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Hands-on science: investigating visitors' experiences in interactive physics exhibitions

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ABSTRACT

This thesis investigates visitors' experiences at two interactive physics exhibitions in Lisbon. The objective is to gain an understanding of the effectiveness of these exhibitions in conveying physics concepts to visitors and stimulating curiosity in the subject. Additionally, the study analyses visitors' personal preferences, challenges faced, and suggestions regarding the exhibits. To achieve this goal, semi-structured interviews were conducted with 50 visitors from each of the two exhibitions at the end of the visit. Both quantitative and qualitative data were collected, and the latter were subsequently analysed by thematic analysis. The results suggest that most of the respondents did not experience a significant increase in their knowledge of physics. However, they mentioned that they felt more curious about it than before. Most visitors read the texts in the intended order and found them easy to follow. Qualitative data indicates that the visual effect of the exhibits was one of the main factors that made them attractive, along with them being beautiful, funny, and surprising. Interestingly, a high level of interaction did not appear to be a crucial factor in attraction. Finally, some suggestions for improvements included simplifying the texts, making them bigger and more appealing by incorporating multimedia elements such as images and explanatory videos. These findings contribute to the literature on visitors' engagement with physics interactive exhibitions and provide useful advices for future exhibitions or improvements for the ones already existing.

Introduction

What is an interactive exhibition?

Exhibitions are composed of various modules also called "exhibits" (www.ecsite.eu) and can be broadly classified into two categories: passive and active (Voase, 2002). Passive exhibits, such as glass showcases, do not encourage visitors to touch or interact with them. In contrast, active exhibits, such as working models and machines, invite visitors to engage with them more directly. These exhibits that allow visitors to physically touch and manipulate them are commonly referred to as "hands-on" or "interactive" (Voase, 2002). Although the terms are often used interchangeably, "hands-on" implies physical manipulation whereas "interactive" may include a range of activities such as simple button pushing or more complex activities with multiple outcomes. However, it is important to note that an exhibit which only involves pushing a button is not truly interactive, but rather reactive, as the outcome is predetermined. Without an adequate alternative term, “hands-on” and “interactive” will be used in this thesis interchangeably, but in both cases, there is an assumption that the terms involve this broader definition given by Caulton in 1998:

> *A hands-on or interactive exhibition has clear educational objectives which encourage individuals or groups of people to work together to understand real objects or real phenomena through physical exploration which involves choice and initiative.*

Feher (1990) also discusses the use of interactive exhibitions as a learning tool in modern science museums. According to her, while schools tend to provide explanations before allowing students to experience natural phenomena, science museums reverse this process. These museums that include interactive exhibitions are most often called “science centres”, and the term will be used in this thesis with this meaning. Science centres present natural phenomena in the form of exhibits that are interactive and manipulable, exhibits whose express purpose is to enable the visitors to explore and experiment. The science centre can be thought of as a laboratory that is always available, with all its experiments ready for use at the visitor's discretion (Feher, 1990).

Origins of interactive exhibitions

Before the 20th century, museums didn't have interactive exhibits. One of the first museums using interactivity as part of their exhibition was the Deutsches Museum in Munich in 1925. Exhibits were

introduced so that visitors could interact with them by pressing buttons and operating levers to explore certain features. Another pioneering development was the display of chemical experiments at the Palais de la Découverte in Paris in 1937. Similar progressions were also seen in the United States. For example, the Chicago Museum of Science and Industry built a simulated coal mine in 1933, while the Franklin Institute in Philadelphia has had a beating heart on display since 1953, which can be walked through on two levels. The Children's Gallery at the Science Museum in London, which opened in 1931, is also considered one of the earliest science centres (Caulton, 1998).

So, interactive exhibits in museums started to appear in the early 20th century, but the first completely interactivity-based museum was founded in 1969 by Frank Oppenheimer in San Francisco, and it was called the "Exploratorium". It was the first of an entirely new kind of institution with a truly hands-on approach, and still attracts hundreds of thousands of visitors annually. The Exploratorium mixes "science, art and human perception" and has the mission to create a culture of learning through innovative environments, programs and tools that help people nurture their curiosity about the world around them (www.exploratorium.edu.).

