.
Originality: The combination of designing interfaces and displays with in mind the goal of focusing on the cognitive process involved in the interaction process.
Applicability: With a focus on discovery of new content, this study aims at providing new ideas for the creation of interfaces and interactive systems that would entice users to be curious and push for discovery.

This study could be narrowed down to the following application to the field of design study:
"Can the shape of an object you interact with carry meaning due to its geometry and help simplify the interaction process at play? Not only how does its affordance affect its usability, but how could it also help define how people behave around it. Can it be a motivation for self discoverability and curiosity?".

1.4.4. Contribution to knowledge science

The understanding of readability, discoverability and how affordance carries cognitive load are applicable to more than tangible interfaces, as we will discuss in our analysis of museum exhibitions in section 3.2.2. A suitable layout of the content could lead to a better enjoyment of an exhibition via improved accessibility and visibility.

The knowledge learned from this research could have potential application in other design fields and even expand further than design disciplines.
Above points have relevance in my contribution for knowledge science as I am trying to understand the mechanisms behind the affordance and cognitive load of a tangible interface's volume and geometry. How it could be synthesized and applied to different array of interaction process between user and access to information is an additional questioning.
The following are the aspects in which this study is participating to knowledge science:

1) **Knowledge creation process:** Could there be "simple" rules that can defines the design of a tangible interface suitable for Curiosity and discoverability?
2) **Application of Knowledge across various discipline**: Could the rules developed from the above point be transferred to neighboring disciplines?
3) **Integration of ideation, creation and fabrication**: Knowing what the end result should look like, could the creation and development process be simplified and streamlined?

The reason I entered this research within the scope of knowledge science and the novelty of this study is based on the following idea: The type of artifact and its complexity might depend on the versatility of tasks it has to perform. An artifact designed specifically to perform a given action will perform better than one designed for a general purpose. For example, the concept Topobo [9] will perform well at what it has been designed for, but a tool like a tablet pc will present more opportunities for its user as it can perform a larger array of tasks.
As this will unfortunately always be the case for artifact specifically designed for a narrow array of tasks, this research purpose is to understand the way users perceive a tangible interface. How the shape of this tangible interface might affect not only the way they perceive how to use it, but also how to understand it, behave around it and if the interface can alleviate some of the cognitive load required during a task that needs problem solving or material discovery (learning).

In consideration to focusing on tangible interfaces, tangible/physical input allows for a more instantaneous understanding of the manipulation needed to be learned or performed. The immediacy of the physical interface communicates rapidly its function to the user [16] and could simplify the cognitive process of discovering new contents.

1.5. Dissertation roadmap

The remaining chapters of this dissertation will be organized as follows.
Chapter two will define areas in which this research is being conducted and the key elements that are not explored yet.
Chapter three introduces a field study analysis as an exploration method to determinate valid concept to be potentially explored in further chapters.
Chapter four presents the first experimental test and first complete user experimentation centered around the behavior of participants in relation to an object.
Chapter five proposes a continuation of chapter four, with in mind the analysis of how participant connect with an object with additional visual support.
Chapter six develops a continuation of the concept presented in the previous chapters, with an emphasis on how the age of the participants might affect the understandability of an interface. This chapter also introduces additional visual supports and the way they could have an impact on how participants can interpret different functions on an object.
Chapter seven summarizes the elements learnt from the dissertation. The key properties of this study are discussed in chapter **three** to **six** and their applicability to research and design study discussed in chapter **seven**.

The following visual map indicates the existing connections between each chapters, see figure 1.2.

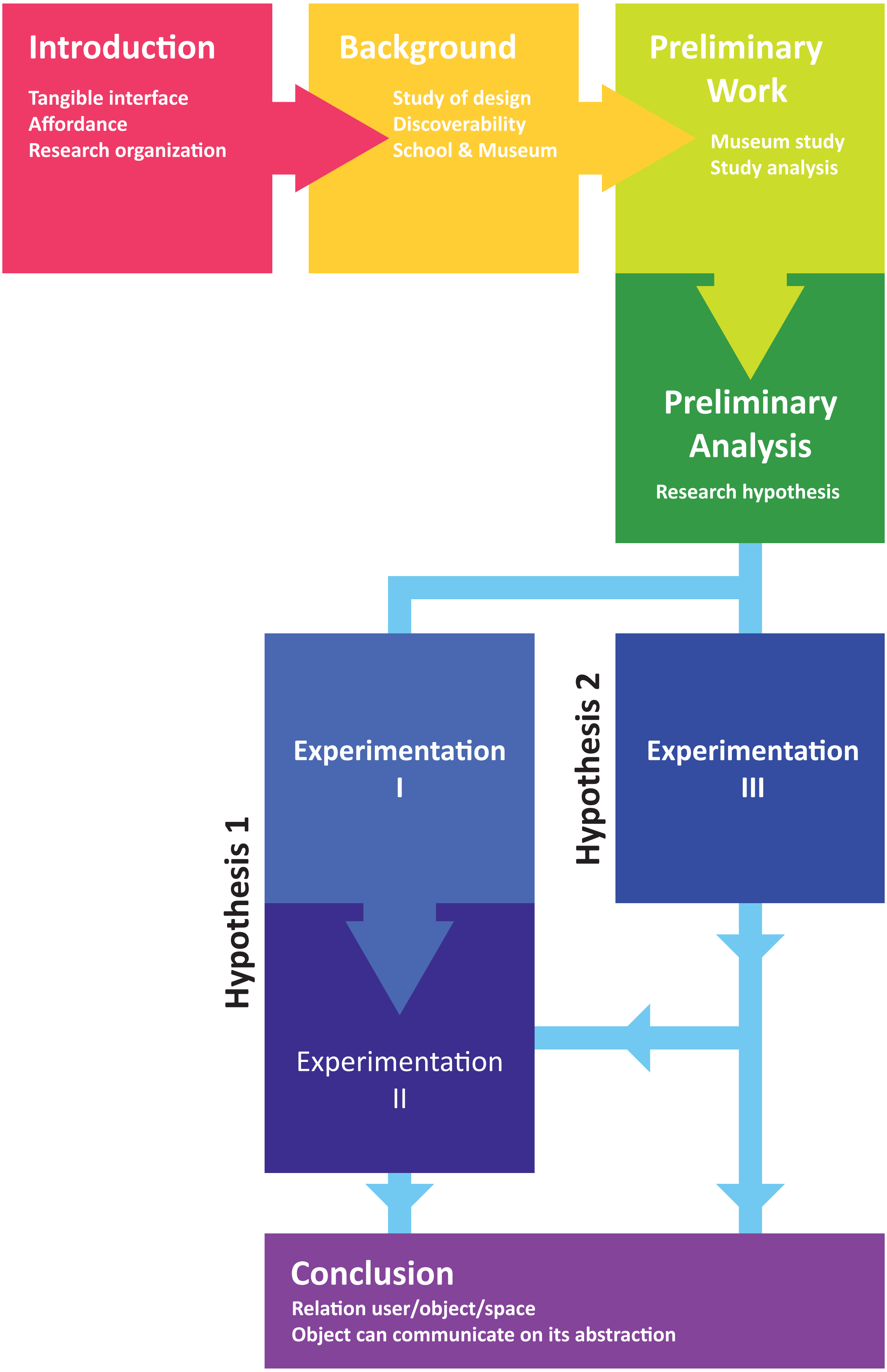

Figure 1.2. Visual representation of this study structure and connections between each chapters.

Chapter 2

Background

This chapter further defines the current state of research in the respective field being studied and provide an in depth analysis of some major design concepts. The presentation of these works is then used as a base analysis to propose key guidelines that will be used in the following chapters for the creation of prototypes and experimentations.

2.1. Interacting with more than the content

As explained in the previous chapter, tangible interfaces are an integral part of interaction design but they obey different rules and behaviors than a traditional Graphical User Interface (GUI), thus they can be prone to innovative interpretations of physicality.

A clear example of these properties is the idea of Token [21]. It introduces the control of digital information through the manipulation of tangible controllers. A token is defined as the object by which user will interact with a system (in this case a table top screen) with constraints that defines the type of interactions the user can perform. A token by itself is free of being placed anywhere on the table top, but pairing a token and a constrain will propose users to, for example: 1) use it as a slider or 2) as a dial (in both case the token retain its original shape, only the constraints changes).

The physical manipulation of tangible interface not only provide context, it also helps users to interact more freely and naturally, being more prone to use two hands gesture to manipulate digital content, resulting in a more natural and intuitive interaction process [22].

That capacity to interact with a direct representation of the content allows not only for innovative ways of creating interfaces, but also creates a one to one understanding of the content being displayed [23; 24]. If the interface and content have similar visual representation and both are recognizable by the users, there is no need for them to learn how to interact with that interface . Users should already know how to proceed just by looking at it [25], for example a button invites the user to press on it.

This process of interacting directly with the content through the interface can be direct with a hands-on manipulation of the interface with a malleable material [25], or via a dynamic and autonomous system. This types of augmented surfaces carrying the capacity to change shape dynamically are known as **Shape Display** [26; 27].

A key elements to the interaction with tangible interface, physical manipulation is not always required to interact with a digital content or create new data. Although not at the center of this thesis, the very position of the user in a larger space like an office could be leveraged and be used as an element of communication within an entity like a company. This might unlock better internal communication by proposing an appropriate set of informations for each users to allow for simpler and time appropriate communication [28]. This aspect of the users not only seen as an actor but also as an environment's component has interesting possible applications where a sufficient amount of users are participating in an interaction process.

2.1.1. Tangible interface

With the increased access to information as well as ways of accessing information (wearable devices, internet of things [29]), the variation in interfaces design has increased. This could be leveraged to assist novel ways of performing tasks and participate in problem solving (for school environment for example).
In terms of usability and problem solving, performances can be improved with an adequate definition and conception of an object's or interface's affordances.

There is a “...physical immediacy of a tangible model. Such an interface could help increase the understanding of a physical systems because the model is physical and its relationship to its environment is not simulated” [2]. The association of meanings with a physical, tangible representation [4] could reduce cognitive load in the problem solving process and allow users to maintain a stable level of concentration on a given task [30].

In its definition of Artifact and classification of embodiment [31], Fishkin, K. defines tangible interfaces in two axes, 1) **Metaphor** and 2) **Embodiment**; the later one composed of 4 types: Full, Nearby, Environment, Distant. The first types of the embodiment axe being relevant to this study, the definition of Full says “the output device is the input device: the state of the device is fully embodied in the device” [31].

Creating novel ways to interact with experimental content can allow for innovative gameplay and experiences. The creation of a dedicated interface to match a corresponding interactive application opens the ways for custom made interface and gameplay that are being fully realized thanks to these dedicated interfaces, with the integration of types of interaction not achievable otherwise (shacking, tapping, rotating or any kind of direct physical manipulation). An example is the creation of small devices with an array of sensors to interact with a simulated living organism to foster its growth and evolution [4], an interaction process very specific to that one project.

These novel interaction opportunities allows users to approach a situation with a different perspective, to test and re-run simulation in an effortless way. The tangibility of the interface allows for direct manipulation by the user and through direct manipulation of physical objects can allow them to discover concepts that have been considered too advanced [32].
Those interfaces can also be used in solving lifestyle based problems, such as eating disorder for children, and propose a novel way to solve the problem by introducing a solution curated for the target user [32].
Based on direct manipulation, tangible interfaces can also benefit from acute recognition of hand gesture and finger position (grasping, pinching) to propose a broader range of interaction [33].

They can also be used as an augmentation of a traditional action. Some interfaces can help analyze the action performed by user, and in return provide motivating activities or rewarding visual to entice the user into continuing its activity. It can also be used as a support to augment a known game and propose new challenges and modes of gameplay [34]
The augmentation of an element is not limited to objects as it can be applied to furniture and help foster collaborative learning [35] as well as architecture and large structures and embed them with additional functionalities [36].

The followings are brief analysis of representative works in tangible interfaces and the key aspects that defines their designs, interaction processes and interests.

System 1) Cord UIs [8]:

Concept:
Interpretation of the state of an electric cable and direct effect on the device it is attached to. The general idea is to cross reference the mental representation of a pipe or water hose and apply this predefined knowledge and understanding of their behaviors to electric cables, see figure 2.1.

Analysis and key points:
This idea of embedding a known entity (in this case electric cable) with novel functionalities while using a known set of mental representations (if a pipe is bended its internal flow will be reduced), provides an interesting interpretation of the direct manipulation of an interface while using predefine knowledge from its users. This in return reduces the shortcomings for the users of not understanding how to use the interface as they most likely are already aware of water hoses’ behavior. Key point is 1) using a known set of knowledge for a novel use.

System 2) Tangible interfaces for Interactive Evolutionary Computation [37]:

Concept:
Creation of a dedicated artifact to interact with a simulation. The idea behind this works is to compare the effectiveness of a tangible interface regarding the enjoyment of a given gameplay in comparison to a more traditional graphical user interface (GUI) on a computer. Having an object to interact with allows them to implement physical manipulation like shaking the object or tapping the object, interaction a traditional computer setup does not allow, see figure 2.1.

Analysis and key points:
This study resulted in showing that among their participant base, the preferred interface was the tangible interface, being considered as a more engaging interface, yielding more "fun" or "excitement". This corresponds with this study interests that direct manipulations can participate in a better involvement and enjoyment of the task by the users. Key point is 1) Creation of a dedicated interface that allows for custom made interaction and an engaging user experience.

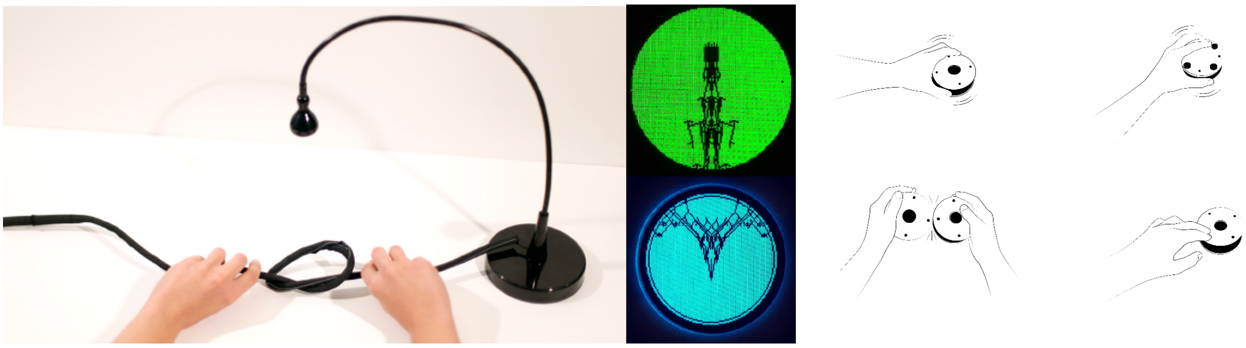

Figure 2.1. Illustration for system 1 (left) and system 2 (center and right). Source [8] and [37].

As define in chapter one, tangible interfaces can be used as a standalone device but can also be paired with a tabletop device and thus increase the interaction achievable with what is called **Augmented tabletop**.

Giving the opportunity for users to interact with tabletop interface or directly through hand gesture with large surface of display from a table top allows for collaborative interaction within a group of users [38].
The integration of embedded display within an interface has its limitation due to the internal volume required to allocate for the interface's structure. Having some objects on a table top limits that problem as the interface has to be placed on the display, this reducing slightly the freedom of movement for the user but allow for an easier tracking of the interface and the display of images on it via potential projection mapping. It can take the shape of an overhead projection mapping [3], or a projection coming from within the tabletop [39]. The later allowing users to grasp the interface without risking to cross the beams of the projectors resulting in the creation of shadows on the display or objects.

As the concept of token explains it, having tangible controllers on a tabletop display participates in creating an accessible interface, the graspable elements of the interface working as landmarks users can process rapidly and enables them to interact with a given system while re-using their past knowledge of manipulating physical objects or environments. [40; 41]

The followings are brief analysis of representative works in Augmented tabletops and the key aspects that defines their designs, interaction processes and interests.

System 3) Token+constraint [21]:

Concept:
Seed concept for tangible interface interacting with a table top. The general idea there is to associate physical interaction with limited range of movements to introduce specific behaviors. Being in the capacity to place an object on a tabletop and having it being recognized and triggering a specific action (loading the images from a phone to the tabletop) is a step toward an ubiquitous environment, but here, the “simple” combination of a shape and a receptacle ends up creating a handle with which users can interact with. The basic idea being, if you combine a square object and place it into a rectangular track, the square becomes a slider that can interact with the tabletop instead of as a simple object being placed there, see figure 2.2.

Analysis and key points:
Combination of two “simple” geometries to induce a novel interface interaction and leveraging on users’s past knowledge of physical manipulation to introduce a reduced cognitive load in the processing of a new interface. Key point is 1) recreation of known physical manipulation by constraining the movements of physical interfaces.

System 4) Tangible 3D Tabletops [3]:

Concept:
Technical solution to track and map object being placed on the tabletop surface. This, in combination with the block being placed on the surface, allows for a straight forward representation of the digital content by mapping it directly to recognizable objects and geometries. In this case, the interpretation of the content is being simplified by using an architectural subject, justifying the use of square blocks as tangible interface, see figure 2.2.

Analysis and key points:
This is an interesting step in combining physical representation with its visual representation to allow users for a direct understanding of the content and processing of the content. Key point is 1) the geometry of the interface corresponds to the visual content the users has to interact with.

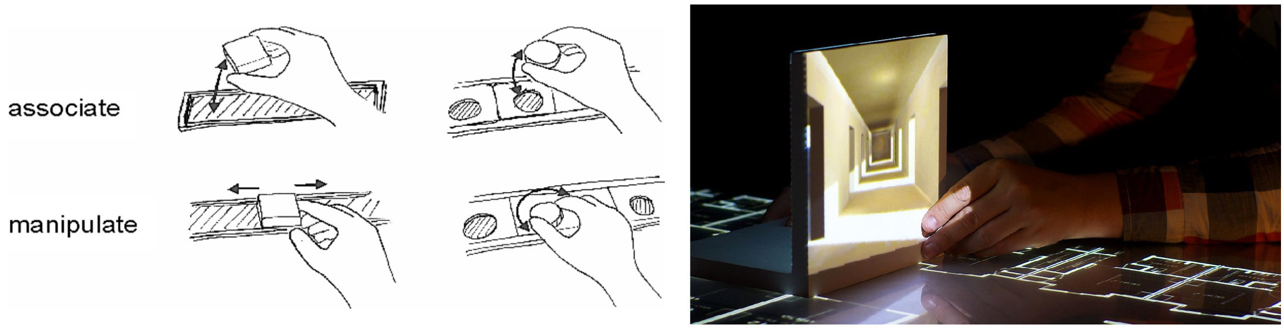

Figure 2.2. Illustrations for system 3 (left) and system 4 (right). Source [21] and [3].

2.1.2. Shape display

Physically interacting with a display has widened the scope of interactions available for users, by either augmenting the screen with tangible interfaces or allowing the display to adapt its geometry to directly generate dynamic physical representation of digital content [42], known as s**hape display**.
Interaction with tangible interfaces on tabletop display allows for more precise and varied affordances and feedbacks. Those artifacts can represent new actions or components to interact with [41], they can also work as handles and give an extra visual input to the users [16; 40]. They work as signifiers for flat displays that usually rely exclusively on visual signifiers for their user interfaces. This wide variety of interaction processes helps to get a better grasp and control under various conditions and needs [22].

The spectrum of interaction can be widened to enable the display to adapt its surface geometry for defined purposes. Users can either directly shape the display [25] to visualize digital contents, or use hand motion to navigate through contents and leave the display reshape itself accordingly [26; 27]. Known as **shape display**, they can either be controlled directly by the users' hand [25], or actuated dynamically with a mechanical actuation (linear actuator, servo motors) [43]. Such display can also be used as ways to physically interact with tangible representation of digital contents [15; 44] (3d models, city maps, etc.) or physical elements (building blocks, balls, devices such as smartphones, etc.).

Acting directly on the surface and the interface without having to resort to traditional controls like key board and mouse participate in creating an interface that is engaging for the user [45]. This capacity to adapt the display shape to "any" situations can reduce the need of those elements.
Additionally, this capacity of having the shape of the display adapt itself to users' input or a running equation lands itself to represent more than the simulation of a volume (landscape analysis for example [25]) but allow the manipulation of the display's topology to assist the users in novel interaction, for example: reshaping the surface of an office desk depending on the need of the users [42]

The recreation of a volume can also support remote collaboration between members of a team, allowing each members to directly interact physically on the volume the display is creating. It alleviates the immediacy of the physical representation of the subject to have each members directly engaging in the collaboration process, members being in the same location or in remote places [15].

The interaction can happen in different ways. The users can 1) interact with the display, 2) the display can change its topology based on users' input and 3) the display can interact with object placed on its surface. The later allows for either moving things around on the display surface [46], or manipulate objects and turn the display into a middle agent where users control the display to move around, assemble or activate the objects placed on the shape display's surface [44].

While allowing for some degrees of shape modifications, shape displays are bounded by the maximum range their array of actuator can move and their definition limited by the amount of actuators being placed in a grid pattern (the more actuator resulting in a more complex and demanding system). The idea should be that someday, a versatile matter would be created, to take any given shape and be aware of its own identity and geometry to communicate with the user [47].

A bit remote from this future idea, the followings are brief analysis of representative works in Shape Display and the key aspects that defines their designs, interaction processes and interests. They both represents similar concepts, one being semi rigid and the second being mechanically actuated.

System 5) Illuminating Clay: A 3-D Tangible interface for Landscape Analysis [25]:

Concept:
Scanning and processing of a hand deformable surface's geometry and matching the resulting geometry with landscape content (projected). This represents the basis of direct manipulation of the content via a tangible interface, in this case the interface being a deformable display. The idea behind this project is that a physical object as an immediacy, users being able to process rapidly what they are interacting with and allowing for a seamless interaction and understanding of the content being displayed, see figure 2.3.

Analysis and key points:
In addition to the technical advancement of scanning a geometry in real time and remapping it with visual content, its core principles revolves around having the interface users are acting upon sharing the same shape and geometry as the content the users are manipulating and working with. Key point is 1) matching the geometry of the interface to the assumed geometry of the content.

The work titled “ClaytricSurface: an interactive surface with dynamic softness control capability” [48] presents a similar idea by semi-automatizing the process and allowing the surface to keeps its volume instead on relaying purely on an semi rigid surface like the previous project. This allows for a control of the surface tension of the display and introduces different material stiffness, enabling the user to experiment different types of physical feedback.

System 6) Physical telepresence: shape capture and display for embodied, computer-mediated remote collaboration [15]:

Concept:
The base idea in this project is to reduce the shortcoming of remote collaboration between group members by allowing for dynamic changes of display’s geometry to physically interact with either a user or object being placed on the display surface. This is using key elements of a shape display to dynamically morph its shape into something else and using the immediacy of its geometry to effortlessly communicate an event (for example: having an object slide across the surface of the display by generating a slop), see figure 2.3.

Analysis and key points:
Being in the capacity to both interact on the geometry of the display and watch other or the system itself change accordingly provides an interesting back and forth communication between the users and the system, allowing for a seamless manipulation of content and emergence of innovative interaction process or gameplay. Key point is 1) Leveraging the geometry of the interface as a vector of communication with and between users.

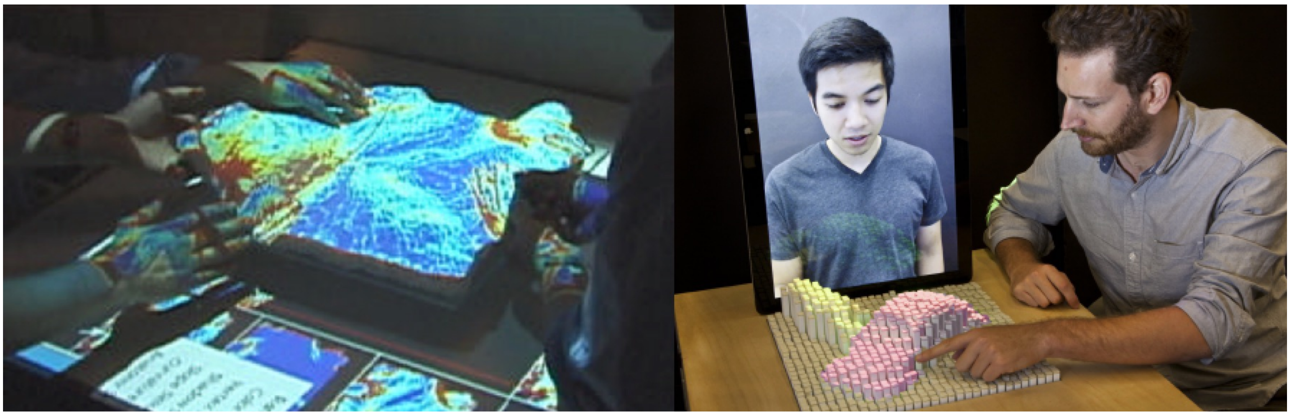

Figure 2.3. Illustration of system 5 (left) and system 6 (right). Source [15] and [25].