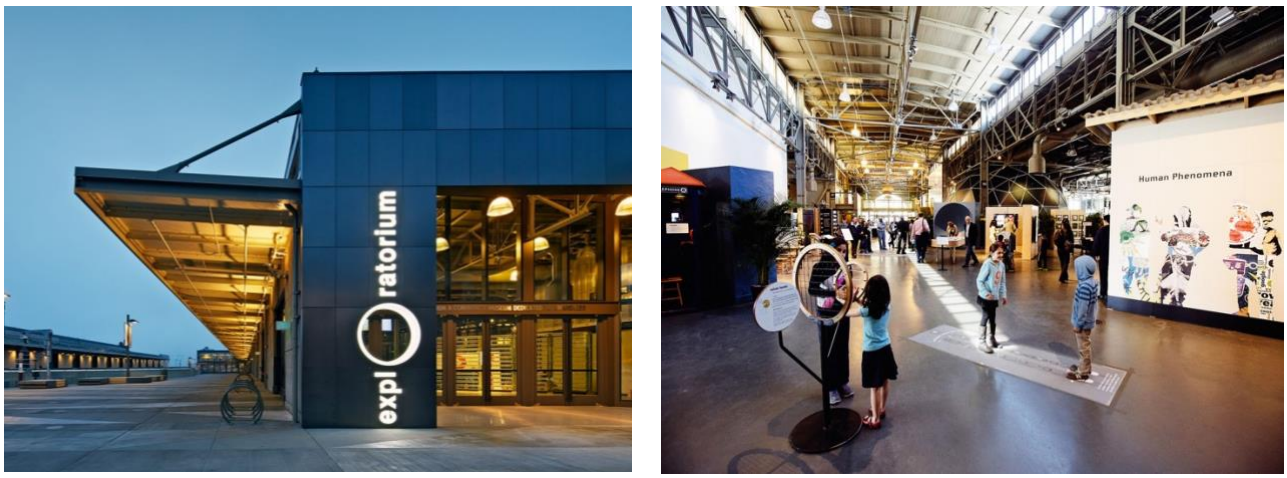


Figure 1 – Exploratorium, San Francisco

The Exploratorium is not only the first truly interactive museum but has been a pioneer for other organisations in the field of science education. It has made available over 200 interactive exhibit recipes through its "Cookbooks". This has enabled other science centres to begin with reliable and proven exhibits. As a result, clones of Exploratorium exhibits can be found in science centres worldwide (www.exploratorium.edu).

The educational context

As explained by Caulton (1998), interactive exhibitions aim to engage visitors with hands-on exhibits, which are more enjoyable than traditional static exhibits. This is evidenced by the popularity of interactive museums and science centres, and the positive responses of visitors. However, it is important to note that these institutions also have educational objectives alongside their entertainment goals.

Much of the educational philosophy behind interactive exhibitions originates from developmental psychologists like Piaget, Froebel, and Vygotsky, who developed the theory of constructivism (Jeffery-Clay, 1998). According to constructivism, individuals or learners do not simply absorb knowledge and understanding through a direct process of knowledge transmission. Instead, they actively construct new knowledge and understanding by integrating new information with their prior knowledge, gained through experiences and social interactions (Sjøberg, 2010).

Piaget believed that children learn by doing rather than just observing, and therefore, they construct knowledge and understanding for themselves. The teacher's role is to create an environment where learning can take place most effectively, instead of simply imparting their knowledge. The objective is to encourage children to ask questions, rather than accept information without thinking (Sjøberg, 2010). As Caulton (1998) explains, Piaget's theory of learning and development has played a significant role in the rise of hands-on learning. Interactive exhibitions provide a framework that meets the three areas of learning identified in Bloom's "taxonomy of learning": that is, they encourage cognitive learning (knowledge and understanding), affective learning (attitudes, interests, and motivation) and psycho-motor development (physical skills of manipulation and coordination).

The fundamental point is that everyone has a unique way of learning and interactive exhibitions have the potential to be particularly effective at accommodating different learning styles compared to other informal learning environments.

Do visitors really learn?

The promotion of science in science centres is seen as a positive step by those who are trying to address the public's disconnection from science. However, there has been much debate (Falk & Dierking 1992; Hooper-Greenhill 1992; Chang 2006; Wareath 2022) surrounding whether visitors are only acquiring a superficial understanding of scientific principles and practices or if science centres are inadvertently promoting scientific misconceptions. The question that arises often is

whether visitors are actually learning or if they are simply playing.

The plasma sphere, shown in Figure 2, is a good example of this. It is a popular attraction in science centres. It reacts to touch and creates beautiful patterns. However, to fully understand the science behind it, visitors need to have a good understanding of the different states of matter, electricity, and gas. Full explanation is often omitted or not read by visitors and as a result, the learning experience is limited to the reaction of touching and obtaining pretty patterns.

Figure 2 – Plasma sphere

As said before, there has been a long debate about the role of science centres and especially the way how they promote the image of science for the public. For example, the centres might give the false idea about scientific inquiry leading to instant solutions, when, in reality, scientific discoveries are often the result of very tedious and long work (Caulton 1998). In the end, however, the answer to the question is subjective, as it depends a lot on one's opinion of the role of science centres in society. In this thesis, an opinion about it will be discussed.

Literature Review

Over the past decades, the study of visitors' learning and engagement in interactive exhibitions has gained considerable attention. Various aspects of this broad topic have been explored, with researchers focusing on exhibit characteristics, time-based statistics, and visitor behaviours. This synthesis aims to provide an overview of the findings from different studies, highlighting the factors influencing visitors' learning and engagement in interactive exhibitions.

In 2003, Sandifer conducted a study to explore the connection between visitor's attention and the features of interactive science exhibits. The research involved tracking forty-seven visitors across two exhibitions that consisted of a total of 61 interactive exhibits. To measure the visitor's attention to

each exhibit, attracting power and average holding time were used. Attracting power is typically defined as the percentage (or fraction) of visitors who stop at a given exhibit for a minimum amount of time (e.g., 5 seconds). An exhibit's average holding time is defined simply as the average time that visitors spend at the exhibit. The primary objective was to determine the characteristics of interactive exhibits that could effectively attract and retain the visitors' attention in a science museum. Four exhibit characteristics were identified and analysed, namely technological novelty, open-endedness, user-centeredness, and sensory stimulation.

An exhibit was considered to be *technologically novel* if it met at least one of the following criteria: 1. The exhibit contained visible state-of-the-art devices. 2. The exhibit, through the use of technology, illustrated phenomena that would otherwise be impossible or laborious for visitors to explore on their own. Examples include exhibits that contain lasers, or sophisticated software (such as the Internet), or an infrared camera. An exhibit was considered to be *open-ended* if it met at least one of the following criteria: 1. The exhibit allowed for the achievement of multiple visitor-set goals. 2. The exhibit allowed for one goal to be achieved in multiple ways. An exhibit was considered to be *user-centred* if the outcome of the exhibit manipulation involved a representation of or an effect on the user's body or voice. Examples include exhibits with mirrors or microphones, where visitors see themselves or hear their own voices. An exhibit was considered to *stimulate the senses* if it met at least one of the following criteria: 1. The exhibit emitted sounds on its own or when in use. 2. The exhibit had one or more visible parts, objects, or images that moved on their own or when the exhibit was in use. 3. The exhibit had lights that blinked or flashed on their own or when the exhibit was in use. The study concluded that open-endedness and technological novelty played a significant role in determining the average holding time, whereas user-centeredness and sensory stimulation did not (Sandifer, 2003).

Boisvert and Slez (1995) conducted a study to observe visitors' behaviours in a science museum. They observed 154 visitors in a discovery space as they interacted with the exhibits. The exhibits were divided into five different styles based on three criteria: (1) high or low interaction, (2) concrete or abstract presentation, and (3) simple or complex information presentation. The data collected indicated significant differences between the exhibit styles and their impact on attraction, holding power, and visitor engagement levels. Attraction levels were highest for exhibits with concrete presentations. Holding power was highest for exhibits with high interaction and concrete presentations. Engagement levels were highest for high interaction exhibits. (Boisvert & Slez, 1995).

Other studies observed children, adults, families, and school groups with a focus on how much time

they spent on the exhibits and what they talked about with each other as well as their status of reading the labels. Laçin-Şimşek & Öztürk (2021b), for example, conducted a study to observe how visitors interact with exhibits in a science centre in Turkey. Data were collected through an observation form and analysed by descriptive analysis. It was found that the most preferred exhibits were seen to be those involving high interaction, open to manipulation, colourful, illuminated, extraordinary, misleading perceptions, involving video or camera, and easy to understand and use (Laçin-Şimşek & Öztürk, 2021b).

Another important study conducted by Laçin-Şimşek & Öztürk (2021a) was aimed to determine the opinions of the visitors in a science centre about the exhibits and labels and to determine their understanding of the exhibits and labels. The research was qualitatively oriented. The data were collected through semi-structured interviews. It was determined that the visitors found the exhibits beautiful and interesting, generally noticed the labels and read them. These visitors stated that the labels should be more colourful, remarkable, and more easily understandable, their fonts should be bigger, and the narration of the label could be supported with visual elements. Most of the visitors stated that they understood what was told in the exhibit, but when asked what they understood, it was seen that the majority of them did not understand it, some of them only described how to use the exhibit (Laçin-Şimşek & Öztürk, 2021a).