2.2. Affordance and discoverability

Discoverability or exploratory learning is tied with affordances. This capacity to understand an object is automatic but can be compromised if instructions are not properly given. Either visible instruction (or affordance) or direct oral instruction in the case of educational environment can help promote the discoverability of an interface or subject.
This study approaches the term affordances as D.Norman defines it, centered around the capacity from an object to communicate its function.
D. Norman says: “Affordances are the possible interactions between people and the environment” [1 p.19]. He also explains that the role of **signifiers** is to indicate the possible interaction offered by an object or something to interact with, for example: A plate on a revolving door indicating where you should push on it. In this case, the signifier is the plate and the affordance is opening the door by pushing that plate.
For the discoverability of content, allowing users some freedom and providing them with fitting explanation results in visible progress.

There are visible differences between pedagogical learning and exploratory learning. With pedagogical learning, children are less likely to discover new elements as they are more likely to master the one demonstrated [17].
In his study [49], Pashler, H. et al says “ Children, unless stifled in some way, are virtuoso as learners ”. This also matches results from Bonawitz, E. et al [17] and Mitra, S. et al [18]: Children can memorize things from a standard teaching methodology, but they can understand and challenge knowledge they discover by themselves. In those situations, children demonstrate impressive results after learning new subject via autonomous learning [50]. The only requirement is to redefine the way content are being taught and interacted upon, in a careful and transparent way (signifiers being easily identifiable).

In the case of this research base study environments, schools are introducing at different rate the use of devices in the learning process for students, although it is not uniformly applied at national level [51 p.108 - p.109]

It has to be considered that schools are now facing a paradigm in which students have access to an infinite amount of information at any given time [52], an evolution of the access to information that could make school look obsolete. As we mentioned above, schools are now integrating internet access and tablets pc, but omit to redefine their own core mechanism (how educational content is being distributed).
“ New technologies are forcing us to redefine the format imposed by books and pages. But How? ” asks Serres, M. [52 p.33].
Not only can we redesign the processes and core mechanics with which students will have access to engaging experiences, it is also a matter of redefining what, or how subject are being taught in class.
Since the avant of internet, “ Facing information overload, student will have to know how to manage “ cognitive overload ” by eliminating, sorting, organizing into hierarchy, verifying and validating information. This will be the role of the Teacher ” says Blais, M. C. [53 p.236], this resonate with 3 simple keywords “ Sorting, organizing, analyzing ” tells Houdé, O. [19 p.83], that indicates what sort of learning process school of tomorrow will need to introduce to student while facing infinite amount of things to look into.

Exploring the potential of a system via trial and error can also bring some effective learning and appreciation of a subject. In a previous study [63], the behavior of children and teenagers were observed while they discovered how to use an interactive system. The goal of that system was to allow participants to build a castle out of wooden blocks, each block being represented in real time on a screen nearby. For each wooden block there was a corresponding 3d representation. The goal of the system was to observe how its users would react and build a tangible castle while an identical copy was recreated digitally. What was noted was that some participants would enthusiastically observe the stacked block from all direction to construct their ideal castle while other began with simple assembly to try and discover each visual representation attach to its respective block. Older participants were noted as more methodic with well constructed castle while younger participants haphazardly placed blocks without real logic, mostly intrigued by the virtual representation of their actions. The direct manipulation of the wooden block allowed for a remarkably simple set of rules easy to understand by most participants. Potentially, the immediacy of the object reminded the participants of their previous experience with castle building or toys in general, reducing the cognitive load necessary to process the steps to follow and directly jump in and enjoy the installation.

As a repetition of this key element presented above, new material can be memorized using a standard teaching methodology, but discovering material on their own can lead students to understand and challenge newly discovered knowledge, taking in consideration that if the interface or the system is not well designed, students might face cognitive overload.

2.3. Cognitive load

This is an addition to what has been previously stated in subsection 2.1.1
The way things are being displayed to student also needs to be considered as Sweller. J says "cognitive effort expended during conventional problem solving leads to the problem goal, not to learning" [54 p.283]. Selecting what information will be displayed to the students, what elements will they need to process simultaneously (both physically and mentally) might have an effect on their cognitive processing capacity, the student could be able to solve a problem proposed by a teacher, but not be able to retain the information for the acquisition of the content [54 p.261].

This capacity to process information is also leveraged by direct manipulation of the content, allowing the students up to age 10 to familiarize themselves with the content as "mental action and operation are born from internalizing real actions" [55].
The primary way in which someone perceives an object can be divided into two categories: **quantitatively**, and **qualitatively** [19 p.26]. Since we are interested in how someone perceives an object's shape, we will be focusing on the second category, shape perception being part of qualitative interpretation, and more precisely on the observable function of an object, or as described previously, its **affordance**.

This study being oriented toward discoverability of tangible interfaces, the focusing capacity of its users has an important role as for example depending on how things are shown and explained to younger children, cognitive shortcuts might happen over time [56] and as a result falsify content perception. This is occurring during children development up to around age 10 and affect their perceptual organization [57].

It has to be noted it is an effect that fades away as a child grows, being prominent in infant and children of young age [58], as the way objects are being perceived by an infant might not match their actual geometry or integrity (an object being perceived as two separate entities if an obstacle is blocking the infant view).

The importance of visual support can also be considered as integral to processing information as the representation of a concept via a diagram " can be superior to a verbal description for solving problems " [59]. The association of multiple representation supports that idea [60].
Context awareness [61] and situated cognition [30] can also assist in processing cognitive load.

Figure 2.4. From left to right, the different steps proposed by Nintendo for their new hybrid game device. Source Nintendo and Nintendo Labo.

The recently announced Nintendo Labo follows this idea, see figure 2.4. Although video game already rely mainly on visuals, Nintendo is proposing to use the embedded technology in its Switch (the manufacturer gaming console launched in 2017) in an innovative way.
The purpose of the system is to transform traditional video games into activities the player can physically be involved with. Unlike motion control based game (from the Wii console era), this time players are required to build tangible interfaces (named ToyCon) in which the Switch and its controller can be inserted.
The purpose, outside of proposing funny and innovative games, is to introduce children and their parents to the technology available in the Switch and how, with a bit of tinkering, an object like a piano or a robot suit can be used as game controllers. The extension of that is to then allow the players to build their own tangible interface and related game. The system is made to let the player open the ToyCon (built following illustrated instructions) and observe how its internals are moving and being recorded by the console (via clever puli systems and reflective sticker for infrared detection), either for curiosity, or to replicate similar ideas or build upon this knowledge to create new game ideas.
Through their new game, Nintendo is promoting self discovery and exploratory learning, allowing players to experiment on their own within a defined but open framework.

As a conclusion to this section, these elements could indicate that objects perception as well as the environment in which they are being displayed can have an importance on how its users (in this case students) will proceed the information and whether or not the cognitive load will be impactful on their capacity to process and integrate the information being learned.

2.4. The logics behind design

As explained in a previous section, affordance is one key defining concept of a design carrying understandable meaning of its usability. It is a concept considered of utmost importance for properly using an object, for practicality, efficiency or even security. This idea of object having a shape that represents its function is easy to imagine for a door, a water tap or anything with the interaction process that goes: from user -> to object properly designed to represent its action -> to that action being performed.
This idea is the key driving feature of this research, because if we apply the same logic to digital content and tangible interfaces, one difference appears: from user -> to tangible interface properly designed to represent its attached digital action -> to that digital action being performed. There are two interrelated elements here to be noted, 1) the interaction goes from tangible to intangible and 2) it now deals with digital contents.
The very idea of something digital it's that it carries no shape or direct representation. One question can then be how could rules of design be applied to the conception of tangible interfaces so that the same process of affordance occurs when its users sees the artifact? Once someone knows how to open a door or drink from a cup, if future object of the same kind are similarly designed, that same person would use its past experiences to open a different door or drink from a different cup.
The same can not be said of computers, smartphones, house intercoms or microwave. In their quest of differentiating themselves from other manufactures, electronics appliances company are designing seemingly similar objects (a TV set is a TV set) but with buttons (on the display or the remote control), interfaces and bespoke options that differs for each products available on the market. This result in a period of acclimatation almost every time someone changes manufacturer for a phone, TV or any other digital embedded artifacts.
In addition to practicality, enjoyable interaction can be extrapolated from affordances. If we can locate the parts of an object that communicates on its functionality, then those parts and their individual interaction processes can be designed to be enjoyable or fun. It doesn't has to be a distraction to be fun, a simple light indicators (that changes colors on a computer charging cable depending on the charge level of the battery), a discreet sound or just the mechanical click (from the crown on a watch, or the track pad on a computer) to indicate that an action is being properly performed validates the perception that the user made of the interface was correct.

If this can be done in a meaningful way, it would then be easier for users to spot these small indicators, confirming that what they are doing is correct. Simple rules of design, emotionally connecting to the object, ergonomics, if adapted to a content without shape, could propose digitally augmented artifact that would be as obvious in their function as a tea cup.
Beautiful, colorful, playful or well designed objects tend to be more attractive for potential buyers than similar objects (computer with identical internal) with a more common and less striking design [67. p68]. In addition, attractive objects will be perceived to be easier to use than object with identical functions but with a less appealing look [67. p17-18].
As affordance can be successfully applied to user interface design to define meaningful and easy to understand visual interfaces [74], it could too be applied to tangible interfaces as long as the set of interactions and representations are meaningful and understandable to user.

As a side note, a phone should not be removed of it's complexity that allows for a large array of ways to enjoy it, but the basic functions should be accessible without having to resort to reading a user guideline or acquire this missing knowledge from your surroundings (source external to the provider of the product, your family, online forums, etc.). There has to be a mid point between novice users and experts.

The following sections will presents existing sets of ideas around this area in design as well as different sets of guidelines that have been assembled throughout the history of design, in an attempt to synthesized what could be the essence of good design.

2.4.1 Sets of rules for effective design

Defined in previous sections, “The pleasure in using these systems (computers with controllers) stems from the capacity to manipulate the object of interest directly and to generate multiple alternatives rapidly” [76]. If using direct manipulation promotes pleasure, could that pleasure be increased if the design of the interfaces was well adapted to its purpose?
Playfulness, among other emotion human being can feel, is part of how we perceive and appreciate an artifact, novel or known [67. p99].

This capacity to emote and feel is what can be the key to designing a feeling of connection, or empathy, to an artifact. “Emotional design can generate positive memories which then motivate users to keep using the emotionally infused interface” [69. p11-13], this due to a release of dopamine by the user’s brain. As Walter .A says, “People will forgive shortcomings, follow your lead, and sing your praises if you reward them with positive emotion.” [69. p15].
Another capacity is to observes something and subtract what is meaningful, this would depend on the viewer. It could be a shape, color or a feeling. This could be considered as abstracting the subject and finding pattern and symbol easily identifiable.
Symbolic and abstract representation (recounting an event to a friend using hand gesture) can be used with good effects to explain or demonstrate something more complex. [71. p48] Norman .D says “The powers of cognition come from abstraction and representation: the ability to represent perceptions, experiences, and thoughts in some medium other than that in which they have occurred, abstracted away from irrelevant details.”[71. p47]. Abstracting and simplifying an idea or a concept still allows someone to understand that concept if key points are conserved.

If enjoyment and emotion are a key to meaningful interaction, making an object fun could be seen as a fool proof solution to make anything enjoyable, but there are some logic to be followed, some underlying structures to be defined if designers want their user to connect with whatever artifacts they design.

The following are not considered as the only rules to follow as they have been described by their various authors as guideline from which to select some knowledge to be applied to the design of novel artifacts. It ranges from purely cognition centric structure to more abstracts ideas of what is good and what is beautiful or emotional, what is simple and what is simplicity in complexity.

The design of tangible interface, or **active artifacts** (clocks, calculators, computers) [71. p81] should follow the same rules as the design of product design. Both are objects and both are to be used efficiently by their users.

For clarity purpose, the key word that are directly understandable were left as is, but the more complex ones received a short description.)

Level of design by D. Norman [67]

Visceral (perception and enjoyment of colors, shapes, etc.), **Behavioral** (affordance), **Reflective** (the image of the design is reflected on ourself, we feel good using it because we look good)

These, could be considered as how to connect emotionally to an object, how these objects participate in how we perceive ourself and other. It propose the idea that beautiful and enjoyable object are not bad for properly using said object. It also defines that a better designed object will be favored to a less impressive one, because it makes the user feel good. But these key concepts should be connected to another set of rules that D. Norman stated, to create objects that people can not only enjoy, but understand and use properly.

Fundamental principles of design by D. Norman [1. p72]

1- **Discoverability** (what actions are possible by looking at the device) 2- **Feedback** (after an action is performed, it's easy to define its new state) 3- **Conceptual model** (the design projects both discoverability and evaluation of results) 4- **Affordances** (indicating the desired action is possible) 5- **Signifiers** (discoverability is well communicated and intelligible) 6- **Mapping** (each actions are identifiable) 7- **Constraints** (they guide actions and ease interpretations).

An object which it is easy to interact with is not only well designed, but well planned. Only by isolating the very essence of the interaction at play than an object can be designed and centered around these well defined actions to be performed: how to indicate them (signifiers), before, during and after (feedback) the interaction, where are they located or grouped on the object.
Simple object are often deceptive, as often to extract simplicity of an action ,meaningful elements needs to be extracted from complexity and organized in a clear fashion.

The laws of simplicity by J. Maeda [72]

1- **Reduce** 2- Organize 3- **Time** (saving in time feels like simplicity) 4- **Learn** (knowledge makes everything simpler) 5- **Differences** 6- **Context** 7- **Emotion** 8- **Trust** (in simplicity we trust) 9- **Failure** (some things can never be made simple)10- **The one** (subtracting the obvious, adding the meaningful)

The first nine laws here can be summarized in the last one, as each steps define how to focus on the essential for different kinds of interaction, keep what is only necessary and augment it by focusing on it.
If someone understands the reasoning behind it, complexity or apparent disorder only obeys an underlying structure set by its owner (a desk that might look messy in the first place). That structure, in addition to someone being aware of it, is how simplicity can be seen in complexity [70. p2].

A list on design laws wouldn't be a good list without the principles of good design by former Braun designer Dieter Rams. This idea, that their might be good and bad design can indicates different types of design: Aesthetic and functional. A well design object (internally) would perform as expected, but if its outer shell isn't appealing, following previous sections, users won't appreciate using it as much as if it was “pretty”.

10 principles of good design by D.Rams [73]

1- Good design is **innovative** 2- … makes a product **useful** 3- … is **aesthetic** 4- … makes a product **understandable** 5- … is **unobtrusive** 6- … is **honest** 7- … is **long lasting** 8- … is thorough down to the last **detail** 9- … is **environmentally friendly** 10- … is as **little** design as possible
The last principle echoes a similar ideas from architect Mies Van Der Rohe, who is famously quoted for saying “less is more”, speaking of his school of thoughts for his architecture and design.
D. Norman says that if we remove the meaningless, “The mind is well equipped to retain large amounts of meaningful material, as long as the material has pattern and structure.” [71. p77].
Good design can be good in measurable variable (useful and more effective than other design, not harmful for the environment) and in abstract, more emotion oriented variables (pretty, simple,).

The design of a good artifact is visible, but its underlying functions and capacity to communicates on its function shouldn’t be ignored.

2.4.2 How to design what is not visible

The very idea of tangible interfaces is that it works with a content that is not visible. What sort of signifiers or affordance can you find when looking for things on your phone that are not directly communicated on.
I experimented with that issue first hand regarding a feature introduced few years ago by Apple on their iPhone. With model starting from their iPhone 6s until today, in addition to being able to tap on the screen, users can now press with more or less strength to ask for sub menus or shortcut. A simple example being if you are on the home screen of the phone with all your apps, force pressing on one would make a sub-menu appear with contextual shortcut related to that application (a force press on the phone function conjures the frequently called numbers).
Although seemingly useful in certain situations, if you have never heard of this feature before, there are no ways to figure out it’s there. I checked with different peoples that upgraded their phone from an older version (previous to the 6s) to a version with forced touch (6s and above), and several people were not aware of this function.
In a way it could be considered as a gimmick because not really life changing in the way you are using your phone daily. Ironically, while I was researching about these features on the iPhone, I discovered one feature I had never heard of before. It turns out, if when typing any sort of text you force press anywhere on the keyboard, a text cursor would appear where your text is, and if you keep pressing and start moving your finger around, the cursor will effortlessly flow over the text, allowing for a very easy text selection. This feature, unlike the first one, would have been welcome if more visible because precisely selecting an area of a text to do some editing is actually not effortless on smartphones.
Not to blame Apple for this, the question would be how to communicate such function without having to resort in using a step by step tutorial? Could it be that, although versatile, modern phones are only using a narrow sets of action achievable by user’s hands?
In his design rent, B. Victor [75] calls this “pictures under glass” and he argues that more meaningful interaction could be achieved if we stopped focusing on designing everything behind screen and restart integrating hand gesture in the interaction process. This idea fall into the same consideration of this study, that direct manipulation can lead to “better” interactions.

Figure 2.5. Left image shows how the game invites the player to move to the right of the screen, right image introduces the capacity to jump at variable height. All this is done without the use of verbal indications. Source Nintendo and Super Mario for NES.

Game design found answers to these questions several decades ago in the shape of the first Super Mario game for the NES, see figure 2.5. Its first level is regarded as the golden standard of good introduction to game mechanics. Instead of introducing the gameplay to new players via a tutorial, the first level was designed in a way that players would have to discover how to play in order to advance. Here is a selection of the different solutions that were designed to communicate with the players:

To indicate that Mario had to move to the right of the screen, the game would start with him visibly standing on the left of the screen, his face pointing toward the right, indicating the way to press on the game controller.
Obstacles of different height were used to indicate that different jump were available to the user, but with only one button allocated for jumped, that meant pressing longer would influence the height of the jump.
These in addition to other explanation of how to kill enemies, what are power ups and how the end looks like made sure that by the time player reached level 1-2, they already had all the tools to play the game.

Another similar example and a bit more modern could be considered. For Super Mario, the NES only had a cross pad for the direction and two buttons for actions. In the game Shovel Knight (2014), see figure 2.6, the player controls a character harmed with a shovel and the game controller now has two more buttons and two sets of shoulder trigger (depending on the console). In order for the player to discover all the possible action available (killing enemy, destroying blocks in front of and bellow you) the game designer forced the player in learning each action by presenting them with one situation at a time. While moving forward in the level, at some point the players would reach a wall blocking their way. Unlike other walls, the lower part there is composed of blocks of a different color that players earlier learnt to destroy with their shovel, indicating that they can dig their way forward. A similar situation would occur later in the same level where the players would be faced with a piece of floor blocking the way forward, this time teaching players to combine their shovel attack with a jump and down press on the directional pad to launch their shovel downward.
These two levels managed to teach their mechanics to players without using any texts box or arrows, simply by using discreet cues (game character looking forward, elements to act upon having different colors and textures than the landscape) or simply forcing players to perform a single action (long jump, destroying a wall).

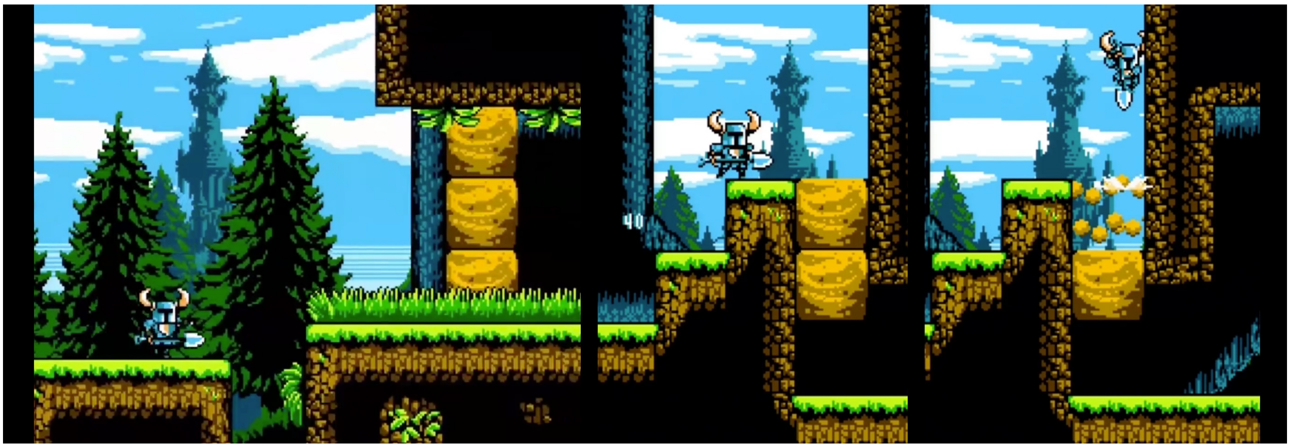

Figure 2.6. Left, the visual difference in block texture indicates areas where an action can be performed. Center and right shows how the game teaches player to place their shovel beneath them in order to break floor blocks. Source Yacht Club Games.

With a limited amount of action that you can perform, designing easy to remember actions is more achievable than if the player has to learn from large array of actions. In addition to that, the more context specific an action his, the more likely the player would forget it.
As A. Anthropy says “An orphaned verb has no relationship to the other verbs, so the other verbs don’t reinforce it, it doesn’t grow, and the player has forgotten about it by the time she reaches the one situation that demands it.” [69. p18]. (in her book, the term “verb” correspond to character actions in video game, such as jumping, sword hit, etc.).
An orphan action is something that should be avoided as it might just confuse the user as well as the design of the object.

2.5. Preliminary Analysis

Here are some of the major keywords defined in previous sections and that carries important meaning for this study.

Situated cognition: meaning can be found by observing the context and environment.

Affordance: the set of actions achievable by an object and how to correctly use it.

Discoverability: what actions are possible by looking at the device

Emotional design: connecting with the object emotionally due to its features (shape, color, aspect)

Cognitive load: meaning that shape carries, learnt from past experiences and memories.

From the various works presented in subsections 2.1.1 and 2.1.2 and section 2.4, we can regroup the key points analyzed in the following general principles connecting users/interfaces/systems/information processing:

1) Using a known set of knowledge (physical manipulation, memories, emotions) for a novel use
2) Matching the geometry of the interface to the assumed geometry of the content

3) Leveraging the geometry of the interface as a vector of communication with and between users

As a general analysis of the different design concept for the related work in addition to the study of their cognitive underpinning, we can extrapolate the following guideline for the creation of tangible interfaces or display that could cater to discoverability and cognitive load. The subsequent design proposition would be created with the principles of affordance, discoverability and control of cognitive load as key mechanism. These guidelines are a combination of this studies and embryos of ideas that sprouted during the first steps of studying the related works.
The general guidelines are as follow:

1) Using one tangible interface to interact on a second tangible interface
2) Interacting directly with the interface and acting on its general shape or aspect
3) Both display and tangible interface are combined in one element
4) Simulating an action (user's motion) with a tangible interface to have an impact on the content being displayed

The reasoning behind each is as following (design wise and cognition wise):
1) A system in which both receiver and controller have a tangible representation in an attempt to reduce the need to us a display. This is an attempt to leverage on existing user's knowledge to analyze both interface and streamline the cognitive steps of discovering an interaction process.
2) A concept applied to both shape displays and tangible interfaces, with interesting potential for direct manipulation by our study subject.
3) A design better suited for "on the go' usability, either during class exploration or autonomous learning by an individual.
4) Recreation of an action performed by the users, but with a scope of motions larger than simply interacting with their hands. This could be more catered toward larger movements like sports or mimicking an action. Direct involvement of user spatial awareness in the interaction process.

In regard to the different field of study presented in this chapter, the positioning of this study can be summarized as follow:

1) In the field of design study, this research is positioned to study the potential relationship between the general shape of a tangible interface and the impact it might have on user's behavior in space.

2) A second position, across design study and cognitive science is the capacity for user to perceive an object, determine a set of potential action with it and see how they can project abstract concept on their mental representation and interpretation of that object.

3) For the field of tangible interfaces, knowing that the physicality of the interface has an impact on user performance and appreciation of a task, the position is to consider the shape and geometry of tangible interfaces (not function and physicality).

Chapter three will combine these observations, principles and reasoning with a case study of exhibition visits. This will attempt to highlight the key mechanism that are observable in the relationship between users and content, visitors and exhibition content. The analysis of this study will enable the definition of two research hypothesis, on which the experiments of chapter four, five and six will be based on.

Chapter 3

Preliminary work

This chapter introduces a preliminary study and two research hypothesis based on it. The chapter begin with a study that presents result of visits performed in 10 selected museum exhibitions across Japan. This chapter ends in the analysis of this study, the presentation of the research hypothesis and opens into the first user experiment, presented in chapter four.

3.1. Structure of the research concept

As explained in chapter one, I chose to develop my concept around the accessibility of information. Prior to proposing experiments with participants, I conducted several visits of museums. This chapter studies how visitors have currently access to work of art, the way it is being displayed and how it might have an impact on the appreciation or enjoyment of art pieces and exhibitions as a whole. This study will help define what would be the key points of this research and aim at solving the following:

1)- Relation between the user and the artifact
2)- Readability and understanding of the artifact
3)- General drawback of the installation

3.2. Museum visit and hierarchization of information

Study of the museums that were visited and impressions recorded of those places, quality of the visit and how does exhibits layout helps showcase the art or sometime suffocates it (bad route planing, too many visitors, small space, too much art per meter square).
The following are case studies of exhibition visited during the 2013-2017 period. A vast majority of the museums are located in Tokyo. This is a selection of the most representative visit performed during the period of study, around 30 exhibitions were visited and the following 10 were retained as most representative.
The following studies are an attempt at identifying key elements of how art pieces are being displayed, taking into consideration the value (fragile, old or monetary) of the artifacts presented during those exhibitions.

3.2.1. Recollection of visits

Important note prior to describing and doing analysis of the exhibition spaces. Due to the nature of the chosen environment, it was impossible to take pictures for most of the exhibitions. Illustrations will be used as a substitute to represent how things were displayed and structured.
For each following exhibition, one key room will described and analyzed. Each room has been chosen as representative of the general organization of each exhibitions. Depending on the architecture of the museum and organization of the exhibition, some exhibitions were divided in multiple smaller rooms wile other were spread in a single room with no physical walls, allowing for a free range of motions for each visitors.
Each exhibitions described below have been chosen to represent different types of visitors, based on their age, interest, fluency in modern art or traditional art or neither.

Exhibition 1)
21_21 Design sight (Midtown, Tokyo)
Frank Gehry "I Have an Idea »

General presentation:
Exhibition oriented toward a public either familiar with Frank Gehry's work or novice. Many scale models, original drawings and videos were displayed as exhibition material as well as large scale pictures. The general idea behind this exhibition was to show the thought process the architect is following, through sketches and quick mockup (scale model).

The room (see figure 3.1):
This was the main room of the exhibition, this room being the particularity of the 21_21 design sight and usually well used for each exhibitions. The room contained most of the scale models from this exhibition, representing works done for clients, as well as drawings. One either side of the room, large pictures were displayed, one showing a panoramic view of Frank Gehry's studio.

Analysis:
Elements were displayed in smaller groups, allowing people to get a rapid overview of the room before diving into detailed drawings and scale model. The perimetry of the room followed this idea of hierarchization with the representation of large photos, giving a rapid overview of the work presented in the room. The amount of scale model presented on each table in the center of the room could become a bit overwhelming, and the arrangement of table in small isle sort of slowed down the pace of the exhibition. Although this could be seen as a bad point, it was a good opportunity to take more time to look at each detailed models.

Overview:
Generally well structured presentation, with large amount of space given around the large scale pictures and more intimate settings for the smaller scale models, major key points are 1) Selection of large model and picture to fill the room 2) Saturation of the presentation table with too many models.

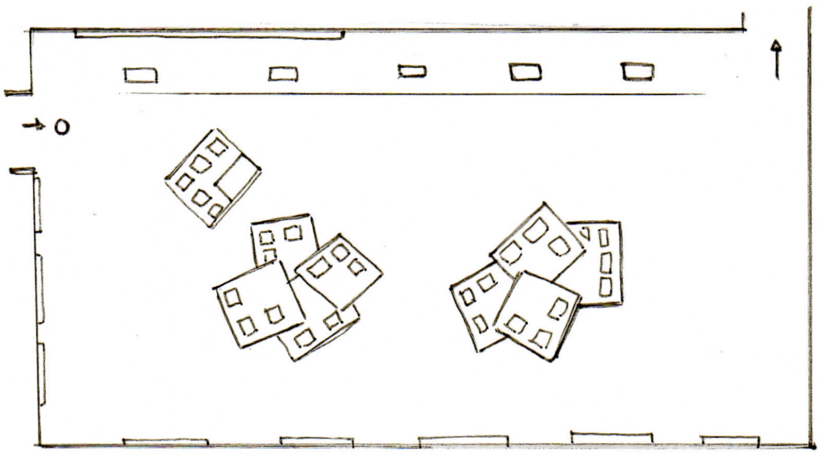

Figure 3.1. Illustration of the exhibition floor at the 21_21 Design sight for the Frank Gehry exhibition.

Exhibition 2)
21_21 Design sight (Midtown, Tokyo)
Design Anatomy: A method for seeing the world through familiar objects

General presentation:
This was an exhibition oriented toward a general public and graphic design enthusiast. Exhibition mostly tailored for visitors fluent in Japanese as most of the detailed explanations were solely written in Japanese. It featured an impressive amount of Meiji's original packaging with an accent placed on every single elements of typography and illustrations. Models of the product presented were also there as well as enlarged version of some of Meiji's most popular products.

The room (see figure 3.2):
Second largest room of the 21_21 design sight, adjacent to the principal room described in the previous exhibition. It was centered around the snacks named "Takenoko no Sato" and "Kinoko no Yama". It featured a very tight array of small stands, all displaying a specific part of the biscuits, the way it was cooked, displaying of all the parts of the packaging and the way it was composed and illustrated. As a center Piece, a Giant version of the biscuit "Kinoko no Yama" was placed in the center of the room.

Analysis:
The organization of the room and the relative small size of the elements presented here in addition to the impressive amount of analysis and poster sized descriptions of the product made it very difficult to move freely in the room. These were in addition to the large flux of visitors. The elements on display being so small, it was practically impossible to view them without either pushing people around or cutting the line. To better observe each details, the only solution was to simply follow the flow of people.

Overview:
Due to the specificity of the exhibition content and the flux of people, the choice of a relatively small museum like 21_21 design sight did not help to provide more space for visitors to freely move around without missing content. It is understandable that the exhibition was designed to be very thorough and detailed, but in doing so it might be alienating visitors not able to read (non Japanese and children) or visitor of shorter stature. Major key points are 1) if the element on display is small, provide enough visibility and access, 2) be mindful of a larger array of potential visitors.

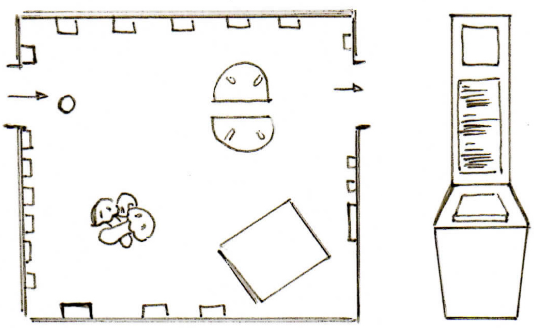

Figure 3.2. Illustration of the exhibition floor at the 21_21 Design sight for the exhibition "Design Anatomy" (left). Reproduction of a presentation stand (right).

Exhibition 3)
21th century modern art museum (Kanazawa)
L'origine du Monde, Anish Kapoor, Museum permanent collection

General presentation:
This piece from the collection of the museum is mostly dedicated to visitor that are used to modern art, although the museum in Kanazawa sees a large array of visitor. The singular goal of this room is to display this single piece from the indian artist Anish Kapoor. It is composed of a large concrete wall, slanted in the direction opposite to the visitor, with an oval shape carved into it and painted black.

The room (see figure 3.3):
The exhibition space for this one is solely dominated by the art piece, with only a narrow piece of floor where visitors can stand. The room has one doorway that works as entry and exit, forcing the visitor to only see the entirety of the piece once they are facing it.

Analysis:
The particularity of this room and art piece is that it's been made for the museum, so it works more as an installation where all the element of the room work toward showcasing the art on display. The museum never bustling with people allow for each visitor to have enough space and time to view and appreciate the installation.

Overview:
The art being designed to fit the room takes all the advantages of it and installs the visitors in the center where they can observe the art piece in the best way they can. Major key point is 1) fit the content to the exhibition space for a maximal effect.

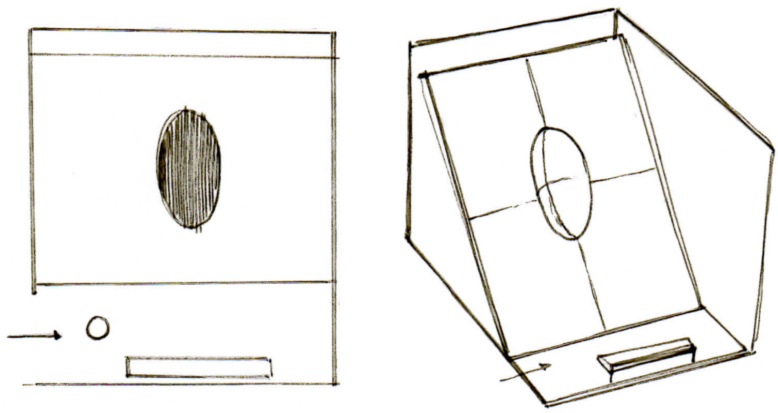

Figure 3.3. Illustration of the exhibition floor at the 21th century modern art museum for the room dedicated to Anish Kapoor.

Exhibition 4)
National Art Center, Tokyo (Tokyo)
Yayoi Kusama: My Eternal Soul

General presentation:
Presentation of Japan most famous artist’s newest art series as well as a retrospective of her previous work. This was an extremely popular exhibition with a very large amount of visitors. It was composed mainly of her newest works displayed in a very large center room, with smaller exhibition spaces placed around it composed with her previous works. Being at the National Art Center, there was not a specific target audience nor age target. The National Art Center in Tokyo is one of the largest museum in the city.

The room (see figure 3.4):
The central room of the exhibition was also the largest, featuring all of the artist new work and three large sculptures. Each paintings (roughly 1.5m by 1.5m canvas) were aligned on all four walls, stacked in an array of two or three, from floor to ceiling. There was not really a path to follow as the room looked more like and open space.

Analysis:
The gigantism of the room and the paintings compensated for the large amount of visitors. The presence of small railing also kept visitor far enough from the paintings to allow a large amount of visitors to get a good view of each paintings. The complete openness of the room also allowed for a complete freedom in the order to follow, although most visitors were moving counter clockwise.

Overview:
Considering the large size and the profusion of paintings combined with the large amount of visitors, having a very large space allowed for the exhibition not to feel claustrophobic or frustrating. Major key point is 1) giving enough space for the large canvas and large crowd to occupy the space freely.

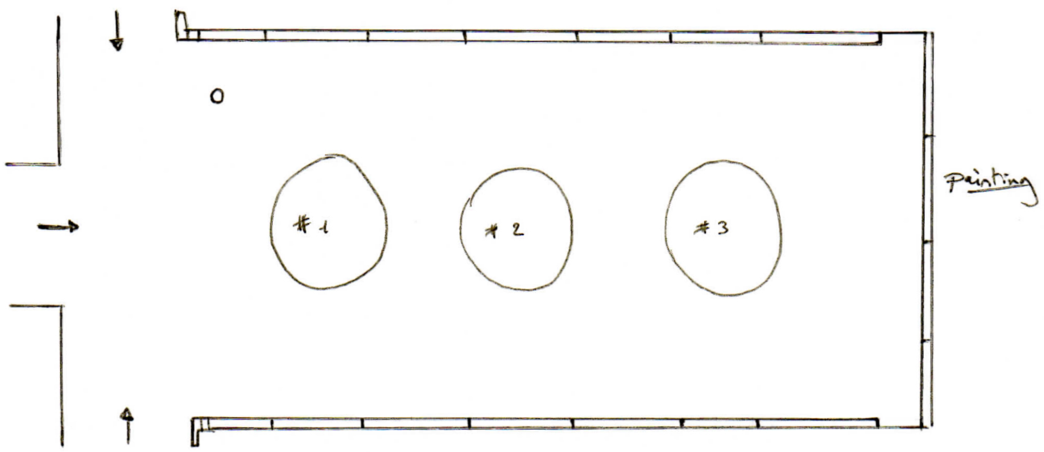

Figure 3.4. Illustration of the exhibition floor at the National Art Center for eh Yayoi Kusama exhibition.

Exhibition 5)
Nezu Museum (Aoyama, Tokyo)
General exhibition

General presentation: Museum with exhibitions and collection strictly oriented toward ancient Japanese/Asian arts and crafts. Very old relics and ancient items are exhibited as well as religious sculptures. The museum also has a traditional Japanese garden visitors can go to and wander around. Generally speaking the attendees of this museum are adults and elders. The museum is composed of two floors, the ground floor has three rooms mostly displaying ancient paintings and scrolls as well as statues placed in the lobby of the museum. The second floor has two rooms showcasing more ancient vessels and plates as well as scrolls. Unless there are some extremely rare painting on display that would attract large crowds, the museum is reasonably frequented.
In each rooms, the ambient lighting is really dark with an emphasis placed on each artifact presented.

The room (see figure 3.5):
The exhibition space in question is the largest of the rooms on the ground floor, large paintings and triptych are usually on display. The paintings are inside glass casings or behind a glass wall that run all the way around from the entrance to the exit of the room. The space could be large enough to allow visitors to move freely, but the extreme precision of the painting on display invites visitors to come closer to appreciate in details each paintings showcased.

Analysis:
Due to the quality and the type of content, it is not really feasible to appreciate the content from a distance and visitors would enjoy the experience better if they come closer to the painting. In doing so, a small line of people can sometime occur and slow down the pace of some visitors. Overall the room and the museum are not really vast so the average visitors would not spend an infinite amount of hours lining up.

Overview:
Because of the type of content on display, a slower pace is necessary to enjoy the museum. The rooms are large enough for visitors who want to simply have a rapid overview of the paintings without hindering the visitors wishing to spend more time looking at each paintings. Major key point is 1) giving enough space to allow for visitor to control their pace.

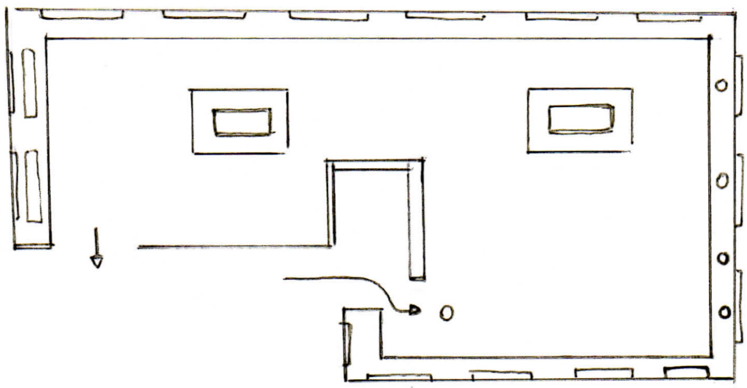

Figure 3.5. Illustration of the exhibition floor at Nezu Museum.

Exhibition 6)
Mori Museum (Mori Tower, Midtown, Tokyo)
Naruto Art exhibition

General presentation:
Note regarding the day of the exhibition. The visit of this exhibition was performed during the middle of a week day outside of public holidays. This precision has an importance as this exhibition was massively popular and the day the visit was conducted the amount of visitor was reasonable. Indication of that being in normal affluence days a waiting time of 2 hours or more was necessary, but during the day of the visit only a wait time of 10 minutes had to be observed before entering the exhibition. This exhibition was celebrating the end of the massively popular Naruto manga and was composed mostly of original pages, research books from the creator and bespoke sculpture, thus catering to a specific types of visitors, mostly fans of the series. It retraced the chronological story of the manga and its key elements. A key elements of this exhibition was the requirement to observe a waiting time as the exhibition curators would only allow a certain amount of people at a time in each sub-sections of the exhibition.

The room (see figure 3.6):
Although it took place in several rooms, the exhibition was design to look like a succession of narrow corridors lined with original drawings, one corridor leading to the next one to the exception of few larger rooms that represented sculptures and the re-creation of the working space where the creator had the original idea for his manga decades ago. The exhibition was divided into several sub-sections, and once a visitor reached the end of a section an exhibition staff will have had visitors waiting so that a sufficient group was created as well as giving more space to the previous group.

Analysis:
Each drawing boards lined on the wall were given enough spacing (around 50cm to 1 meter between each boards) to allow for more than one person to look at it as well as allow people to walk faster and get a sufficient overview of each boards. The amount of elements on display was not overwhelming neither was it underwhelming. The general idea of having people to wait once in a while only to allow them more space and freedom to move around and get a better look at each board was a successful attempt at managing the pace of the exhibition (considering the reduced affluence on that particular day).

Overview:
For drawing board roughly the size of A3, enough space was given for visitors to get close to each boards as well as allow other visitors to look at the same board without having to wait too long. Controlling the pace of the visitors' flow helped in giving enough space for each visitors. Major points being 1) Not overflowing the walls with content and giving enough freedom for the visitor to be up close with the board, 2) artificially controlling the pace to ensure enough space for everybody.

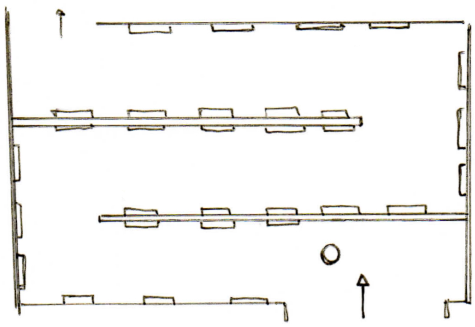

Figure 3.6. Illustration of the exhibition floor at the Mori Museum for the Naruto exhibition.

Exhibition 7)
Edo Tokyo Open Air Museum (Tokyo)
The architecture of Ghibli

General presentation:
Exhibition dedicated only to the architecture created for the movies from the Japanese studio Ghibli. Exhibition catered toward fans of the films as well as families. The Edo Tokyo open Air Museum is a relatively small museum and the exhibition was divided into two rooms. Movies were presented in chronological order, from most recent movies to oldest one. The exhibition contained mostly drawings from each movies and some large scale model depicting houses created for each movies. A note concerning the exhibition, it was very popular and there was a long queue starting outside of the museum. A possible reason behind why such exhibition was displayed in a small museum like this one might be due to the relative close proximity of the Ghibli film studio from the museum (around 30 minutes by foot).

The room (see figure 3.7):
The room in question was the first one you entered directly from the main entry of the museum. The exhibition was organized around a single path and lined with walls to guide people around. Every walls had drawing placed on them. Where there were some opening large scale model had been installed.

Analysis:
In combination with the large crowd attempting to visit the exhibition, the very narrow installation allowed for zero freedom of movement as visitors were lining from the entry of the museum to the exit of the exhibition. This set was most likely motivated to allow for a maximum amount of drawing to be displayed, but it resulted in creating a very constricted path with almost no control on the time visitors could spend on one drawing. Unlike during exhibition 6, the pace of the exhibition was not controlled by any museum staff and visitors just had to follow the person ahead of them.

Overview:
Understandably the curator tried to have on display as much content as possible, but the small size of the museum in addition to the narrow exhibition path and the continuous line of people did not help in creating a comfortable and flexible experience. I am assuming as an adult I had more restrain and calm than most of the young children who came there to look at the drawings. Major key elements being 1) Underestimating the popularity of the content, 2) designing a space too narrow and rigid to allow for a minimum of freedom.

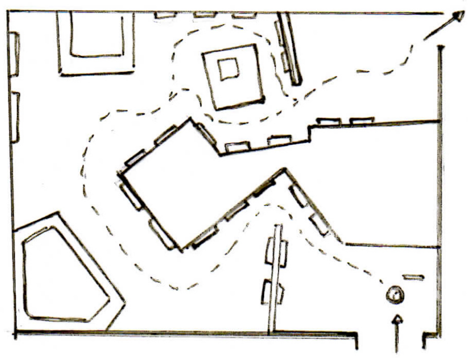

Figure 3.7. Illustration of the exhibition floor at the Edo Tokyo Open Air Museum for the Ghibli exhibition.

Exhibition 8)
Museum of contemporary art Tokyo (Tokyo)
Thomas the tank train

General presentation:
Exhibition catered around families and young children in a museum that usually combines exhibition hosted for a large array of visitors, from families to art amateur. The exhibition retraced the history of the book for children Thomas the tank train. It was composed of old edition books, scale model and large model of trains as well as a children sized railways with moving trains children could sit on. During the visit, most of the visitors were families with children aged three to ten. The exhibition was composed of two parts, the first one regrouping pictures and drawing from the original books, the second one centered around larger installation with the train for children and some interactive installation centered around railways and trains.

The room (see figure 3.8):
This was the first section of the exhibition, composed with table housing original drawings and books featuring Thomas. The walls were also covered with several books and drawing, giving a nice general point of view from every angle of the room.

Analysis:
Although the content displayed was relatively small (each drawing and books were around 15 cm by 15 cm), the large space provided by the room and the settings of the table allowed for everyone to move freely and allow for children to look closer at the drawings. This exhibition having for subject a train character for children, having regular height table and drawing placed at average adult height may have been too high for children.

Overview:
The size of the room helped compensate for the size of the content being displayed and allowed for enough freedom of motion around the exhibition space. Major key point is 1) Compensating for the size of the content by giving enough freedom of movement to the visitors.

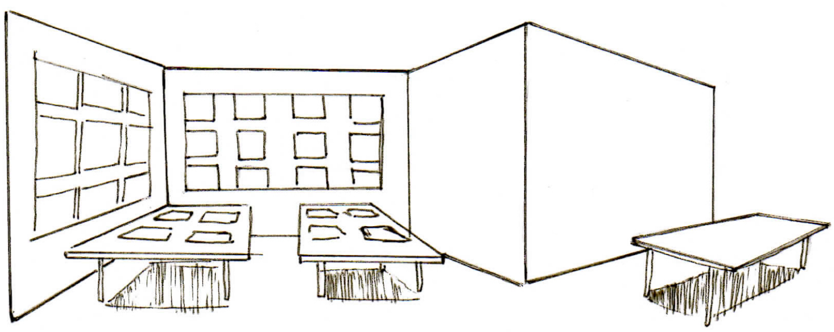

Figure 3.8. Illustration of the exhibition floor at the Museum of contemporary art for the Thomas the tank train exhibition.

Exhibition 9)
Miraikan (Odaiba, Tokyo)
Special Exhibition "Toilet!? - Human Waste & Earth's Future"

General presentation: Exhibition taking place in a science museum (Miraikan in Japanese can be directly translated into “Future Museum”). This exhibition as well as the museum is catered around families with children and young teenager coming there to discover educational content in a hands on way. Unlike the other museums, the Miraikan is situated in the bay area of Tokyo, allowing this museum to have a great amount of large exhibition space compared to other smaller museums located in the center of Tokyo. The subject of this exhibition was centered around human waste, how it is produced, its composition, how toilet works and how suage networks function. The exhibition was composed of different kinds of installations, with interactive contents, movies, and as a center piece a giant toilet where people could climb in and slide down to access the rest of the exhibition (this exhibition cleverly mixed fun experimentations with more serious data and explanations).

The room (see figure 3.9):
This exhibition was composed of one large room with several booth organized in a large semi open space. There was a given path to follow but enough freedom were given to visitors to get an overview of the space and decide where to go to. Each installation had a large indication board on its side to allow for good visibility. There were enough stands, thus limiting the creation of small crowds.

Analysis:
Beside the originality of the exhibition's content, the large space, the sufficient amount of stand and the large indication boards helped to make the experience fluid and enjoyable. The only bottle neck was the giant slide toilet (this path was optional) where people had to line up for a bit due to safety reason. Beside this understandable measure, the rest of the exhibition was well designed and organized.

Overview:
The sufficient amount of attraction helps cater to different age groups of children and young teenager with contents of various degree of complexity. Major key points 1) Designing content adapted for different types of visitor, 2) giving enough space so that each stands were large enough and had good visibility and readability.

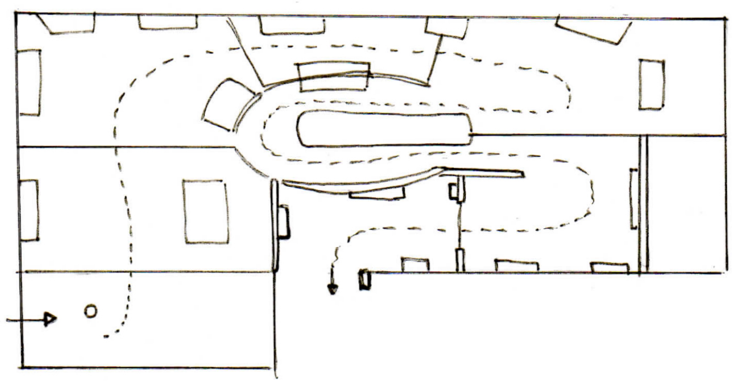

Figure 3.9. Illustration of the exhibition floor at the Miraikan for the “Toilet!?” exhibition.

Exhibition 10)
National museum of nature and science (Ueno, tokyo)
General exhibition

General presentation: Large science museum oriented for families with an impressive amount of floors and buildings. Like most national museum in Tokyo there is a constant flow of people roaming around. The large size of the museum help dilute the crowd effect. The larger room with the more interesting subjects for families (large collection of taxidermy animals, fossil rooms) tend to draw the largest crowd. Subject presented there ranges from science to the first men in Japan, dinosaur fossil, marine life and the animal kingdom.

The room (see figure 3.10):
Large fossil room, located in one of the basement floor. The particularity of this room is the presence of very large fossil of bipedal animal as well as marine animal suspended to the ceiling so visitor can walk underneath and appreciate the size of these extinct animals.

Analysis:

One of the main attraction of the museum, the fossil room has a figure height loop configuration that allows visitor to choose their path of visite. Most of the visitors flux is oriented toward the larger fossil of whales and ancient mammals, these fossils being placed in areas with the most open space to allow for a good point of view and visitor's circulation. There are information placed around the room to give extra informations on the fossil, but with the large fossil being hung from the ceiling, it is possible to miss some of the information if the visitor is not backtracking a little.

Overview:
Original presentation of the fossil that allow visitor to get a good look, large room with enough open space to move freely around and dictate your own pace. Major key points 1) the size of the room is suitable for the size of the fossils on display, 2) original way of displaying each fossil that allows visitor to get a good look without taking any risk in the visitor touching them.

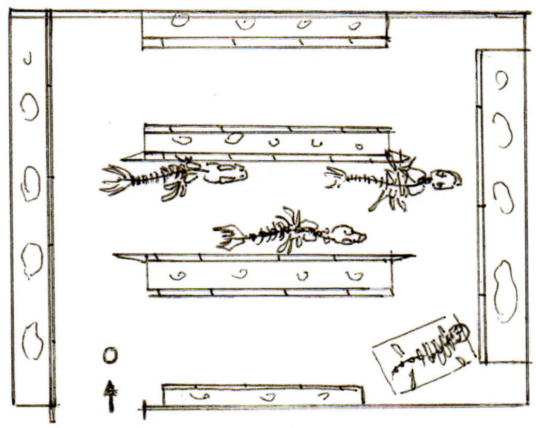

Figure 3.10. Illustration of the exhibition floor at the National museum of nature and since for the fossil exhibition.

3.2.2. Analysis and discussion

Table 3.1. Overview of each exhibition

Exhibition	Content	Room size	Access	Pros	Cons
1	Architecture	Large	Spatious	Large models	Too many small models
2	Design	Medium (8m by 8m)	Crowded	Very detailed exhibition	Not enough visibility and access
3	Modern Art	Small	Easy	Content matches the room's size	Modern art (not everybody will appreciate)
4	Modern Art	Large	Acceptable	Large paintings in a large room	A bit chaotic (very popular exhibition)
5	Traditional Art	Medium	Easy	Enough space given for visiting freely	Linear presentation
6	Illustration (Popular manga)	Long and narrow	Acceptable	- Reasonable amount of illustration - Control of the pace	Very popular content, it might be impossible to visit if too crowded
7	Illustration (Popular anime)	Long and narrow	Overly crowded	Large amount of illustration	- Large amount of illustration - Limited space - Small museum for a very popular content
8	Collection (Children book)	Medium	Easy	Small object but enough space to get close to it	Everything not perfectly accessible for children
9	Educational (Society subject)	Large	Spatious	- Content well curated - Easy access	Museum far from Tokyo center
10	Educational (Natural science)	Large	Spatious	- Large room for large fossils - Easy access	Vast museum

Above, see table 3.1, the different elements of information for all ten exhibitions are represented. From all these visits and analysis, the major key points can be regrouped as follows:

- Content that fill the space provided (large room large picture)
- For smaller content, providing enough room to move freely around
- Spacing the content apart enough to allow for good visibility
- Managing the amount of elements on display regarding available space and not overflowing it
- Controlling the pace of the exhibition to provide enough space for each visitor
- Not underestimating the popularity of the content
- Adapting the content to the types of visitors (for spaces catering to a wide range of visitors)
- Finding original ways of displaying the content to allow for better experiences

This is a representation of some key elements that could assist in the creation of exhibition concept that might offer conformable experience for visitors. Some elements could be considered as not controllable such as the popularity of the exhibition. Admitting the content prior to being displayed at the museum is already popular (case of exhibitions 4, 6 and 7) should give an indication of the measure to be followed to allow for a good organization.
Although these are studies of museums, the very act of displaying content, may it be for art purpose or other, obey similar rules. Not counting for the museum specific key points, the remaining could be applied to our potentially school environment or any types of environment that needs to display any kinds of information.
Key points learned from these visits are that navigation around the displayed content should be facilitated with enough open space that allows for more visitors' freedom. Connected to that, the size of the content itself should be sized in accordance to the space available. This could be solved starting from two different points:

1) There is a given space and the content can be sized to fit the environment. This could be applied to bespoke exhibition with custom made installation, information boards and content of a digital nature such as pictures or video projection.

2) There is a given size for the content and the space can be sized accordingly. This could apply to natural science like fossil, paintings or anything that is not expandable or shrinkable.

In addition, they could also be crossed with the capacity to control the amount of elements on display to not cause an overflow of information for the visitor.

Key elements such as adapting the content to the types of visitors (age, proficiency in the subject, goal of the visit) or finding original ways of displaying contents are closer to concept common in interaction design and answer to the questions who (target user) and how (general interaction process).

Overall, the enjoyment of an exhibition is relatively abstract and each individual can experience a similar exhibition differently. It depends on factors outside of the control of designer such as visitor's current mood, group size resulting in possible stress if someone get loss thus reducing their interest for the content on display. It might also vary based on their personal background and previous knowledge (visitors already being familiar with some of the content on display) on the subject. This also is unfortunately not accounting for impaired people or people with reduced mobility. The popularity of exhibition content could also be categorized as relatively unpredictable, as showed during the visit of exhibition 6, a usually crowded space can suddenly become enjoyable if the visitor is lucky and visit in low moment of attendance.
But in general, the concept of good visibility and accessibility, relative freedom of movement and innovative ways of displaying content are concept that seams recurring in more than one instance, giving an indication that they could be applicable or at a minimum create a better average exhibitions, regardless of variable factors.

It has to be noted that, due to the nature of each exhibitions (contents and location), the way visitors consumes the exhibition are not fully comparable. All 10 exhibitions can be divided into four larger groups of content: 1) Design content (exhibition 1 and 2), 2) Art and Modern art (exhibition 3,4 and 5),3) Documentary type content, providing an insight in the creation of already known content (products, movies, etc.) (exhibition 6,7 and 8) and, 4) "Traditional" educational content (exhibition 9 and 10).
Strictly speaking, outside of Art and modern art, the other three kinds of exhibitions provides content to acquire new knowledge or add new elements of knowledge to an already familiar subject. Although it can be considered that learning about the work of an artist would add elements of knowledge to someone's culture, it is more prone to interpretation and personal liking of the art subject. In the case of learning about dinosaurs, the goal is to educate and gather a better understanding with unquestionable data. Content 1 and 3 are similar, but the nature of the content

itself is targeted to different type of population, design being more specific while general documentary type exhibition can be considered more accessible to a larger audience.

3.3. Analysis and key points

As a starting point we will use the general concept established in subsection 3.2.2. and base on the analysis of how to exhibit content and the relationship with the exhibition space:

- Visibility and accessibility
- Relative freedom of movement
- Innovative way of displaying content

The basic design concept defined in section 2.5 were used as concept ideation base and resulted in the following combination and creation of proposal of potential tangible interfaces guidelines.
As a reminder, the basic design concept defined in section 2.5 are the following:

1) Using one tangible interface to interact on a second tangible interface
2) Interacting directly with the interface and acting on its general shape or aspect
3) Both display and tangible interface are combined in one element
4) Simulating an action (user's motion) with a tangible interface to have an impact on the content being displayed

These four propositions were introduced in section 2.5, but could be summarized as follow:
- System composed of two or more tangible interfaces, for example a controller acting on a separated receiving interface (small size).
- Direct manipulation of an interface with shape shifting features (hands on control).
- Participant can carry around a device with an embedded display (all in one system).
- Mimicking an action such as practicing an exercise (playing tennis) with a tangible interface shaped to represent the action to be performed (shape like a tennis racket) (large scale interaction).

In addition to these, key concepts emerged from the study of museums' visits.
The physical integrity of the subject and its representation being one of those concepts. The way users would perceive the subject or interface would define the quality of their interaction. If users weren't able to experience enough freedom in interacting with the content as well as moving around it could result in a less than optimal enjoyment of the content. This could be split into two comprehensive ideas:

1) What are the relationships between the users, the interface and the environment?
2) In what proportion the geometry of the interface could support mental abstraction of a subject?

The first idea revolves around the proposal that the size of the interface in combination to the freedom of motion given to users/viewers could have an effect on the way the content would be experienced, understood and appreciated.

The second idea revolved around the proposal that the physical appearance of an interface (its affordance) could carry meaning that users/viewers could interpret based on their own previous knowledge. This idea is sort of similar to identifying a known shape with the random appearance of clouds, although someone thinks he/she might be seeing a rabbit in the sky, it is mostly an abstraction of clouds' random shapes and its association with a previous knowledge that seems to be matching.

3.4. Hypothesis and what to test

From the analysis presented in the previous sub-sections, we could propose the following research hypothesis:

> H1) The volume (dimensions) and geometry of an object (interface) has an impact on the participant behavior (movement around the object).

This parameters will be concerning the dimensions and geometry of the interfaces as well as the freedom of motion given to user. This set of questions will be studied in chapter four and five. This hypothesis originate from the study of museum, in which the size of the content and the exhibition could define how visitors would enjoy content.

> H2) User can match digital task to corresponding object's geometries, either for practicality or enjoyment.

This parameters will be concerning the type of interfaces' geometry as well as what sets of tasks could benefits the most from this? Could visual support be an aid to the interface geometry or parasite mental abstraction? This set of questions will be studied in chapter six. This hypothesis originates from the study of tangible interface in chapter two. These studies focused on the physical representation of a subject, in an attempt to make the interaction process seamless and effortless for the user in some cases. In order no to bias the experimental process, simple prototypes and experimentation have been designed to ensure that each participants understood all three tests properly.

Chapter 4

Interface's geometry and its effect on viewer's behavior

This chapter presents the first experimental test of this study and its following results and analysis. The first section describes the research hypothesis and preliminary work done on building the objects that will be used for the experimental process. The second section introduces this experimentation aim, objectives and general proceeding. The third section describes the component of the experiment as well as the pool of participants and the set of tasks they were asked to perform. Section four explains in detail how the experiment was conducted, performed and recorded. Section five presents the experiment results and its analysis. Finally section six proposes a discussion on the proceeding of the experiment, its results and a comparison with results from chapter five.

4.1. Research question

As a reminder of what has been stated in section 3.4, the following is the hypothesis and elements of study for this chapter:

H1) The volume (dimensions) and geometry of an object (interface) has an impact on the participant behavior (movement around the object).

This experimentation was an opportunity to experiment with a different age group of participants. The majority of this study's participants were from children and young adults group (as explained in chapter six). For the experimentation presented in this chapter I had the opportunity to experiment with 21 adult participants, giving a sufficient amount of data to see if this abstract subject could be equally understood across all tested age groups.

4.2. Research aim and objective

This iteration of the experimentation will solely compose of testing the relationship between user/object/space, removing any additional elements (visual support). The experimentation was carefully designed with no action to perform, no rules to follow beside two stated at the beginning of each test sessions, both rules only related to the relation user/object/space.
Those rules are as follow:
Each participants received one object at a time, four in total for each participants. Facing toward the object, each participants had to follow two simple rules:

1) You can look at the object, but you can't touch it nor move from your starting position. Upper body movement were allowed.

2) Once the first rule is observed for each object and you are satisfied, you can now move around freely, but not touch the object.

Those rules are a combination of both sub experimentation performed in chapter five. There, the second experimentation will focus on upper body movement while the first experimentation focuses on participant's movement around an object. The purpose of this chapter is to run hypothesis H1 by removing the potential confusion created by any sort of game rules or visual support. This time the focus should be on the relation user/object/space and not user/game on an object/space. This relation will be tested in depth in chapter five and six.

For this version of the experimentation, the assumed result would be that the shape of a given object has an impact on how participants behave in space. If results in chapter five are representative, then it can be expected of the participant to use any openings offered by the geometry of an object, be guided in their movement if the object is pointing in one direction. It can also be expected that the incapacity to first view each object in its entirety would motivate participant to move around in some fashion to observe all angles of each objects.

As proposed in the discussion in chapter five, introducing more variation on the shapes and volumes of each object could impact or not participants behavior.

As a brief summary, the ideas proposed for this experiment are an attempt to answer the following hypothesis:

> H1) The volume (dimensions) and geometry of an object (interface) has an impact on the participant behavior (movement around the object).

Two objects related rules were also defined to observe how participants would behave with and without constraints around each objects. 1) the participant can only perform upper body movements, 2) the participant can move freely around (each time without the capacity to touch the objects).

4.3. Research method

Section 4.2 introduced the assumed way this experiment will be performed by the participants. The experiment will be composed of four objects. The participants will be standing in front of the four aligned objects. As described in the previous section, participants will be asked to perform two simple rules that indicates them with how much freedom they can move around each objects.

The pool of participants was composed of 21 participants, all part of the same age groups beside two younger participants (4 women and 17 men, from age 22 to 68 years old, from age 30 to 68 years old in the adult group, young adult participants being 22 and 25). All participants were fluent English speaker or had a native Japanese translator to ensure the instruction were clearly understood. Each participants signed up voluntarily for the experiment. All participant were from my design studio in Tokyo but were not aware of the nature of this study prior to performing the tests.

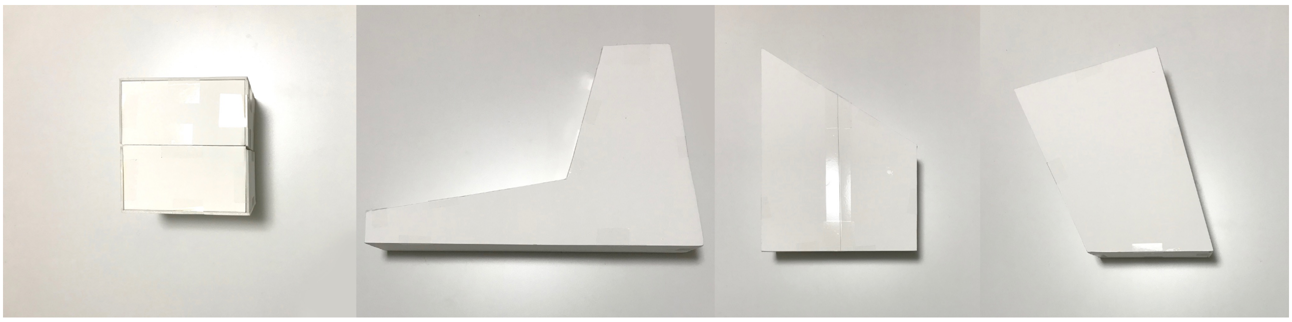

Figure 4.1. The four objects from left to right: 1) Cube 2) Long 3) House 4) Slanted.

As described in previous section, this experimentation will be composed of two sections and four objects (different geometry from chapter five), see figure.4.1.
Object 1) a 15cm by 15cm by 15cm cube
Object 2) a 50cm by 40cm by 10cm L shaped extrusion
Object 3) a 40cm by 20cm and 40cm (left and right side) by 10 cm house shape extrusion
Object 4) a 20cm and 30cm (base and top) by 40cm by 10cm slanted quad extrusion

All objects were placed on a waist high table (around 70cm) to allow a stable base for each participants.

In term of positioning in this study, placing it as a first experimentation made sense even if it is a re-run of chapter five. With the elements learn from testing with and without visual support in chapter six, visual support can be considered to disrupt the readability of an object geometry and this might have affected participants behavior in the iteration of this test in chapter five. These findings will be described in details in chapter five and six.

4.4. Experimentations

Before describing the proceeding of this test, it has to be noted that due to time constraints (participants taking on their lunch break to participate) each session featured a group of four participants. It can be considered that due to the nature of this test, participating one by one or by groups of four wouldn't affect participants general behavior. Each participants had to focus on the object presented in front of them and wait to receive the remaining three. All object were rotated simultaneously between each participants, manipulation being done by myself so participant could stay focused on their posture.

The entire experimentation was completed with 7 groups of participants, ranging from one to four participants (in order to accommodate everyone's schedule), see figure 4.2.

Figure 4.2. Two groups of participants participating in the first section of the experimentation, right picture showing how participants might have moved around the objects.

All group sessions went similarly, each sessions being filmed by myself to recored everybody's movement and reaction. Each participants were asked to voice their satisfactions once they considered they had seen enough of each object.

First, each participants were asked to stand in front of the table, and before presenting them with the objects, they were told the experimentation would be divided in two section. First section they would look at each objects, but they would not be allowed to move from their started position.
Once the first section was completed, all object were placed on the table at the same time and participant were then told they could move freely around.

Results will be describe in details in the next sections, but several general behavior were observed during the experimentation.

Not sure of what they were looking for, most participants bended far enough so that their face would almost touch the object in front of them. It is note worthy when considering that all objects had different shapes and volumes, meaning for the cube participants had to bend further than for the taller objects. This was in addition to participants moving with more left and right amplitude for the L object.

Not unlike result in chapter five, the clear slanted orientation of all three object beside the cube invited the participants to move in a predictable fashion.

During the second section, all participants unanimously first stepped backward to get a better glance of all four object to then walk across the room to the opposite side of the table. Being three to four participants at a time, they would stand on opposite corner of the room and observe from there, see figure 4.3.

Figure 4.3. During the second section of the experimentation, participants unanimously went to the opposite side as soon as they were allowed to.

Some participants would also take one or two additional step back to view the entirety of the table and the four objects. Each participants would then individually move around if necessary.
These preliminary observations matched the expected behaviors stated in section 4.2:

> "For this version of the experimentation, the assumed result would be that the shape of a given object has an impact on how participants behave in space. If results in chapter five are representative, then it can be expected of the participant to use any openings offered by the geometry of an object, be guided in their movement if the object is pointing in one direction. It can also be expected that the incapacity to first view each object in its entirety would motivate participant to move around in some fashion to observe all angles of each objects."

The next section will describe in details the data observed during both sections, but as a general observation it can be said that, all participants and for both sections, showed some similar behavior to those observed in chapter five.

4.5. Results

The result noted from the recorded videos of each group and section has been compiled in table 4.1. For each participants, all movement were noted as either moving left right, close to the objects, staying away, etc as visible on the table 4.1.

All objects'' geometry were selected to simulated the same type of behaviors observable in chapter five as well as additional elements such as varying the size and length of each objects to observe any emerging behaviors.

The Left/Right results focuses on participants who mainly moved around for one object, without really stopping in one clear spot around the object.

Before describing each object and observable behaviors, each movement have been classified as the following:
1) Away means participants stayed in position without any noticeable change of posture
2) Around means participants moved a bit closer, but were not decided where to look at
3) Left/Right indicates the tendency of few participant to move closer and jump back and forth between left and right without really stopping nor looking in other direction
4) Close indicates getting his/her face close to the object (ranged from approximately 5cm to 40cm)
5) Short side is specific for object 2 and 3, it indicates the smaller side of the object
6) Opened area indicates the negative space created by the volume of object 2, 3 and 4

It has to be noted that some participants displayed more than one observable behavior, so it has been added to the board, this is why most of the results are higher than 21 out of 21 participants.

Table 4.1. Results gathered from participants movement during both sections of the experimentation.

	Object 1 (Cube)	Object 2 (Long)	Object 3 (House)	Object 4 (Slanted)
Section one				
Away	10	2	7	8
Around	2	2	1	1
Left/Right	1	1	2	1
Close	9	1	5	1
Short side	/	8	4	/
Opened area	/	13	2	15
Section two				
Step away	21	21	21	21
Opposite side	21	21	21	21
Wall around	21	21	21	21

For each objects, visible tendencies could be noted, object 2 and 4 both having more than half the number of participants getting close enough to look into the object main feature (the opened area in the L for object 2 and under the slanted side for object 4).

Object 1: Roughly half of the participants did not engage with the object and the other half got really close. Either the geometry was not interesting enough (meaning they would stay away) or the small size motivated them to get closer.
It is the first time that such a small object was tested, and these results do not really indicate a strong preference or not. The result being half and half shows the size might have an impact, but the simplicity of the cube might have not been interesting for some.

Object 2: The elongated shape seemed to have invited the participants to displace there body far enough to look at the short side wile the opening created by the L shape invited more than half of the participants to get their head close to that area.

This object had the most “extreme” shape of all 4 objects, and the preferences from participants to get very close and follow the direction of the L might indicate an observable behavior.

Object 3: Average result across most movements, with a small preference for not moving too much.
Compared to object 2 and 4, it could be considered that the gap in height between the tall and short side was not large enough to create a point of interest for participants to look into.

Object 4: Most participants showed an interest to look under the slanted side of the object, some choosing to stay a bit away while looking under the object.
This tendency can be crossed with the result for object 2 and compared to object 3. Compared to the later they both invited participants to move closer were a void had been created by their geometry (more than half of the participants for both objects).

Almost as expected, once they had the opportunity to move around all 21 participants rapidly went to the opposite side of the table to observe all objects from a different point of view. All participants displayed almost identical behaviors, the only difference being some people moving faster than other.

Additionally when visualized, the tracking data from the participants shows some distinguishable areas of interest for all four objects, see figure 4.4.

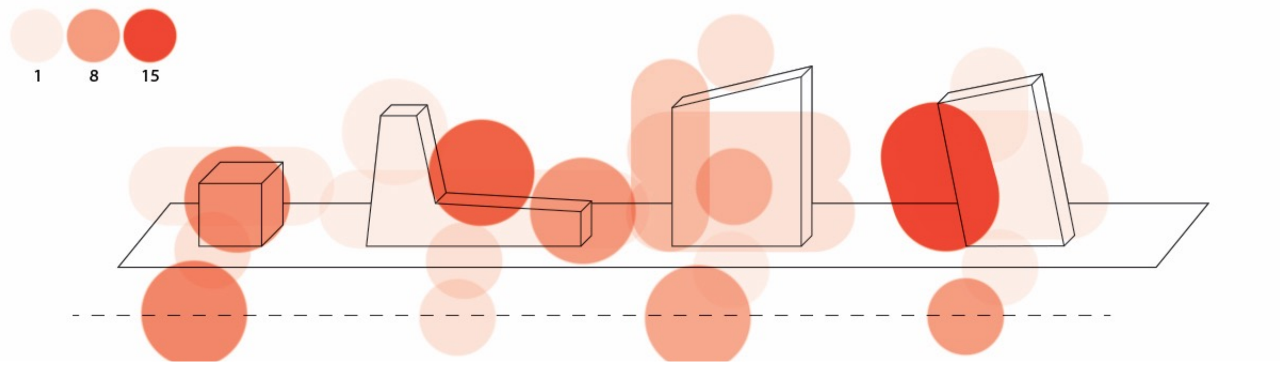

Figure 4.4. Color graduations represents the data shown in table 7.1, minimum data being 1 and maximum data 15 (numbers of participants to position their body in that area), dashed line representing participants standing point.

The potential findings will be discussed in section 4.6, but a preliminary comparison can be made with the finding assumed in chapter five, which could consider that regardless of rules and visual supports, the geometry of an object can guide participant to move in predictable ways as long as the geometry of the objects invites them to do so.

4.6. Discussion

The goal of this experimentation was to validate or refute the findings assumed in chapter five by removing the elements of the experimentation that can be considered as too strong, risking the participants to only answer to visual supports and game rules and not really consider the volume of each objects.

With the limited amount of participants (21), results can not be accepted as entirely representative of participants behavior, but the findings can be considered as a strong indication of the sort of behaviors to be observed when participants are facing objects of various geometries.

The shared goal of both chapter four and five was to test if the creation of blind spot would motivate participants to move around and if object with visibly deformed geometries would invite participants to move (toward opened areas above and around the object).
For the first element, this first experimentation can only indicate that when first forced to not move, the reflex from participants would be to move around and see the hidden faces of the objects. It can not really be considered as a blind spot and more as a constraint.
So it could be considered that if participants were to be constrained and then released of said constraint, their first potential action would be to perform the action that they could not perform under constraints. This assumption originate from observing that unanimously, once the participants were able to move for the second section, they all directly went to see the opposite side of the four objects.They could have performed different actions such as stepping backward or move even closer to the table, crouch or stand on a chair to get a higher vantage point. There are a few numbers of potential actions they could have performed, but all 21 participants chose to walk around the table and stand opposite to where they were in section one.

To prevent some potential error in the analysis process of this test, a statistical analysis of variance (ANOVA) was run to try and define if the parameters of the test (variation in geometry of the interfaces) could be considered to be significant or not.
This analysis was set up to verify any potential effect of the different interface's geometry on participants' answers. The possibilities were either the interface has some effect, or participants results are similar and the types of interfaces doesn't have a noticeable impact on their answers.
A two way analysis was achieved, participant's answers entered as results, each participants entered as factor #1 and the different tasked completed (each displays) as factor #2.
The relevant p value to look for here is the factor #2 value, indicating if the changes in display could be considered as the reason for participants varying answers.
Results showing a variance of p=0.000 (rounded to p=0.001, considered similar) tends to show that the factors in question are statistically valid, the threshold value being p=0.05. Any value superior to 0.05 would indicate that regardless of the change of display, participant's answer would be similar.

Table 4.2. Analysis of variance for the first test.

ANOVA							
Source of Variation	*SS*	*d.f.*	*MS*	*F*	*p-value*	*F crit*	*Omega Sqr.*
Factor #1 (Participants)	89.80952	20	4.49048	1.69503	0.06003	1.74798	#N/A
Factor #2 (Test)	94.79762	3	31.59921	11.92780	3.16024E-6	2.75808	#N/A
Within Groups	158.95238	60	2.64921				
Total	343.55952	83	4.13927				

The analysis results, see table 4.2, tend to show that during the test the parameters of factor #2 (object geometry variation) were sufficient enough, with a variance of p=0.001.
This can indicate that the change in display geometry do have an impact on participants' behaviors.

Regarding the geometry of the object guiding where participants would move their upper body, several key elements are observable:
Changing the size of the object might have an effect on participants behavior.
Object with clear dynamism (short and tall side visually different) and large or curious opened area seems to have a influence on participants behavior. Related to that, object with discreet shapes seems to be not as striking and participants might not share any interest in following the shape of the object (from tall side to short side)

In graphic design, this principle of using strong visual cues to guide viewer eyes around can be coined as "**perceptual salience**", and as such "Cartographers employ a set of visual variables (e.g., size, color hue, color value, orientation, etc.)"…, to guide viewers toward relevant element of

knowledge [81]. This hierarchization of visual cues to indicate a context or guide the viewer can affect viewing behavior and response time [81].
This capacity to guide novice or expert to focus on pre-determined elements of information via graphically emphasizing an element of information could be applicable to the design of objects.
This can correspond to the tendencies from this chapter's participants to be guided toward strong features of an object while mild looking object could be considered as less interesting, or less salient.
This value of saliency could also have an effect on the perception of an object and will be discussed in chapter five and six via the use of visual support.

With or without the visual support and game rules from chapter five, results tends to show that participants would be influenced by the geometry of an object, as long as there's a strong visual indication of a direction where to look into.

The behavior observed during the experiment process as well as the result point toward confirming the previously stated proposition:

> H1) The volume (dimensions) and geometry of an object (interface) has an impact on the participant behavior (movement around the object).

As stated previously this experimentation is a continuation of chapter five, but was organized after the completion of chapter six. The design of this experiment has been curated to account for what has been discovered in chapter six, visual support having a strong influence on participants behaviors. The result also stated that participants could project some level of abstraction on objects (see chapter six section 6.6).

Chapter 5

Interface's geometry with visual support and its effect on viewer's behavior

This chapter presents the second experimental test of this study and its following results and analysis. The first section describes the research hypothesis and preliminary work done on building the objects that will be used for the experimental process. The second section introduces this experimentation aim, objectives and general proceeding. The third section describes the component of the experiment as well as the pool of participants and the set of tasks they were asked to perform. Section four explains in detail how the experiment was conducted, performed and recorded. Section five presents the experiment results and its analysis. Finally section six proposes a discussion on the proceeding of the experiment, its results and possible evolutions and or additional implementation that could form a second type of experimental tests (presented in chapter four).

5.1. Research question

As a reminder of what has been stated in section 3.4, the following is the hypothesis and elements of study for this chapter:

> H1) The volume (dimensions) and geometry of an object (interface) has an impact on the participant behavior (movement around the object).

This parameters will be concerning the dimensions and geometry of the interfaces as well as the freedom of motion given to users.
To answer this question, the following experiment will be composed by a set of two tests. The first will focus on studying the movement of participants around a medium sized object. The second test will focus on studying the upper body position of participants when they are force to stand still in a specified location.

Previously stated in sub-section 3.3, giving enough space around something on display allows for a better visibility, but the artifact itself has to be of a suitable size for the available space surrounding it to be useful. This can be applicable in different aspect of "giving enough" space for better visibility.
As observed during the museum analysis, the freedom of movement for visitors can be based on the following factors:

- The space where the subject is being displayed is not physically big enough and thus reduces greatly visitors' freedom of motions (either the space is too small or the art piece is too big)
- The museum artificially controls the space by creating a perimeter around the subject where the visitor is not allowed (mostly due to safety, the visitors are not suppose to touch the art piece)

These points could be considered environment specific to museums, but as developed earlier in chapter two, having the capacity to directly (physical manipulation) and freely interact with a tangible elements allows for a more engaging experience. In this case, the act of physically interacting could be replaced by the act of moving around and observing freely an object.

In order to run some experiments on this set of ideas, it was decided to fabricate a series of objects that would be used as experimental support. These objects will then be combined to a combination of rules the experiment participants will need to obey to.
Decision was taken to first build test objects and assess their geometries to try and analyze the sort of participants' behavior to be triggered.

For a starting point, the dimension of the first object was set at 50 cm x 50 cm for its base. From there adjustment could be made to create smaller or larger objects if the general aspect of the object was not deemed interesting enough.

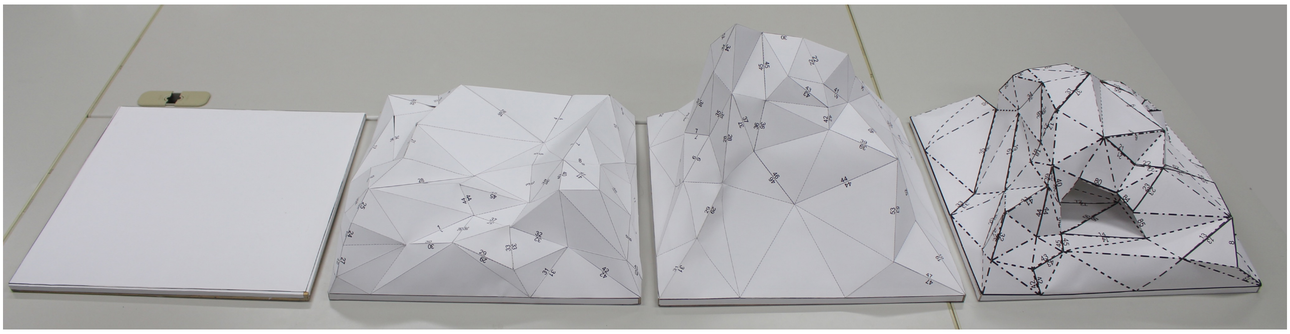

Figure 5.1. Picture of the first series of objects (from left to right) object one to object four.

The following object was created, see figure 5.1 second object to the left, and an important key point emerged from its conception. Due to its size and geometry and if something were to be projected on it, someone who would be directly looking at it will not be able to see the entirety of the image projected without being subject to some blindspots.
This element struck as something that could be used as a motivation to get the participants to move around (if we were to allow them) or else they would miss some of the images projected.
From there, a series of four medium size objects were developed, see figure 5.1, as well as a small "game" that would entice the participant to move around the object. These will be explained further in section 5.2.
If this experiment was to be a test to see and analyze how participants would move freely around the object, an experiment could also be set to see how the geometry of a different object could force them to behave in a predictive way. For this, a series of six dedicated object were created in combination with two small "games" that would test how participants would behave when limited to standing still and only have upper body freedom. Whereas the previous set of objects were 50 cm x 50 cm, decision was taken to build this series smaller (30 cm x 30 cm) in order to allow participants for more freedom of movement. These will as well be explained further in section 5.2.

For practical reason, both sets of objects were constructed from folded and assembled paper and wood frames. Due to the different nature of both tests, the series of four large object was designed with a little bit of a complex geometry that required the use of paper craft technics. The series of six would have a simpler sets of geometries so it was decided to use mainly large flat areas of paper with laser cut holding plates on both sides. The reasoning behind the choice for each geometries will also be described in section 5.2.

5.2. Research aim and objective

This experiment has for objective to determinate if there are any relationships between the way participants behave around an object and an object's shape. It also aims at defining if participant's behavior can be acted upon in different degrees: limited motion (upper body) and free movement in space. To do so, this chapter will describe two tests.
The first test will be following this guidelines:
The main motivation for this first test came from the following discovery when building the preliminary test object: Could the creation of blind spots on an object be a motivation for participants to move around?
Decision was also taken not to give direct indication to the users that they had to move around, the geometry of the object and the set of action should be able to trigger that behavior for them.

To do so, a small game was created: a set of five red targets will be projected on the surface of each objects. Each objects will be placed in front of the participant one after another. The participant would only be able to get to the next object if he/she were able to find all five targets.

In order to make sure that as little verbal direction will be given to the participants, the series of four objects were designed to assist the participants in discovering the rules of the game.
- The first object would be a simple flat plane, where it would be instantaneous to count the five red target displayed on it.
- The second object would introduce a bumpy geometry, with one target placed in one of the faces opposite to the participants, rendering it not visible if participants were to stand still.
- The third object will introduce a much steeper geometry (sort of like a paper mountain) and it would have two target hidden.
- The fourth and last geometry will introduce a bridge shape, with one of the target being placed on the underside of the bridge part.

It was also decided to only use three verbal commands to communicate with the participants: 1) If you need to you can move freely around, 2) how many targets do you see on the surface, 3) answering yes or no to participant's targets' count (yes to 5 targets, no to any other answer).
The only requirement was for them to always reset their starting position in front of the object for each four objects.

The following ideas of the experiment flow were assumed:
For the first object, it would be obvious to see that five targets were displayed. This would be used to create a constant, "five targets are being displayed". For the second object, it was assumed either participants would be confused and move around to look for five targets, or rapidly answer four. To this I would answer no until they find the fifth target. This was assumed to reenforce the constant that only five targets are displayed and also introduce the idea that if one target is missing, the participants needs to move around to find the remaining one. The third object would be used as a confirmation of object two, the only difference being in a steeper geometry. Object four will be used as a final test, to discover if the introduction of a hole in the object geometry would invite participants to look inside it if they were not able to find all five targets.

The second test will be following this guidelines:
The idea from this test came as a development of the embryo of idea develop during the first test. If the geometry of an object and a fitting set of rules motivate the participants to move around, how would they be behaving if they were force to stand still? Could the geometry of the object guide them in moving their upper body in a controllable fashion?

To do so and test this assertion, a series of six objects were created as well as a small game. Opposite to test one, all six object shares similar geometries with a slight modification.
- Object one would be flat and as for test one be used as an introduction to the set of rules and constants.
- Object two would introduce a similar object, with a raised middle section (10 cm on the right side). The particularity of this section will be that the right side will be few centimeter taller than the left side.
- Object three to six would obey the same idea, increasingly raising the middle section (by increment of +10 cm) of the objects' middle section and constantly having the right side higher than the left side. The difference in hight would grow from 5 cm of difference to 20 cm, see figure 5.2 and 5.3.

The rule of the game would be as followed, five stripes of five different colors would be displayed on the object using a projection. The goal for each participants would be to count how many stripes and how many colors they could see.
For this test it was decided that verbal command weren't necessary beside indicating the participants that they had to stay on a fix spot (allowed to move within a small restricted area).

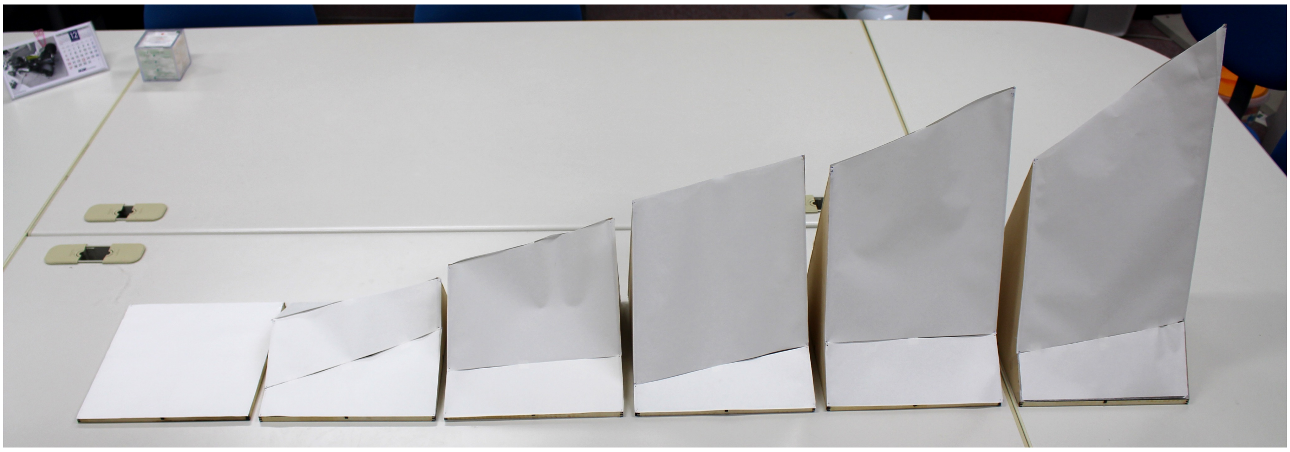

Figure 5.2. Picture of the second series of objects (from left to right) object one to object six.

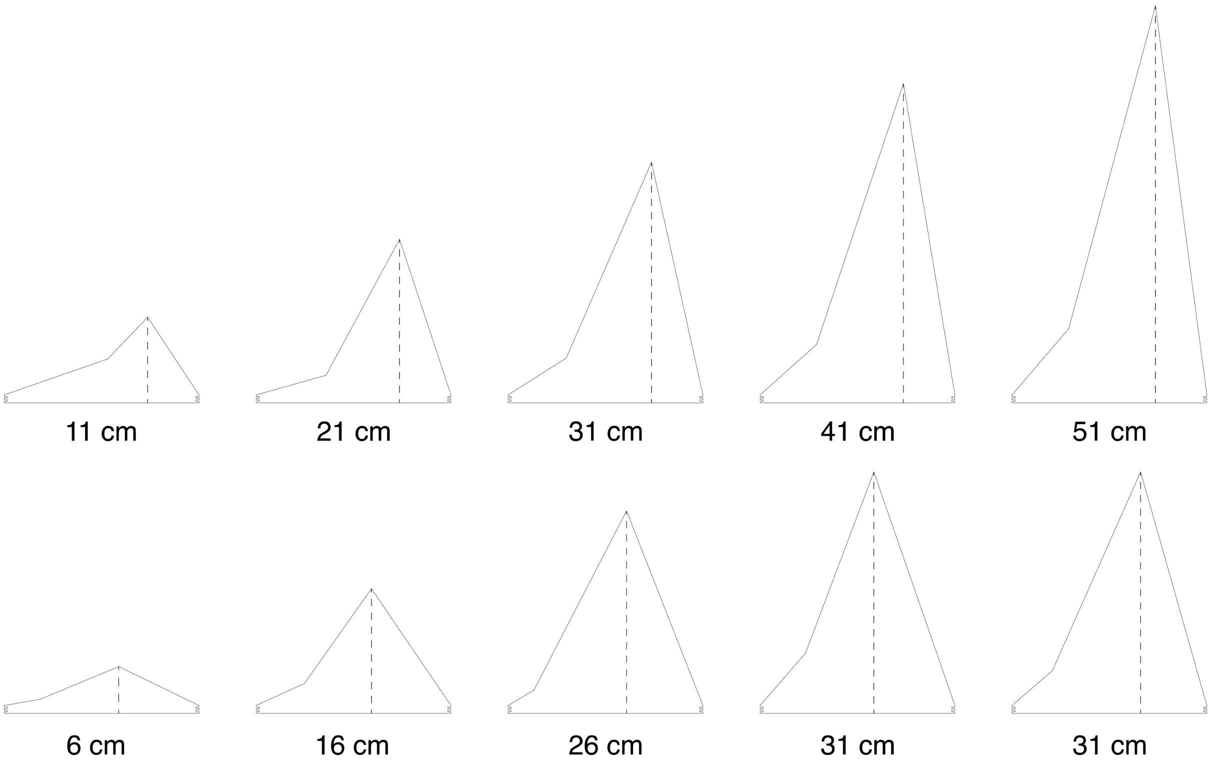

Figure 5.3. (Top, left to right), right side section of each objects, (bottom, left to right) left side section of each objects.

The following ideas of the experiment flow were assumed: For object one, participant would not encounter much difficulty and find five stripes of five colors, this in an attempt to set a constant, five and five. For object two, the geometry would change slightly but not enough to block the participants' view. It was assumed that with the further introduction of a steeper middle section and a raised right section, participants would start to lean forward to look past the raised section and tilt their upper body to the left, and by doing so using the open space left by the left side of the object being lower. By limiting participants motion to only their upper body and creating an opening for them to lean in, it was assumed most participants would end up tip toeing to their left for object five and six.
As a brief summary, the ideas proposed for this experiment are an attempt to answer the following hypothesis:

H1) The volume (dimensions) and geometry of an object (interface) has an impact on the participant behavior (movement around the object).

The proposition to answer this question is: This behavior could be triggered if we let the participants know they have to look for something, and subsequently block or obstruct their point of view to force them to react and move.
Test one and two are used to observe different potential behavior from a similar idea. The goal is to discover how the geometry of these objects might affect participants' movements and behavior. Test one will help observe how participants can be motivated to move around an object freely, while test two will try to discern how participants would react if they were limited in their movement and if the object they were facing can persuade them to move in a controllable way.

5.3. Research method

Section 5.2 introduced the assumed way each test will be performed by the participants. Test one will be composed of four objects and two video projector. A cross on the ground would define the starting point from which the participants will be allowed to start moving around the objects.
As described in section 5.2, participants will be asked to find five red targets being projected on the objects, see figure 5.4. Each objects will be placed one after another in front of the participants.

Test two will be composed of six objects and one video projector. A square on the ground would indicate the participants where they have to stand and the area they can not exit.
As described in section 5.2, participants will be asked to find five stripes and five colors being projected on the objects, see figure 5.4. Each objects are placed one after another in front of the participants.

The pool of participants was composed of 24 student participants, with a repartition of 7 women and 17 men. All participants were fluent English speaker or had a native Japanese translator to ensure the instruction were clearly understood. Each participants signed up voluntarily for the experiment. They each were requested to indicate their height (varying from 1,55m to 1,86m, the average being 1.69m). They all were members of JAIST student body.

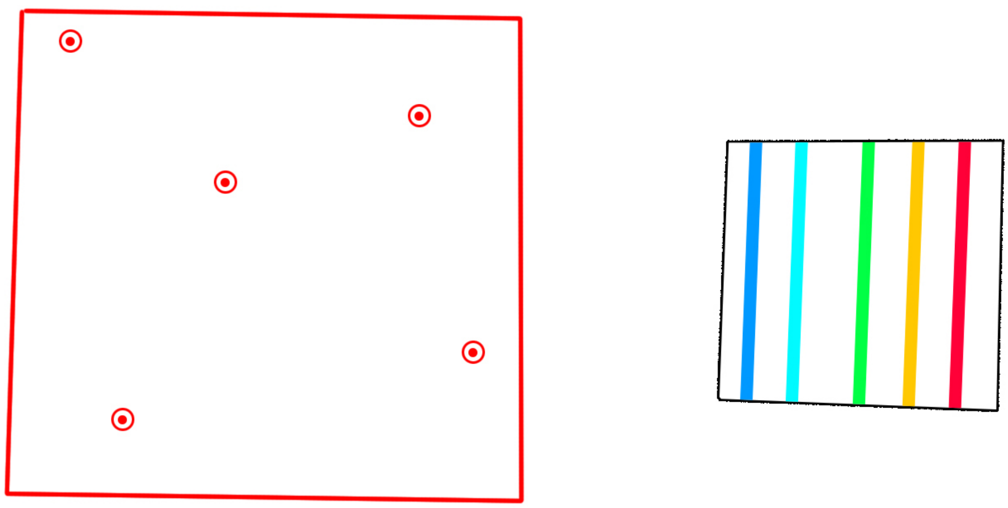

Figure 5.4. (Left) One of the target arrangement (third object) projected, (right) stripes and colors projected on all six objects.

5.4. Experimentations

As a preliminary statement before beginning the recollection of both tests, the assumed behavior stated in section 5.2 were very close to the observed behaviors of participants during both

test. The use of a simpler flat object as an introduction to define a constant worked and gave enough clues to participants to figure out on their own how they should behave.
For each participants, both test were recorded using a camera so each performance could be studied in more details afterward. I would personally be conducting the experiment, standing few meters away from the participants to not interfere with their movements.
For the first test, the following elements will be looked into; 1) the time it would take participants to find enough targets, 2) the amount of targets they would find and 3) the types of movements they would performed.

For the second test, the following elements will be looked into; 1) if participants would take a step forward or not (within the limit of the determined section) and 2) the direction of their upper body (forward? left? right?).

Each participants would be performing both tests, one after an another in a single test session that lasted roughly 15 minutes to 20 minutes on average.

Recollection of test one: each participants behaved in a similar way and no unusual behaviors or attempt were observed. The detailed results of this test will be presented in section 5.5.
For object one, the capacity of the participants to view rapidly all five target was confirmed and there were no struggles to be observed, see figure 5.5.
Object two showed a clear separation in behavior and proficiency to find all five targets. Most participants were at first confused, but after some hesitation and tip toeing most figured out they had to move around to find all five targets.The few participants that did not move from their origin point ended up finding only four targets, see figure 5.5.
Object three showed a clear improvement as all participants found all five targets and exhibited more freedom as they moved around rapidly around the object to find all targets. From this point it was assumed they all figured out the amount of targets was fixed to five and the only modification was where they were projected on the objects, see figure 5.5.
Object four proved to be more complex as only five participants found all five targets. All participants spend a significantly longer time to give their final answer, going round and round around the object trying to see if they had missed something, see figure 5.5.

In addition to their increasing ease to move around the objects, it was also observed that their attitude changed as they were getting familiar with the content, at first acting a bit rigid and cautiously to finally move freely, leaning around and displaying some sign of enjoyment (smiles and relaxed faces).

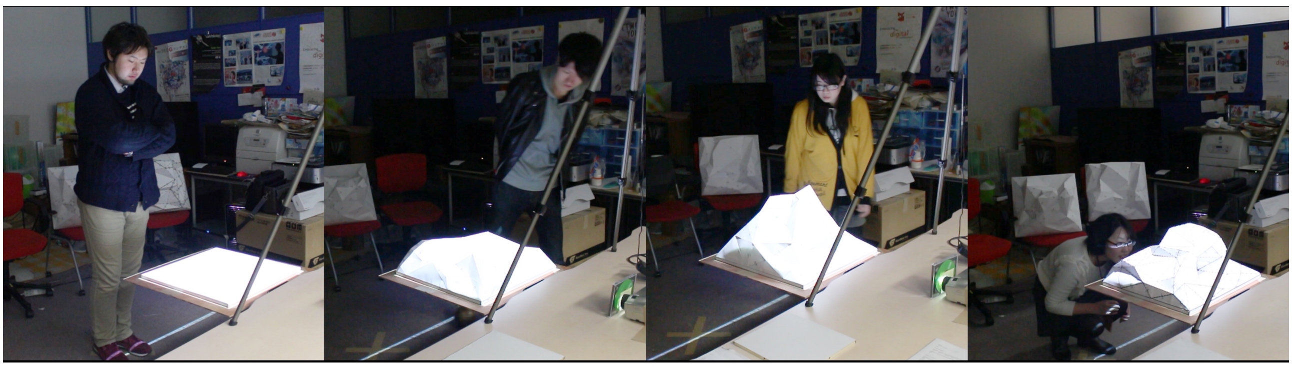

Figure 5.5. (from left to right) Still frame from the recording of the experimentation, representing object one to four. Visible demonstration of the behavior change from object one to object four.

Recollection of test two: similar to test one, each participants behaved in a similar way and no unusual behaviors or attempt were observed aside from one single occurrence were one participant left the delimited area for one of the taller object (it was assumed the participant had forgotten not to move). The detailed results of this test will be presented in section 5.5.

Figure 5.6. (from left to right) Still frame from the recording of the experimentation, representing object one to six. Visible demonstration of the upper body change from object one to object four.

Similar to test one, the first object posed no problem and all five stripes and five colors were found easily. It has to be noted that no participant showed struggle to find both five stripes and five colors during the entirety of the second test.
The higher the middle section was raised, the more forward and to the left participants started to move. It was not really noticeable for object two, but in the case of object five and six, all participants were leaning over the object to see past the middle raised section with their body tilted to the left to compensate for the right side being significantly higher, see figure 5.6.

It was never mentioned to them what they could do, it was just stated what they couldn't do: Exit the delimited space on the ground. From this, they all assumed it was safe to take a step to the edge of the delimited space and lean forward and sideways.

The next section will describe in details the data observed during both tests, but as a general observation it can be said that, all participants and for both tests, showed an incline to either move around the objects or tilt their upper body in an attempt to complete the tasks.

5.5. Results

The results of both test have been compiled in the following two tables for test one and an illustration representing the general position of each participant upper body during test two.
For test one, table 5.1 present the average time it took participants to complete the task or give their final answer. Table 5.2 represent their recorded movements as well as proficiency to complete the task (find all five targets).

Table 5.1. Average time taken by participants to complete the task or give their final answer.

	Object 1 (Flat)	Object 2 (Mild)	Object 3 (Steep)	Object 4 (Bridge)
Time	3.987s	10.967s	11.375s	46.63s
Min	0.9s	5.2s	4.6s	15.4s
Max	18.5s	23.2s	33s	92s

Table 5.2. Recorded movement and participants' proficiency to complete the tasks.

	Object 1 (Flat)	Object 2 (Mild)	Object 3 (Steep)	Object 4 (Bridge)
Moved	0	17	24	24
Looked inside	-	-	-	18
5 target	24	17	24	5

A rapid overview of the timed results shows that once the participants had to move around in order to find all five targets, they took on average 3 times longer to complete the task. Although not as successful, the longer average time for the fourth object indicates the time spent by each participants to decide whether or not they were convinced to have found all targets. This could display a deeper involvement in the task from object one to object four.

Object two and four proposes similar conditions where participants weren't sure if they had found all targets. In the case of object two, participants rapidly decided they had found all targets even if table 5.2 shows that was not the case. The difference with object four is that they persevered, stayed engage in their task and taking on average four times longer to come up with an answer.
Even if the final results of object four does not displays a perfect score with only 5 people succeeding in finding all five targets, the longer engagement and the high number of participants who tried to look inside the bridge shows the effect that changing the geometry of the object had on a seemingly simple task.

As table 5.2 shows, it took participants some trial to get used to moving around the objects to complete the task correctly. On the first test of movement with object two, less than half of participants failed to found all five targets. On the following test of movement with object three, the table shows that all participant moved around and all found all five targets. Interestingly, almost the same amount of participants moved on object two and four where they were suppose to discover that mechanism on their own.

For test two, participants' upper body movements and orientation were recorded and transcribed into six graphical representation, see figure 5.7.
The choice of a graphical representation was made to give a rapid and clear overview of the general behaviors to be observed. Each squares representing one of the six objects, the dashed line indicating the area where participants had to stand, the white dot indicating the locations of participant upper body and the shade of red indicating the amount of participants who adopted that position and orientation. For each position recorded, a spot of red was drawn at low opacity, and with overlapping the shade turned redder where there was the most occurrence of a position.
From the illustration, it appears clearly that as the elevation of the middle section gets taller and the right side becomes more prominent (salient), the clouds of position recored slides forward and then to the left while the shades of reds indicates the same tendencies.

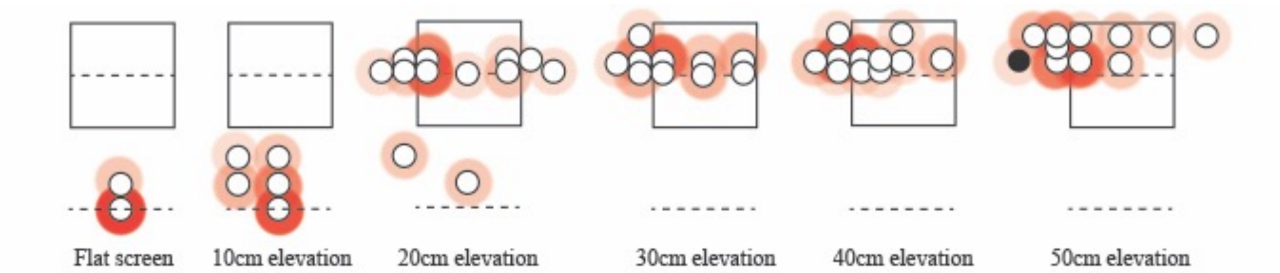

Figure 5.7. Recorded position of participants movements and upper body orientation (the black dot represent the data from the participant who moved out of position).

The discrepancies in position can also be related to the height of each participant, this test being particularly sensitive to participant capacity to reach over the objects raised midd section. Participants being shorter (1m60 to 1m70) needed to reach forward and to the left more rapidly than the taller participants (1m80 and higher). These result are then predictable for "shorter" people as they would feel the need to reach forward more rapidly, taller participants had all the freedom to move as little as possible yet the cloud of red shade and dot indicate a clear tendency to lean opposite the tallest point of the object (in this case the right side).

5.6. Discussion

The behavior observed during the experiment process as well as the result could be considered to point toward confirming the previously stated proposition that we could solve the following question:

> H1) The volume (dimensions) and geometry of an object (interface) has an impact on the participant behavior (movement around the object).

The proposition to answer this question was: This behavior could be triggered if we let the participants know they have to look for something, and subsequently block or obstruct their point of view to force them to react and move.

Although there is not a 100% certainty that these would always be effective, it can be safely assumes that the geometry of an object has some effects on discoverability and participants ‘behavior in this case (in combination with projected images). We can also assume that specific geometries can trigger equally specific behaviors from participants if the rules are well understood. For example, the creation of a hole inside one of the object in test one invited more than half of the participants to look into it. In test two, the visibly taller right side of the objects forced participants to lean to the left while looking over each objects, in both case in an attempt to complete the tasks provided.

To prevent some potential error in the analysis process of this test, two ANOVA analysis were ran to try and define if the parameters of the test (variation in geometry of the interfaces) could be considered to be significant or not.
Both analysis were set up to verify any potential effect of the different interface’s geometry on participants answer. The possibilities were either the interface has some effects, or participants results are similar and the types of interfaces doesn’t have a noticeable impact on their answers.
For these, a two way analysis was achieved, participant’s answers entered as results, each participants entered as factor #1 and the different tasks completed (each displays) as factor #2.
The relevant p value to look for here is the factor #2 value, indicating if the changes in display could be considered as the reason for participants varying answers.
As described in section 4.6, any value superior to 0.05 would indicate that regardless of the change of display, participants’ answers would be similar.

Table 5.3. Analysis of variance for the first test.

ANOVA							
Source of Variation	*SS*	*d.f.*	*MS*	*F*	*p-value*	*F crit*	*Omega Sqr.*
Factor #1 (Participants)	2.98958	23	0.12998	1.38647	0.15021	1.68690	#N/A
Factor #2 (Test)	37.78125	3	12.59375	134.33333	0	2.73749	#N/A
Within Groups	6.46875	69	0.09375				
Total	47.23958	95	0.49726				

Table 5.4. Analysis of variance for the second test

ANOVA							
Source of Variation	*SS*	*d.f.*	*MS*	*F*	*p-value*	*F crit*	*Omega Sqr.*
Factor #1 (Participants)	55.35655	23	2.40681	3.10057	0.00003	1.62360	#N/A
Factor #2 (Test)	116.3125	5	23.2625	29.96789	0.00000	2.29320	#N/A
Within Groups	89.26845	115	0.77625				
Total	260.9375	143	1.82474				

Both analysis results, see table 5.3 and 5.4, tend to show that during both tests the parameters of factor #2 (object geometry variation) are sufficient enough, with a variance for $p=0.001$.
.

This can indicate that the change in display geometries does have an impact on participants' behaviors.

Also in a more abstract interpretation, the overall behavior and facial expression of each participants went from a rigid and focused mindset to more relaxed and "happy" expressions. These could be triggered by the geometry of the objects and how it affect participants' perception of what task can be performed and how. This change in behavior could also be a result of the participants getting more comfortable with the task and rules the more they were performing it.

The size of the display might have had an effect on users' involvement in the action they were performing. [62] We could assume the same could be applicable to object perception and how the participants are being guided by the objects' geometry. It is slightly noticeable on the video recordings that the participants seemed to be enjoying the test one better than test two probably due to the following reason:

- The size of the object could be more engaging the bigger it is
- The task in test two was less challenging
- After 15 minutes of experimental tests they could have been showing signs of fatigue

Although these results could be considered as direct answers, I have to also identify that mainly, participants were answering to the sets of rules for each test rather that strictly looking at the objects themselves. In order to properly answer to hypothesis 1, results of those two experimentations need to be crossed with the results from chapter four and considered as two levels of the same experimentation.
Similar ideas were tested, with the difference that in this chapter visual support were added as an additional incentive for participants to move around.

In other studies [79], visual support are coined as **advance organizers** and are considered to have an impact on the perception and effectiveness to integrate elements of knowledge more efficiently than without visual support [79]. This capacity to recall information in the learning phase [80] shows the effectiveness of using visual support as a strong cues for recalling memorized elements of knowledge.
Similarities could be drawn for chapter five and six considering the way participants would want to prioritize a clear view of the visual supports presented to them.

The results of this first experimentation are not moot as they can be applied to visual content and geometry that works in tandem. In specific cases, these types of combination (a set of rules and some objects) could be applicable, and the use of blindspots and larger objects could be applied to propose meaningful experiences.

If similar tests needed to be re-ran, a larger variation of the objects sizes in both tests could allow for a novel angle of approach. Would participants experience the same type of blind spot in test one if they were to move around a small object. Will test two even be possible if the objects were larger and taller, physically limiting what could be seen by the participants.

These observation were applied to the redesign version of this experiment, previously demonstrated in chapter four.

A noticeable piece of comment that were spoken by several participants could be tied to the next set of experimentation presented in chapter six. For test one, it was said that object three had striking resemblance to a mountain while the fourth object (the bridge) looked like a cave. These properties could be tied in with the proposal that the geometry of an object could carry some cognitive load and meaning for participants, and if used correctly could reduce some load off the cognitive process of discovering new content.

Chapter 6

Effect of visual support and interface affordance

This chapter presents the third experimental test of this study and its following results and analysis. The first section describes the research hypothesis and preliminary work done on building the objects that will be used for the experimental process. The second section introduces this experimentation aim, objectives and general proceeding. The third section describes the component of the experiment as well as the pool of participants and the set of tasks they were asked to perform. Section four explains in detail how the experiment was conducted, performed and recorded. Section five presents the experiment results and its analysis. Finally section six proposes a discussion on the proceeding of the experiment, its results and possible evolution.

6.1. Research question

As a reminder of what has been stated in section 3.4, the following is the hypothesis and elements of study for this chapter:

> H2) User can match digital task to corresponding object's geometries, either for practicality or enjoyment.

This parameters will be concerning the types of interfaces' geometry as well as what sets of tasks could benefits the most from this? Could visual support be an aid to the interface geometry or parasite mental abstraction?
To answer these questions, a set of nine tasks, usually performed on a computer or tablet pc were selected in addition to three displays made out of paper (30 cm x 30 cm) each representing the following idea (see figure 6.1):

- A flat display to be used as a control surface
- A display shaped like a mountain to determine it geometry and mental abstraction could match
- A split surface to determine if visibly separated area of a display could invite user to segment their interpretation of an action.

This version of the experimentation presented here is the final combination of two similar experimentations and the results presented in section 6.5 will be a combination of both.
Both experimentation are following an identical process to the one described in this chapter. Test began with experiment one and were only conducted on two age groups, young adult and children. It also differs in the use of visual support, in its first iteration only the children group performed the experiment twice, once without visual support and once with visual support. Due to the effectiveness of visual support in some cases, it was decided to introduce it for older age groups as well. The full proceeding of the complete experimentation will be described in section 6.3.

Similar to the first experiment described in the previous chapter, decision was taken to build a series of objects, three of them, each having distinct geometries. Having been proven useful in the previous chapter, one of these three object was used as a constant (flat topology), on which the affordance of the two other object would be compared to.
In this experiment, we choose to call these objects displays, in relation to the selection of relevant tasks usually performed on a tablet pc or computer. This was in an attempt to edge closer to behavior and cognitive process closer to some observable in a daily environment (real life, not simulated).

An other important step in gathering more relatable data was to broaden the scope of participants to other age groups. In this version, in addition to the original young adult (students) group, a children group (primary school students) and adult (office workers) were added.

This was for two reasons; 1) to gather data on the key subject of our study (processing cognitive load), comparing children to adults and 2) broaden the age range and proficiency of participant to observe possible fluctuation in experiment results (pre-existing knowledge).
To solidify the findings, we also extended the amount of total participants to 105 participants.

6.2. Research aim and objective

This experiment has for objective to determinate if participants of different age groups perceive abstract object similarly. It also aims at defining if visual support could have an impact on participant's perception of an object's volume, and to what extend one would interfere with the other. To do so this chapter will describe one test (performed six times), ran across three age groups, with and without visual support. Its content is as follow:
The nine tasks were chosen specifically to represent particular ways of using a device, either in a active (directly interacting with the content) or passive (simply looking at the content) way. They were also chosen to be as non-specific as possible to an age group, although some adjustment were made. These tasks were also chosen for their simplicity and commonality, most participants probably aware of what each tasks would be. This is in order to reduce the possibility of miss-interpreting one of the task and impacting their effectiveness in the experimental process. The list below represents the set of nine tasks chosen for this experimentation:

- Reading
- Typing
- Writing
- Watching video
- Playing video game
- Geographical map
- Weather forecast
- Social media or browsing internet
- Working or doing schoolwork

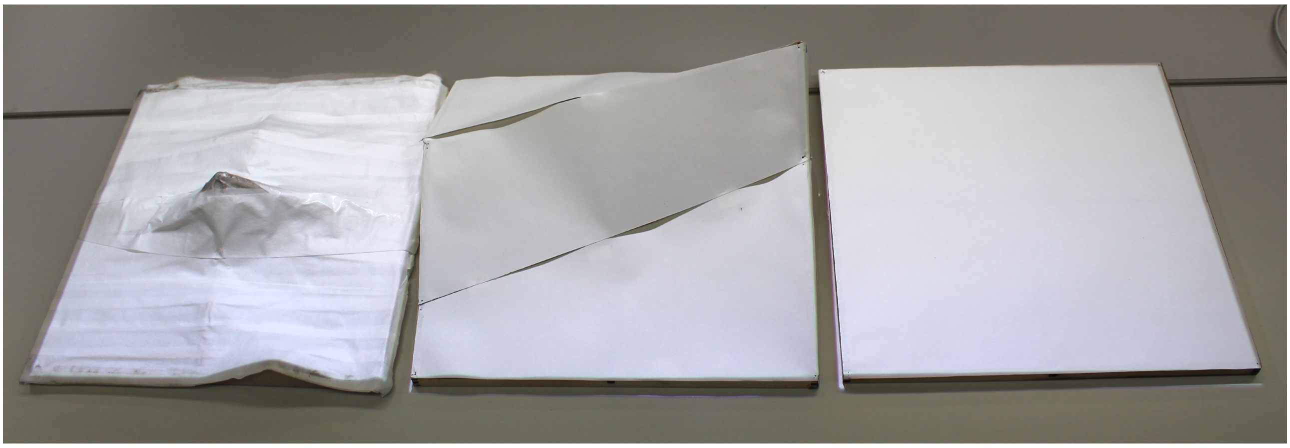

Figure 6.1. Series of three display built for the second experiment. (From left to right), mountain display, split display and flat display.

Adjustments were made for some age groups. Doing schoolwork applied to both children and young adult group but not adult group, so for them it was mentioned as "Working". Due to the young age of the children participants, the task of "social media" was mentioned as "browsing internet".
In addition to these, the choices of some tasks were specifically oriented toward a particular geometry of display. This was in an attempt to observe if a given geometry could trigger "matching" task. The pair of display and task are: Typing with the split display. This display having a small inclination, it was assumed it could be used as a hand support (similar to a type writer). This is also why the difference was made between Typing (keyboard) and Writing (with a pen). An important

element was to see if the affordance of the display (ergonomic) could communicate to the user this similarity to a hand rest. The second geometry specific task was the geographical map and the mountain display. This being one of the key aspect of this experiment in observing if participants would find a connection between the content of a map and the model of a mountain.

As mentioned in section 6.1, during a first attempt of this experiment tests were ran on both young adult and children groups. All participants had to face all three blank displays and provide their answers. At that time it was assumed some children might not be able to perform a suitable level of abstraction and thus resulting in them not understanding the tasks to perform. A second version of the task was developed for the children group were they had to perform the task twice. The second time would feature images projected from above (video projector) and would propose a visual support for all nine tasks. Afterward it was decided to extend this experimental protocol to other groups as well.

The experiment proceeding would be similar for all three groups.
Each participant, after being seated in front of the three displays, was asked to take a good look at each displays and successively indicate which display would be the most suitable to perform each tasks. The questions were asked one by one, in order to provide enough time for each participants to figure out which display would fit the best Typing or Watching a video.
Once completed, the same set of nine questions were asked, having each participant participating twice in the experiment. For the second attempt, visual support representing each tasks were projected on the three surfaces, providing support for all participants to gather a better understanding of the task they could be performing, see figure 6.2.

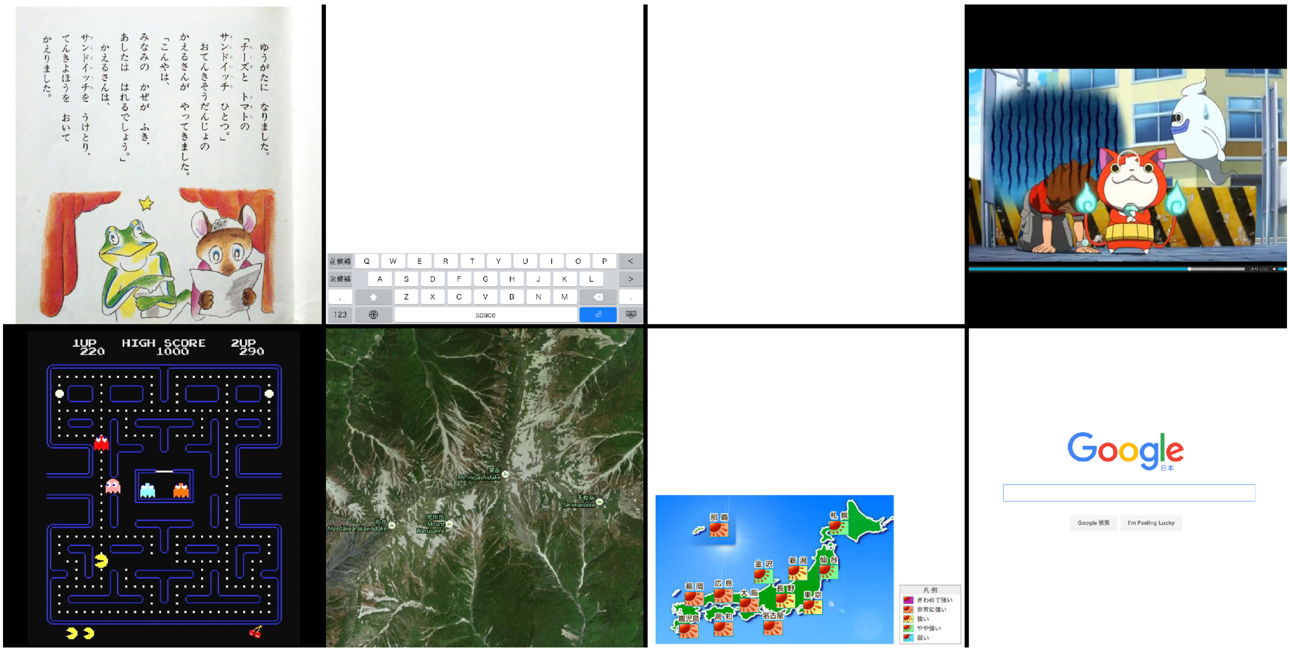

Figure 6.2. (From left to right, top to bottom) visual support chosen for all nine tasks, 1) Reading a book, 2 and 9) Typing / working, 3) Writing (blank space to represent a white page), 4) Watching a Video, 5) Playing video game, 6) Geographical map, 7) Weather forecast, 8) Browsing internet.
Source in Order; Google image search, Apple, Level 5 and Yokai Watch, Namco and Pac-Man, Google map, Google image search, Google.

From this experiment proceeding, it was assumed that most participant would choose the flat display for non specific tasks, but would choose the mountain display for the geography related tasks (Geographical map and Weather forecast) and the split display for Reading and Typing.

As a brief summary, the ideas proposed for this experiment are an attempt to answer the following hypothesis:

> H2) User can match digital task to corresponding object's geometries, either for practicality or enjoyment.

The proposition to answer this question is: Can related content be perceived as suitable for display with a given geometry? To what extend visual support might have an impact on object perception?

6.3. Research method

Section 6.2 introduced the assumed way this experiment will be performed by the participants. The experiment will be composed of three displays and one video projector. The participants will be seated in front of the three aligned displays. As described in the previous section, participants will be asked to match nine common tasks usually performed with a tablet pc or computer to one of the proposed three displays. This will be performed twice by each participants. Once without visual supports and once with. The participants were also asked to express the reasoning behind their choices.

The pool of participants was composed of 105 participants, each part of three distinct age groups, with a repartition of 51 children (31 girls and 20 boys, from age 7 to 10 years old), 38 young adults (10 women and 28 men, from age 22 to 30 years old) and 16 adults (15 women and 1 man, from age 31 to 54 years old). All participants were fluent English speaker or had a native Japanese translator to ensure the instruction were clearly understood. Each participants signed up voluntarily for the experiment. Children were from the Children's house in Miyatake and Terai center children's house, see figure 6.3. The students were from the JAIST student body. The adults were office workers from the Secretarial Service Department at JAIST.
We chose not to work with children younger than 7 years old to avoid, or at least reduce, any possible misinterpretation or cognitive shortcuts when given the task to analyze the features of a given object's geometry [19 p.46 - p.47], in our case displays.

Figure 6.3. Picture taken from the Terai center children's house, representing how the experimentation was conducted.

6.4. Experimentations

For both test (with and without visual support) these elements will be looked into 1) how displays and tasks will be matched, 2) possible fluctuation once visual support are added, 3) Reasoning behind their choices (I chose this one because…)
The overall experimentation time was around 20 minutes per participants, roughly 10 minutes each section of the test.

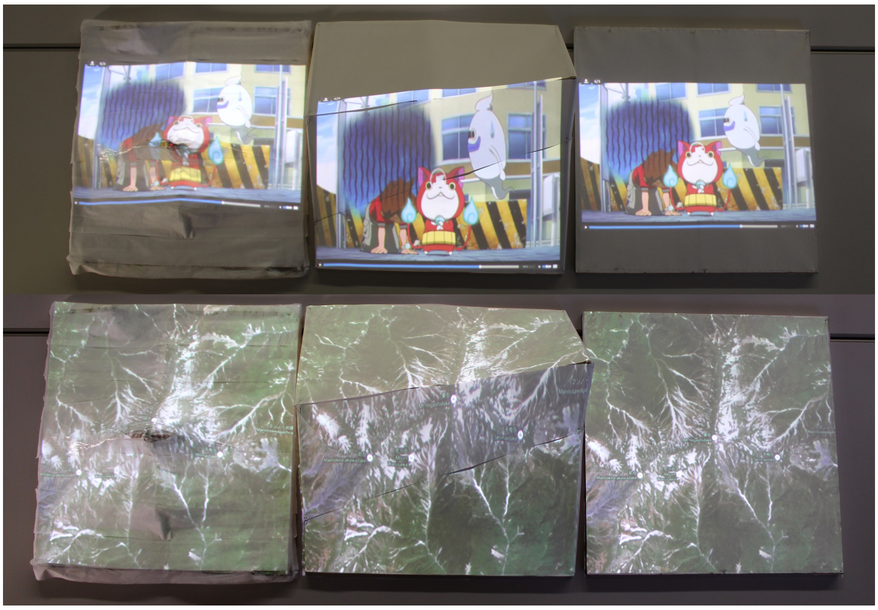

Figure 6.4. The three displays with visual support projected on. (Top) visual representation of the task “Watching video” and (bottom) visual representation of the task “Geographic map”.
Source top images Level 5 and Yokai Watch, source bottom images Google map.

As stated in the previous sections, participant will be taking this test individually. Unfortunately, due to time restriction for the adults (possibility to run tests during lunch break only), their experiment was conducted with four to five participant at a time. Similarly to the individual experiment, all participant in those four/five persons groups were gathered facing the three aligned displays.
Following is a rrecollection of all six tests, all three groups tested twice:

Although with a relatively large array of participants, in general similar behaviors were observed throughout all groups. The detailed results of this test will be presented in section 6.5.
Having chosen a relative small size of display (30 cm x 30 cm) to match the size of a potential tablet pc, all participants were seated closely to the desk or table where all three displays were aligned.

All tests went smoothly once the instructions were clearly understood by each participants. After spending a short moment explaining what was expected from them, meaning being able to consider an object made out of paper as the potential representation of a display, the matching of tasks and displays became simple. Even for children, where it might be assumed the most trouble could have been encountered, the task was rapidly understood after a short explanation.
Unlike the experiment presented in chapter four, here the understanding of the tasks and the approach to the displays were linear and stable throughout the entirety of all tests once the explanations were understood.
A noticeable change in the participants’ behavior was visible once the experimentation with visual support started. They showed an increased accuracy in their reasoning and answer as well as a sudden focus on readability and visibility. Most answers in the test without visual support were oriented toward more personal interpretation of the displays and what sort of tasks they could project themselves performing.

This change was expected and was part of the choice of adding visual support for all groups. Could visual support aid or parasite the interpretation of the displays’ geometry?
This experimentation was design to study the mental process of the participant rather than their behaviors and body language. Due to this focus, there was not much change in behaviors beside a noticeable one for the children: Once the second experimentation would begin and the first images would be project on the displays, almost all of the children corrected their seating position and sat upright, leaning closer to the displays than in the first part of the test.

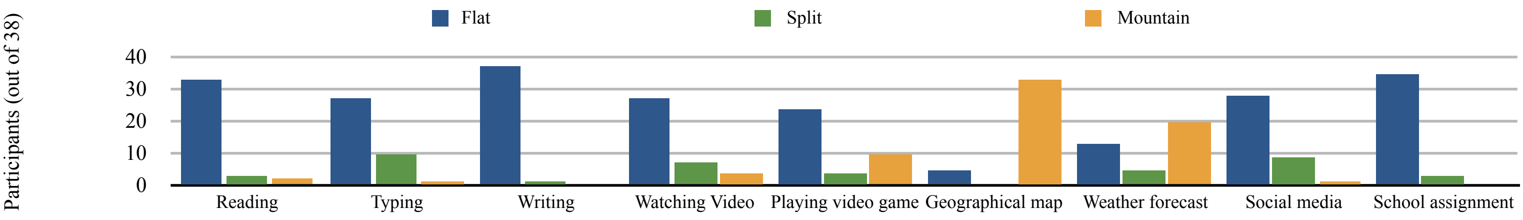

Figure 6.5. Results from the experiment with the young adult group without visual support.

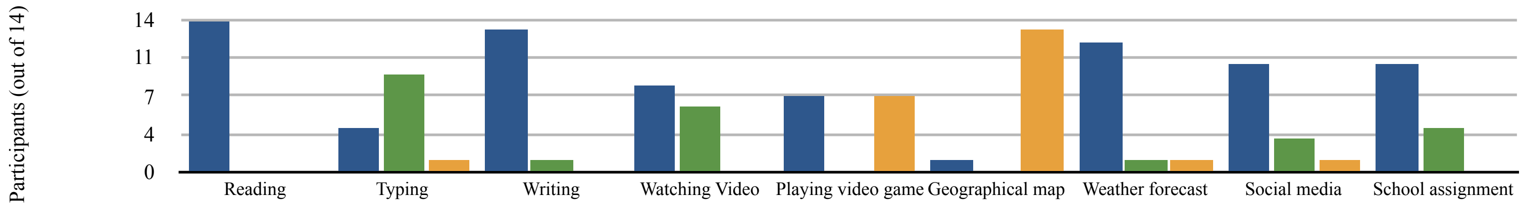

Figure 6.6. Results from the experiment with the young adult group with visual support (from a video projector).

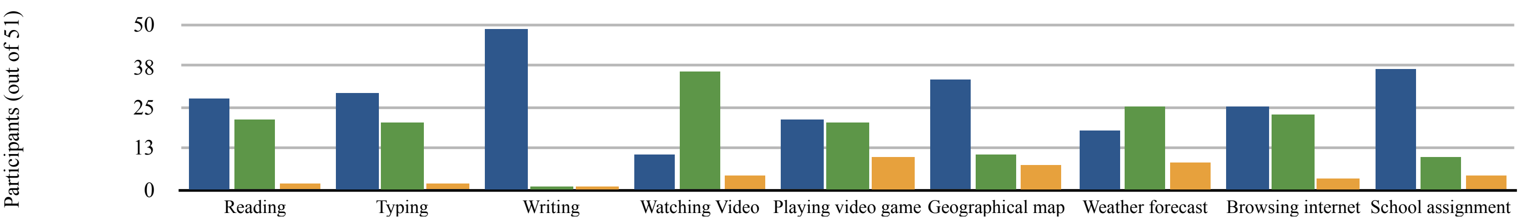

Figure 6.7. Results from the experiment with the children group without visual support.

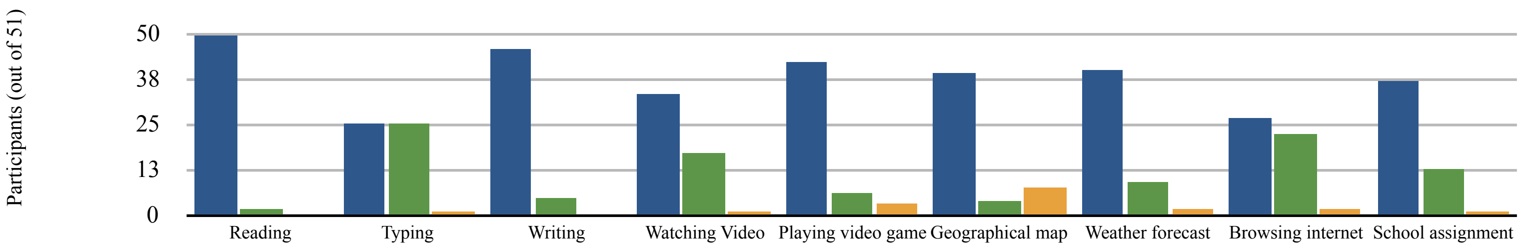

Figure 6.8. Results from the experiment with the children group with visual support (from a video projector).

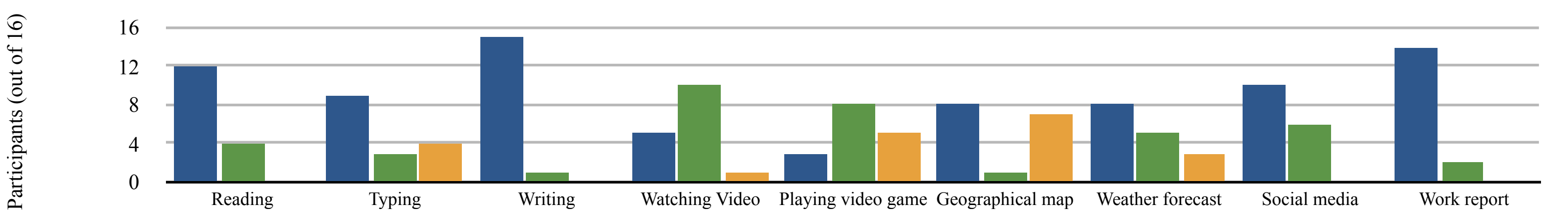

Figure 6.9. Results from the experiment with the adult group without visual support.

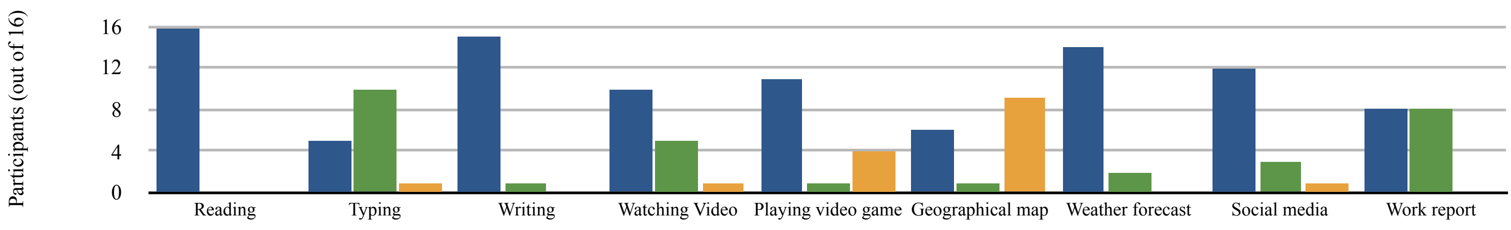

Figure 6.10. Results from the experiment with the adult group with visual support (from a video projector).

The next section will describe in details the data observed during all the tests, but as a general observation it can be said that, all participants and for both test, showed some unexpected interpretation of the displays' geometry and how it could be connected to a given task.

6.5. Results

The results of all tests have been combined in figure 6.5 to 6.10 and the comments provided by participants, regarding the split and mountain displays, are compiled in table 6.1.

For the six figures above, the vertical axes represent the number of participants in each group and the horizontal axes represent the nine tasks proposed to each participants.

With regards to our decision to experiment with children not younger than 7 years old, we can note that the understanding of abstraction is not linear in child development, and children of similar ages might have unequal abilities to understand abstraction [19 p.77] which might result in some fluctuation in the interpretation of the displays' for some children participants.
Prior to analyzing the data, it has to be noted the amount of young adult in figure 6.5 and 6.6 are not identical. As explain in a previous section, this is due to the combination of two separate set of tests, one ran before the addition of testing visual supports for all groups.

Interpretation of the displays' geometry without visual support:
It is interesting to note that each age groups had a different focus on their interpretation of the displays.
- Young adults showed a remarkable correlation of the mountain display and Geographical content Weather forecast in a smaller degree but did not show much interest in the split display. The majority of the answer were oriented toward the choice of the flat display, mostly because it simulated a screen or tablet pc and seemed more familiar than the two other "unusual" displays. Contrary to the mountain display, our preliminary statement that the slanted surface of the split display could be used as a hand rest in case of typing was not as much perceived as expected.
- Children did not pay much attention to the mountain display but showed an interesting and slightly unexpected interpretation of the split display. As seen in figure 6.3. they associated it with six out of nine tasks counting the task of "Typing", with Watching video and Weather forecast being the prime choice of this group. Their reasoning behind it revolved around the slanted surface of the split display and how it could be perceived as a screen angled toward them. Being angled this way meant for them they could have a good head posture and not pull on their neck. This could be considered as the children making a connection between comfort of use and the geometry that could propose them the most comfort.
- Adults presented the same interpretation of the split display for the tasks of Watching video and Video game, with an interest of matching Geographical content to the mountain display, see figure 6.9 and 6.10.The rest of their choice being centered around the practicality of use provided by the flat display. Similarly to the two other groups, the split display was not perceived as a suitable choice for typing.

Interpretation of the displays' geometry with visual support:
An overall tendency that can be observed is the increase choice of the flat display once the participant had the visual support projected.

- Young adults kept and interest for viewing a Geographical map on the mountain display, general comment indicated that the visual support of the map was more understandable with this display. Some comments also indicates that if the mountain display could dynamically changes its shapes and for example follow the terrain of the map would make it even easier to understand. For the task of typing, the split display was preferred with comment indicating that the lower raised part of the display could be used a hand rest/support (ergonomic). There were some interesting interpretations of how a game could be played on the mountain display, once again indicating that if the display could change its shape, it would make the gaming experience more entertaining. Overall the flat display was selected for most tasks since the other two displays were introducing too much deformation on the content being projected, rendering it difficult to read.
- Children made a massive switch to the flat display, see figure 6.7 and 6.8. Similarly to the young adults group indicating that the images project on the split and mountain displays were too distorted and unreadable, see figure 6.4.Typing and Browsing internet were attached to the split display, children also indicating that the space on the lower part of the split display could be used to place their hands.
- Adults gave a similar set of answers, with comment on readability and visibility guiding their choices for the flat display. The geographical map was considered more understandable once the volume of the display matched the content being projected. Being office worker and seeing a keyboard on the lower part of the lower raised part of the split display motivated their choices to select the split display for Typing.

Participants interpretation of the display's geometry:

Table 6.1. Comments gathered from participants and their interpretation of display's geometry.

	Split display	Mountain display
Young adults	- The angled screen is better for watching a video. - Top part could be a screen and bottom part could house the button or controller in case of a video game. -The volume could be used as a 3D representation of graphs for weather forecast. - Each part could be used to display slices of a landscape: Land, rain snow or wind, sky. - Could be used to have content of different kinds (categories, information) on each surface for social media. -The different areas of the display could represent content organized by country (Facebook contacts from different countries in that case). - It could be used to protect your information, with the blind spot the geometry creates, you can hide your private information from others (referring to the front of the display, hidden when a second viewer is facing from the opposite direction). - The content on the display could be split, top part is for screen and bottom part is for typing.	- The surface could be dynamic to amplify player emotion in a video game. - The volume could have more impact with a 3D effect to make the game look more real. - If it's a game with a mountain scenery, it would be easier to understand how to play the game.
Children	- Easy to look at with the slanted surface for a book or a text. - It looks like a small television so it's probably easier for watching video. - It looks like a small television, it reminds me of my television in my home when we watch weather forecast.	- If the display was much bigger, we could sit on a small mountain and watch the video on one of the bigger mountains, like a large couch to watch TV. - The forecast could be divided into each town if the geometry of the display could be changed to match the real cities' topographies. - The mountain can represent a country. If it's raining on the map, it's easy to understand where it is in the real world. The higher the mountain elevation goes, more clouds could be visible. Displaying the different layers of cloud depending on their position (elevation) in the sky.
Adults	- Easy to look at with the slanted surface as it look like a mini television for watching videos. - The slanted part of the screen can be used as a support for my hand. The shape looks like a keyboard in a way.	- If the shape of the map can change according to the mountain images projected, it could be easier to understand the geography of an area compare to a regular map

Overall, the proposed combination of mountain display and geographical content as well as split display and Typing was well integrated, see table 6.1. In both cases, participants proposed interpretations of the tasks that corresponded to the preliminary statement developed as the base of this experiment. 1) The geometry of an object and its abstraction can be related to tasks using related subject. 2) Local areas of an object could be interpreted as suitable for tasks requiring particular need.

It should also be noted that visual support seems to have a stronger impact on object perception than the abstraction of the object, participants almost consistently choosing the display where the content would be the less deformed or distorted.

Interestingly there were answers specific to each group, children showing as expected being less prone to abstraction and focused more on practicality and readability. It should be noted that JAIST being an environment were students research advance topics, their proficiency in finding original way of interpreting abstract concept could be based on their proficiency in advanced studies. It also should be noted that participating as a group rather than individual, adults participants did not have an opportunity to seat right in front of the displays, so it should be considered that their perception could have been marginally altered. Most of them did stand up and move around to get a better point of view of all three displays, more specifically with the visual support projected.

6.6. Discussion

The behaviors observed during the experiment process as well as the results point toward confirming the previously stated proposition:

> H2) User can match digital task to corresponding object's geometries, either for practicality or enjoyment.

The proposition to answer this question was: Can related content be perceived as suitable for display with a given geometry? To what extend visual support might have an impact on object perception?

Regarding the size of our participant body of a 105 participants, it can not be entirely confirmed but we can assumed the result presented in section 5.5 are a representation of legitimate behaviors. As noted, the main development of this experiment was the scale at which visual support impacted on the perception of objects' affordance and their potential to communicate abstract concepts, regardless of the age groups. The majority of the comments revolved around the poor readability of the content projected and how unsuitable the split or mountain surfaces were for some subjects. This was in stark contrast from some comments receive during the test without visual support, comments centered around how participants could see themselves interacting in some manner with the split display or mountain display.
One example of this behavior was from a boy, who had chosen the mountain display as a support for Geographical content without visual support but had switched to the flat display once the visual support were projected. His reasoning behind his thinking was that what was projected no longer corresponded with the idea he had made himself of the map.
This behavior was observed on other participants from all age groups but was mostly present in the children group.
In a previous unrelated study, the same comment had been observed from children. In this case children were asked to build a castle out of wooden block. The solution developed at the time was to reproduce dynamically the assembly of block the children were creating and generate a 3D version of that castle. In this 3D version, the basic wooden block were replaced by "realistic" models. Children had indicated they did not really like the 3D end result because it was not corresponding to the castle they had created in their imagination [63].

To prevent some potential error in the analysis process of this test, six ANOVA analysis were ran to try and define if the parameters of the test (interpretation of each tasks, without or with visual support) could be considered to be significant or not.
All six analysis were set up to verify any potential effect of the nine tasks and their potential interpretation on participants answers. The possibilities are either the mental representation of each tasks has some effect, or participants results are similar and the types of actions does not have a noticeable impact on their answers.
For these, a two way analysis was achieved, participant's answers entered as results, each participants entered as factor #1 and the different tasked completed (all nine tasks) as factor #2.
The relevant p value to look for here is the factor #2 value, indicating if the changes in tasks could be considered as the reason for participants varying answers.
As described in section 4.6, any value superior to 0.05 would indicate that regardless of the change of display, participant's answer would be similar.

Table 6.2. Analysis of variance for the young adult experimentation without visual support.

ANOVA							
Source of Variation	SS	d.f.	MS	F	p-value	F crit	Omega Sqr.
Factor #1 (Participants)	25.00585	37	0.67583	1.93342	0.00151	1.45128	#N/A
Factor #2 (Test)	98.53216	8	12.31652	35.23501	0	1.96974	#N/A
Within Groups	103.46784	296	0.34955				
Total	227.00585	341	0.66571				

Table 6.3. Analysis of variance for the young adult experimentation with visual support.

ANOVA							
Source of Variation	SS	d.f.	MS	F	p-value	F crit	Omega Sqr.
Factor #1 (Participants)	7.11111	13	0.54701	1.79200	0.05381	1.81541	#N/A
Factor #2 (Test)	38.25397	8	4.78175	15.665	0.00000	2.02865	#N/A
Within Groups	31.74603	104	0.30525				
Total	77.11111	125	0.61689				

Table 6.4. Analysis of variance for the children experimentation without visual support.

ANOVA							
Source of Variation	SS	d.f.	MS	F	p-value	F crit	Omega Sqr.
Factor #1 (Participants)	40.14379	50	0.80288	2.48664	5.64858E-7	1.38266	#N/A
Factor #2 (Test)	24.62745	8	3.07843	9.53441	4.22921E-12	1.96156	#N/A
Within Groups	129.15033	400	0.32288				
Total	193.92157	458	0.42341				

Table 6.5. Analysis of variance for the children experimentation with visual support.

ANOVA							
Source of Variation	SS	d.f.	MS	F	p-value	F crit	Omega Sqr.
Factor #1 (Participants)	32.46187	50	0.64924	2.91957	2.84231E-9	1.38266	#N/A
Factor #2 (Test)	11.49455	8	1.43682	6.46125	6.43460E-8	1.96156	#N/A
Within Groups	88.94989	400	0.22237				
Total	132.90632	458	0.29019				

Table 6.6. Analysis of variance for the adult experimentation without visual support.

ANOVA							
Source of Variation	SS	d.f.	MS	F	p-value	F crit	Omega Sqr.
Factor #1 (Participants)	12	15	0.8	2.08696	0.01481	1.75050	#N/A
Factor #2 (Test)	17.55556	8	2.19444	5.72464	3.59698E-6	2.01643	#N/A
Within Groups	46	120	0.38333				
Total	75.55556	143	0.52836				

Table 6.7. Analysis of variance for the adult experimentation with visual support.

ANOVA							
Source of Variation	SS	d.f.	MS	F	p-value	F crit	Omega Sqr.
Factor #1 (Participants)	13.21528	15	0.88102	2.91871	0.00058	1.75050	#N/A
Factor #2 (Test)	18	8	2.25	7.45399	4.93924E-8	2.01643	#N/A
Within Groups	36.22222	120	0.30185				
Total	67.4375	143	0.47159				

All 6 analysis results, see table 6.2 to 6.7, tend to show that during each test the parameters of factor #2 (interpretation of each tasks, without or with visual support) are sufficient enough, with a variance of p=0.001.
This can indicate that the change in tasks do have an impact on participants interpretation of an object.

During this series of tests, it was assumed that participants could perceive the potential functionality of an object through different level of abstractions. For the classification of objects, all three displays, although part of the same group of object all had different surface geometry and complexities. According to Rosch, E. [78], “Categories below the basic level will be bundles of common and, thus, predictable attributes and functions but contain many attributes that overlap with other categories (for example, kitchen chair shares most of its attributes with other kinds of chairs).”
Here the basic level of classification being all objects presented are displays, having in common the same functionality, the level of abstraction being the division of each display into three types of geometry, flat (simple), geometric (limited to few faces) and realistic (complex).
Similar to identifying that kitchen chair and desk chair although of the same group of objects carries meaning for their environment of use, the difference types of display could carry meaning for their potential use.

Additionally, as the participants’ answers shows, the relationship between the nature of the geographical content and the geometry of the mountain display were matched by the participants in both case of visual support or not. For the relationship between typing task and the split display, this idea seemed to be supported only with the addition of visual support, adding a layer of contextual elements and guiding more bluntly the interpretation of the split display’s geometry as suitable.

In addition, participants seems to be supporting the original proposition that the geometry of an object can support abstraction and the combination of digital content to the affordance of an object.

Chapter 7

Conclusion

This chapter presents the closing words of this study. The first section summarizes the results of all the studies and experimentations presented in previous chapters. The second section defines the contribution of this research to its respective fields of study. The third section presents the limitation encountered in this study and the possible work based upon these learnings. Finally, the fourth section opens the perspective of further projects by introducing future prospects in the field of design for entertainment and museums.

7.1. Summary

The study presented here was an attempt at verifying the following hypothesis:

H1) The volume (dimensions) and geometry of an object (interface) has an impact on the participant behavior (movement around the object).

H2) User can match digital task to corresponding object's geometries, either for practicality or enjoyment.

From two base educational environments of study, a case study analysis of exhibition was conducted to detect and define what would constitute a suitable exhibition environment and how could these guidelines be applied to the design of tangible interface aimed at promoting discoverability and a reduced cognitive process. A clear access to the content, with enough visibility and freedom provided to the visitors were elements observed during these exhibitions and applied to the design of preliminary ideas. Through these ideas, basic understanding and hypothesis were proposed, this resulted in the creation of three separated experimentations.
The first experiment, a simple version of the second experiment resulted in the following findings: the geometry of an object will have an impact on how participants behave as long as the object's geometry strongly communicates on its "function" (for example inviting people toward the shortest side of the L shaped object in chapter four). There can also be an assumption that large or smaller object will invite participants to look closer or further away. This might not be entirely correct as the simplicity or complexity of the geometry could also play a role in influencing participants behaviors.
The second one resulted in the following assumptions: with suitable verbal indication, the volume of an object might have an effect on users behavior in space (free or constrained), enjoyment of a tasks and work as an invitation to discoverability. A key guideline to this is the creation of blindspots or physical barrier (from the object's geometry) that would invite users to perform and move in a certain way.
After reconsideration, this experimentation did not really confirm a relation ship participant/object/space, but further indicated as sated with experiment two that visual support can override the potential cognitive load supported by an object geometry.
The third experiment resulted in the following findings: with a corresponding pair of content and physical abstraction (in the shape of a display), users might be able project their interpretation of the subject onto the object geometry and imagine on their own the sort of actions achievable, in a way reducing the cognitive process at play by leaning more on the object's geometry.
A second finding was the importance of visual support in mobilizing the attention of the users and reorienting their interpretations of an object by instead focusing on clarity and readability of the content.

7.2. Discussion

The starting point of this study was to explore the potential relationship between object and user, not only by the physical manipulation of the object but the perception of the object itself. That question intrigued me, because as explain at the beginning of this study, whereas affordance is understandable for object with identifiable functionalities, tangible interfaces and digital content don't properly own a physical representation. Being able to understand and appreciate the functionality of digital content through a physical representation might also help user connect with that object. Connect not only mentally in term of what's achievable, but also emotionally. What would be the best way for you, the user, to use this object, and could you enjoy it?

While proceeding with the preliminary studies of chapter three and four, the interpretation of the potential connection user/object grew into two complementary subjects:
- The relation user/object/space that would focus on how the shape of an object could influence user movement around the object.
- The perception of object abstraction and how users could project themselves using that object.
Results from both subject across three experimentations points toward this idea, that the shape of an object, however abstract, can influence how user perceives it and behave around it.
If the object has a visual opening into it, user may be tempted to look in that precise area. When given the task to interpret the potential usability of an object (connecting an action with an object geometry), user perception is being oriented by the shape of the object. It should be noted that for an identical task, providing users with a visual support will greatly impact the users' perception of the object.

If there is just an object, user might be tempted to project innovative ways of interacting (if the shape is ergonomic, I could rest my hand there). By introducing visual support, user switches their attention to visibility and readability, disregarding the geometry of the object as a distraction if it interfere with the access to the visual imagery. This idea echoed the experimentation from chapter five and seven, both testing the same idea, but the first experimentation relying on visual support.
Both experimentation ran with visual support shares similarities in participants focusing on reading properly the images projected, the shape of the object becoming secondary.

As it is, the goal of tangible interfaces shouldn't be to try and remove entirely the use of screens and projection. Visual clues can be very powerful in the appreciation of interactive process, so it could be considered that an effective tangible interface would allow for physical interaction, possess a shape that communicates properly on its interactive potential and use visual support to enhance the physical feature of the interface.
Result of chapter six shows that, if an object and its visual support share similarities (geographical map and mountain display) then participants shows a great interest in that combination, one element enhancing the other.

The principal drawback of this idea is based on the physicality of the object. As long as we are limited in the access to shape shifting interfaces, only niche situation would benefit from such interfaces. A company like Nintendo and their project Labo might have a solution, by proposing disposable interfaces (made of cardboard) with a versatile hardware that can be used in a large array of situation. For installation in museum, such system could be justifiable as there is only a need to cater to a specific set of action and content to be provided to visitors.

Having been able to test across different age group, result might indicate that while the capacity of each groups to perceive potential function of an object is not limited by their age, the interpretation of these functions are varying with the age of the participants. Younger participants had the tendency to focus mainly (but not exclusively) on practicality, accessibility and comfort of use while their older counterpart would propose more innovative perceptions and interpretations of similar objects.

The following section will present how these findings are applicable to its related fields of study.

7.3. Contribution

The following three points were to be considered for applicable contribution to the field of interaction design:

Novelty: Approaching this subject with in mind the clear goal of defining underlying properties and relationships between an interface, its geometry and the user's behavior. It is also considering the approach that, with ever increasing complexity of interaction processes, how could interfaces be designed to both accurately represent their content and connect meaningfully with users.

Originality: The combination of designing interfaces and displays with in mind the goal of focusing on the cognitive process involved in the interaction process.

Applicability: With a focus on discovery of new content, this study aims at providing new ideas for the creation of interfaces and interactive systems that would entice users to be curious and push for discovery.

Considering that with user being able to abstract meaning from object (that are not carrying exact representation of a subject), the definition of tangible interfaces could be refined by considering the following guidelines for their design:

> **Visibility**: User will favor visual content (imagery) and won't focus as much on analyzing the potential interaction of an object.
>
> **Readability**: If information need to be displayed, there has to be a suitable area of the object for that, preferably away from the elements user are interacting with.
>
> **Posture**: The geometry of the object would invite participants to discover potentially hidden features of the object (the object needs to visually indicate that).
>
> **Rhythm**: Instead of evenly spreading visual cues all around, the creation of point of focus will help the user to experiment with that group of action (related to visibility and how visual cues can override participants perception).
>
> **Recognizable**: If its visibility is not impaired by visual support, user will be able to connect the shape of an object with a digital content.

The definition of these five potential guidelines stems from the result of all three experimentations as well as the integration of known rules, but applied to tangible interfaces for this study. Some of the eight golden rules of Ben Schneiderman [77] can be used as a reference to validate or counterbalance some of the guidelines proposed above.

The rules **Strive for consistency** (utilization of familiar icons or known elements) and **Reduce short-term memory load** (recognizing something is simpler than recalling a memory) can be related to the proposed **Recognizable** guideline: The general idea is that users have the potential to recognize known shapes or concept. This provides simplicity to the interaction process and help guide users in properly using and enjoying their experience.

His rules called **Offer informative feedback** (letting users know of what is going on) could be related to the proposed **Readability** guideline: Users will look for landmark or recognizable patterns, so making sure that the information given to them is clear enough would prevent them from being lost in their interactions.

Although not a direct product or interaction design rules, it's commonly accepted in graphic design and in advertising that strong lines in an image will guide viewers' sight across a picture toward defined target area (a product, a logo, graphics on a map, etc.), [81]. This can be related to the

proposed **Posture** guideline: Although from different media (2d for graphic design and tangible interfaces for this study), the general idea of guiding someone silently via the physical language of an object could have an impact on how users approach an object.
The following three point were to be considered for applicable contribution to the field of knowledge science:

1) **Knowledge creation process:** Could there be "simple" rule that can define the design of an interface suitable for curiosity and discoverability?

- The design guidelines presented in **Novelty** and **Originality** are not subject specific and could be applied to other mediums. It was presented in chapter five and six as games and completion of tasks, but their application to different medium on chapter six demonstrates the simplicity to create new knowledge by following these guidelines.

2) **Application of Knowledge across various discipline**: Could the rules developed from the above point be transferred to neighboring disciplines?

- This study could be applied to other disciplines in design, product design being a close neighbor to this subject. It could also be applied back to the field of exhibition presentation, providing simple key elements to follow to provide a "better" museum experience to visitors.

3) **Integration of ideation, creation and fabrication**: Knowing what the end result should look like, could the creation and development process be simplified and streamlined?

- Knowing that the subject can be directly represented by the interface and communicates properly on its content provides a clear path for the creation process. As long as a suitable set of content and interaction process are define (how to interact with the object, what to interact on), the only remaining part is to fabricate the interface.

The elements found in this study can easily be at first applicable to other branches of design, product design being almost a twin subject. Parallels can be drawn between this study and interior design or exhibition set up, the movement of visitors in space being associable with users being invited to move around due to a given geometry.

7.4. Limitation and future work

A key limiting element was the difficulty to access and reach the environment in which a project proposal could be integrated into. This in combination to finding appropriate experiment candidates could be considered the limiting parts of researching educational environment with children as the primary subject.
Future iteration of this study could be based on, with a bit or perseverance, trying to integrate a working prototype based on the proposed guideline in section 7.2 in one of the chosen environment of study.
It seems also relatively difficult to disturb a traditional classroom schedule to integrate an experimental process. By running experiment with children participants in an environment such as an after-school program (chapter six), there is a possibility that the children mindset is not similar as in a classroom. Children may be more relaxed, feel less incentive to answer questions since there is not any grading provided in the end. Testing general behaviors is suitable for this types of after-school environment, but in the case of an actual prototype designed to observe how school subjects could be presented, it might require to be integrated in an actual classroom schedule, if educational environment are chosen as a suitable environment.

This study relied purely on a one-on-one interaction process between the object and the participants. An additional step for a future work should be to run similar experimentations with groups of participants of various sizes. In the case of children, they are hardly ever alone during the visit of a museums or the discovery of a new subject in class.
Other environment of work could be looked into, in an attempt to apply the knowledge learned during the development of this study to broader subjects.

Bibliography

[1] Norman, D. (2013). The design of everyday things: Revised and expanded edition. Basic Books (AZ).

[2] Ratti, C., Wang, Y., Ishii, H., Piper, B., & Frenchman, D. (2004). Tangible User Interfaces (TUIs): a novel paradigm for GIS. Transactions in GIS, 8(4), 407-421.

[3] Dalsgaard, P., & Halskov, K. (2014). Tangible 3D tabletops. interactions, 21(5), 42-47.

[4] Resnick, M., Martin, F., Berg, R., Borovoy, R., Colella, V., Kramer, K., & Silverman, B. (1998, January). Digital manipulatives: new toys to think with. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 281-287). ACM Press/Addison-Wesley Publishing Co..

[5] Ryokai, K., Marti, S., & Ishii, H. (2004, April). I/O brush: drawing with everyday objects as ink. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 303-310). ACM.

[6] Muratsu, K., Ishiyama, A., Kusunoki, F., Inagaki, S., & Terano, T. (2014, June). StampOn in a museum: helping children's scientific inquiry. In Proceedings of the 2014 conference on Interaction design and children (pp. 233-236). ACM.

[7] Thébault, P. Bihanic, D. Samier, H., and Richir, S. The bridge between physical and digital worlds: implication for the design of Internet-enabled products. In Proceedings of the Virtual Reality International Conference – VRIC (13th International symposium), Laval, April 6-8, 2011.

[8] Schoessler, P., Leigh, S. W., Jagannath, K., van Hoof, P., & Ishii, H. (2015, January). Cord UIs: controlling devices with augmented cables. In Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction (pp. 395-398). ACM.

[9] Raffle, H. S., Parkes, A. J., & Ishii, H. (2004, April). Topobo: a constructive assembly system with kinetic memory. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 647-654). ACM.

[10] Ogata, M., & Fukumoto, M. (2015, April). FluxPaper: reinventing paper with dynamic actuation powered by magnetic flux. In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (pp. 29-38). ACM.

[11] Weiser, M. (1999). The computer for the 21st century. Mobile Computing and Communications Review, 3(3), 3-11.

[12] Greenfield, A. (2010). Everyware: The dawning age of ubiquitous computing. New Riders.

[13] J. Bleecker. A Manifesto for Networked Objects – Cohabiting with Pi- geons, Arphids and Aibos in the Internet of Things – Why Things Matter What' s a Blogject? What about Spimes? Proc. of the 13th International Conference on Human-Computer Interaction with Mobile Devices and Services, MobileHCI. September 2006.

[14] Sterling, B. (2005). Shaping Things (Mediaworks Pamphlets).

[15] Leithinger, D., Follmer, S., Olwal, A., & Ishii, H. (2014, October). Physical telepresence: shape capture and display for embodied, computer-mediated remote collaboration. In Proceedings of the 27th annual ACM symposium on User interface software and technology (pp. 461-470). ACM.

[16] Tuddenham, P., Kirk, D., & Izadi, S. (2010, April). Graspables revisited: multi-touch vs. tangible input for tabletop displays in acquisition and manipulation tasks. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 2223-2232). ACM.

[17] Bonawitz, E., Shafto, P., Gweon, H., Goodman, N. D., Spelke, E., & Schulz, L. (2011). The double-edged sword of pedagogy: Instruction limits spontaneous exploration and discovery. Cognition, 120(3), 322-330.

[18] Mitra, S., Dangwal, R., Chatterjee, S., Jha, S., Bisht, R. S., & Kapur, P. (2005). Acquisition of computing literacy on shared public computers: Children and the" hole in the wall". Australasian Journal of Educational Technology, 21(3).

[19] Houdé, O. (2015). Apprendre à résister. Le Pommier.

[20] Hattie, J., & Anderman, E. M. (Eds.). (2013). International guide to student achievement. Routledge.

[21] Ullmer, B., Ishii, H., & Jacob, R. J. (2005). Token+ constraint systems for tangible interaction with digital information. ACM Transactions on Computer-Human Interaction (TOCHI), 12(1), 81-118.

[22] Terrenghi, L., Kirk, D., Sellen, A., & Izadi, S. (2007, April). Affordances for manipulation of physical versus digital media on interactive surfaces. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 1157-1166). ACM.

[23] Ratti, C., Wang, Y., Piper, B., Ishii, H., & Biderman, A. (2004, August). PHOXEL-SPACE: an interface for exploring volumetric data with physical voxels. In Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques (pp. 289-296). ACM.

[24] Ishii, H., Ratti, C., Piper, B., Wang, Y., Biderman, A., & Ben-Joseph, E. (2004). Bringing clay and sand into digital design—continuous tangible user interfaces. BT technology journal, 22(4), 287-299.

[25] Piper, B., Ratti, C., & Ishii, H. (2002, April). Illuminating clay: a 3-D tangible interface for landscape analysis. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 355-362). ACM.

[26] Leithinger, D., Lakatos, D., DeVincenzi, A., Blackshaw, M., & Ishii, H. (2011, October). Direct and gestural interaction with relief: a 2.5 D shape display. In Proceedings of the 24th annual ACM symposium on User interface software and technology (pp. 541-548). ACM.

[27] Leithinger, D., & Ishii, H. (2010, January). Relief: a scalable actuated shape display. In Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction (pp. 221-222). ACM.

[28] Want, R., Hopper, A., Falcao, V., & Gibbons, J. (1992). The active badge location system. ACM Transactions on Information Systems (TOIS), 10(1), 91-102.

[29] Swan, M. (2012). Sensor mania! the internet of things, wearable computing, objective metrics, and the quantified self 2.0. Journal of Sensor and Actuator Networks, 1(3), 217-253.

[30] Hutchins, E. (1995). How a cockpit remembers its speeds. Cognitive science, 19(3), 265-288.

[31] Fishkin, K. P. (2004). A taxonomy for and analysis of tangible interfaces. Personal and Ubiquitous Computing, 8(5), 347-358.

[32] Kadomura, A., Li, C. Y., Tsukada, K., Chu, H. H., & Siio, I. (2014, September). Persuasive technology to improve eating behavior using a sensor-embedded fork. In Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing (pp. 319-329). ACM.

[33] Sato, M., Poupyrev, I., & Harrison, C. (2012, May). Touché: enhancing touch interaction on humans, screens, liquids, and everyday objects. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 483-492). ACM.

[34] Ishii, H., Wisneski, C., Orbanes, J., Chun, B., & Paradiso, J. (1999, May). PingPongPlus: design of an athletic-tangible interface for computer-supported cooperative play. In Proceedings of the SIGCHI conference on Human Factors in Computing Systems (pp. 394-401). ACM.

[35] Huang, J., Cherubini, M., Nova, N., & Dillenbourg, P. (2009). Why would furniture be relevant for collaborative learning?. In Interactive artifacts and furniture supporting collaborative work and learning (pp. 1-13). Springer US.

[36] Wiberg, M. (2015). Interaction design meets architectural thinking. interactions, 22(2), 60-63.

[37] Mitchell, T., Bennett, P., Madgwick, S., Davies, E., & Tew, P. (2016, May). Tangible interfaces for interactive evolutionary computation. In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems (pp. 2609-2616). ACM.

[38] Matsushita, M., Iida, M., Ohguro, T., Shirai, Y., Kakehi, Y., & Naemura, T. (2004, November). Lumisight table: a face-to-face collaboration support system that optimizes direction of projected information to each stakeholder. In Proceedings of the 2004 ACM conference on Computer supported cooperative work (pp. 274-283). ACM.

[39] Kakehi, Y., Naemura, T., & Matsushita, M. (2007, October). Tablescape plus: Interactive small-sized vertical displays on a horizontal tabletop display. In Horizontal Interactive Human-Computer Systems, 2007. TABLETOP'07. Second Annual IEEE International Workshop on (pp. 155-162). IEEE.

[40] Terrenghi, L., Kirk, D., Richter, H., Krämer, S., Hilliges, O., & Butz, A. (2008, May). Physical handles at the interactive surface: Exploring tangibility and its benefits. In Proceedings of the working conference on Advanced visual interfaces (pp. 138-145). ACM.

[41] Kirk, D., Sellen, A., Taylor, S., Villar, N., & Izadi, S. (2009, September). Putting the physical into the digital: issues in designing hybrid interactive surfaces. In Proceedings of the 23rd British HCI Group Annual Conference on People and Computers: Celebrating People and Technology (pp. 35-44). British Computer Society.

[42] Leithinger, D., Follmer, S., Olwal, A., & Ishii, H. (2015). Shape displays: Spatial interaction with dynamic physical form. IEEE computer graphics and applications, 35(5), 5-11.

[43] Blackshaw, M., DeVincenzi, A., Lakatos, D., Leithinger, D., & Ishii, H. (2011, May). Recompose: direct and gestural interaction with an actuated surface. In CHI'11 Extended Abstracts on Human Factors in Computing Systems (pp. 1237-1242). ACM.

[44] Schoessler, P., Windham, D., Leithinger, D., Follmer, S., & Ishii, H. (2015, November). Kinetic blocks: Actuated constructive assembly for interaction and display. In Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology (pp. 341-349). ACM.

[45] Piper, B., Ratti, C., & Ishii, H. (2002, September). Illuminating clay: a tangible interface with potential GRASS applications. In Open Source GIS-GRASS User's Conference.

[46] Follmer, S., Leithinger, D., Olwal, A., Hogge, A., & Ishii, H. (2013, October). inFORM: dynamic physical affordances and constraints through shape and object actuation. In Uist (Vol. 13, pp. 417-426).

[47] Ishii, H., Lakatos, D., Bonanni, L., & Labrune, J. B. (2012). Radical atoms: beyond tangible bits, toward transformable materials. interactions, 19(1), 38-51.

[48] Matoba, Y., Sato, T., Takahashi, N., & Koike, H. (2012, August). ClaytricSurface: an interactive surface with dynamic softness control capability. In ACM SIGGRAPH 2012 Emerging Technologies (p. 6). ACM.

[49] Pashler, H., McDaniel, M., Rohrer, D., & Bjork, R. (2008). Learning styles concepts and evidence. Psychological science in the public interest, 9(3), 105-119.

[50] Joshua Davis, 2013. The Next Steve Jobs, p154-163. Wired, November issue.

[51] Durpaire, F., & Mabilon-Bonfils, B. (2014). La fin de l'école: l'ère du savoir-relation. Presses universitaires de France.

[52] Serres, M. (2015). Petite poucette. Le pommier.

[53] Blais, M. C., Gauchet, M., Ottavi, D., Gauchet, M., & Ottavi, D. (2014). Transmettre, apprendre. Stock.

[54] Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. Cognitive science, 12(2), 257-285.

[55] Soare, A., & Popescu, E. (2013). The Effects of Education Led through Practical Museum Programs for School Children. Procedia-Social and Behavioral Sciences, 76, 739-743.

[56] Son, J. Y., Smith, L. B., & Goldstone, R. L. (2008). Simplicity and generalization: Short-cutting abstraction in children's object categorizations. Cognition, 108(3), 626-638.

[57] Kovács, I. (2000). Human development of perceptual organization. Vision research, 40(10), 1301-1310.

[58] Spelke, E. S. (1990). Principles of object perception. Cognitive science, 14(1), 29-56.

[59] Larkin, J. H., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. Cognitive science, 11(1), 65-100.

[60] Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. Learning and instruction, 16(3), 183-198.

[61] Abowd, G., Dey, A., Brown, P., Davies, N., Smith, M., & Steggles, P. (1999). Towards a better understanding of context and context-awareness. In Handheld and ubiquitous computing (pp. 304-307). Springer Berlin/Heidelberg.

[62] Tan, D. S., Gergle, D., Scupelli, P., & Pausch, R. (2006). Physically large displays improve performance on spatial tasks. ACM Transactions on Computer-Human Interaction (TOCHI), 13(1), 71-99.

[63] Nagai, J., Numano, T., Higashi, T., Tessier, M., & Miyata, K. (2013, March). TSUMIKI CASTLE: interactive VR system using toy blocks. In Proceedings of the Virtual Reality International Conference: Laval Virtual (p. 26). ACM.

[64] Wang, G., Yao, L., Wang, W., Ou, J., Cheng, C. Y., & Ishii, H. (2016, May). xPrint: A Modularized Liquid Printer for Smart Materials Deposition. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (pp. 5743-5752). ACM.

[65] Yoshida, H., Igarashi, T., Obuchi, Y., Takami, Y., Sato, J., Araki, M., ... & Igarashi, S. (2015). Architecture-scale human-assisted additive manufacturing. ACM Transactions on Graphics (TOG), 34(4), 88.

[66] Tessier, M., Ura, M., Miyata, K., Shape Changing Tangible Interface Designed for Supporting Exploratory Learning: A Flower on a Pot, proceeding for ACM SIGGRAPH VRCAI 2015, Poster #27, poster presentation,October 30th to November 1st 2015,Kobe Port Island Center, Kobe, Japan.

[67] Norman, D. A. (2004). Emotional design: Why we love (or hate) everyday things. Basic Civitas Books.

[68] Anthropy, A., & Clark, N. (2013). A game design vocabulary: Exploring the foundational principles behind good game design. Pearson Education.

[69] Walter, A., & Spool, J. M. (2011). *Designing for emotion* (pp. 978-1). New York: A book apart.

[70] Norman, D. A. (2010). *Living with complexity*. MIT press.

[71] Norman, D. A. (1993). Things that make us smart.

[72] Maeda, J. (2006). The laws of simplicity. MIT press.

[73] https://www.vitsoe.com/rw/about/good-design

[74] Gaver, W. W. (1991, April). Technology affordances. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 79-84). ACM.

[75] http://worrydream.com/ABriefRantOnTheFutureOfInteractionDesign/

[76] Shneiderman, B. (1981, May). Direct manipulation: A step beyond programming languages. In *ACM SIGSOC Bulletin* (Vol. 13, No. 2-3, p. 143). ACM.

[77] Shneiderman, B. Eight golden rules of design https://www.interaction-design.org/literature/article/shneiderman-s-eight-golden-rules-will-help-you-design-better-interfaces

[78] Rosch, E., & Lloyd, B. B. (Eds.). (1978). Cognition and categorization.

[79] Herron, C. A., Hanley, J. E., & Cole, S. P. (1995). A comparison study of two advance organizers for introducing beginning foreign language students to video. *The Modern Language Journal*, *79*(3), 387-395.

[80] Ogasawara, S. (1995). Using Pictures to Facilitate EFL Students' Comprehension and Recall of Unillustrated Prose Information in Listening Comprehension Practice. 長崎大学教養部創立 *30* 周年記念論文集 *(Bull. Faculty of Liberal Arts)*, *35*(Special issue), 367-381.

[81] Fabrikant, S. I., Hespanha, S. R., & Hegarty, M. (2010). Cognitively inspired and perceptually salient graphic displays for efficient spatial inference making. *Annals of the Association of American Geographers*, *100*(1), 13-29.