This comprehensive review highlights the multifaceted nature of studies on visitor learning and engagement in science centres. From exhibit characteristics and time-based statistics to direct interviews, researchers continue to explore diverse dimensions to enhance the educational impact of interactive exhibits.

Research questions

While many studies have directly observed visitors, only a few have conducted direct interviews to explore visitors' opinions on their learning, curiosity, attitudes, and preferences in such exhibitions. This research aims to gather insights about visitors' experiences in two interactive physics exhibitions, through conducting direct interviews. The aim of the study is to evaluate the effectiveness of physics exhibitions in conveying scientific concepts to visitors and sparking their curiosity in the subject. Furthermore, the research seeks to analyze visitors' individual preferences, the challenges they face, and their suggestions regarding the exhibits. The findings of this study could prove useful for museum educators and designers in the evaluation and improvement of interactive exhibitions. To

achieve this goal, the study aims to answer the following research questions and sub-questions:

1. **Do interactive exhibitions effectively convey Physics concepts and stimulate curiosity among visitors?**
   1.1 Do visitors learn something new while visiting an interactive physics exhibition?
   1.2 Do visitors feel more curious about physics after visiting an interactive exhibition?
   1.3 How do visitors engage with texts?

2. **What do visitors like the most in an interactive Physics exhibition and what suggestions would they give to improve it?**
   2.1 Which exhibits do visitors enjoy the most, and what factors contribute to their enjoyment?
   2.2 Which exhibits do visitors find most challenging to understand, and what factors may contribute to these challenges?
   2.3 What suggestions do visitors provide to improve the overall exhibition experience?

Structure of the thesis

The thesis is articulated in three chapters.
The first chapter describes the methodology used in the study. It gives a brief description of the two exhibitions and explains the process of creating questionnaires, along with the data analysis technique used. The second chapter presents the main findings of the study, following the order of the questionnaire used for the interviews. The third chapter discusses the findings in relation to the literature review and presents the limitations of the study. Finally, the thesis ends by summarising the key research findings and discussing their value and contributions. It also reviews the limitations of the study and proposes some opportunities for future research.

CHAPTER 1 – Methodology

1.1 Exhibition analysed

The research for this thesis was conducted in two interactive physics exhibitions in the city of Lisbon: one at the "Museu Nacional de História Natural e da Ciência" (National Museum of Natural History and Science) and the other at the "Pavilhão do Conhecimento" (Pavilion of Knowledge) science centre. From now on the English name and the abbreviations “Museum” and “Pavilion” will be used. Both exhibitions aim to communicate scientific concepts in an engaging way to the visitors, but they differ in their approach. Each exhibition will be further described in more detail after a brief historical overview.

1.1.1 National Museum of Natural History and Science

Figure 3 - National Museum of Natural History and Science, Lisbon

Lisbon's National Museum of Natural History and Science is situated in Principe Real along the Rua da Escola Politécnica and belongs to the University of Lisbon. The building, with its neoclassical design, was built for the Polytechnic School of Lisbon between 1857 and 1878 on the remains of a previous building, destroyed by fire.

The National Museum of Natural History originated from the Royal Museum of Natural History and Botanical Garden which was established in the second half of the 18th century in Ajuda, Lisbon. After a brief stay at the Royal Academy of Sciences, it was finally moved to the Polytechnic School, and in 1861, it was named “National Museum of Lisbon”.

In 1911, with the creation of the University of Lisbon, the Museum was declared an establishment attached to the Faculty of Sciences and was renamed the “National Museum of Natural History” in 1926. In March 1978, a violent fire destroyed a large part of the former Polytechnic School building,

and the Faculty of Sciences then began the process of relocating. In May 1985, in the same building of the old Polytechnic School, the "Science Museum of the University of Lisbon" was created, sharing the space with the "National Museum of Natural History".

In 2011, the two museums merged into one single museum called the "National Museum of Natural History and Science". Its collections included the former buildings of the Polytechnic School, the Lisbon Botanical Garden, and the Ajuda Astronomical Observatory. Their mission is to promote curiosity and public understanding of nature and science, bringing the University closer to society (museus.ulisboa.pt).

Among many different exhibitions hosted at the Museum, there is one devoted entirely to Physics called the "Historical and Participatory Physics Exhibition". It dates to 1992, when its curator, Fernando Bragança Gil, decided to create it as part of the "Science Museum of the University of Lisbon" of which he was the director. Fernando Bragança Gil believed that interactive exhibitions like this one should also be about teaching something and not just entertaining visitors.

The exhibition consists of 61 modules in total, divided into four thematic areas: Mechanics, Vibrations and Waves, Magnetism and Electricity, and Optics. The modules are all located within one large room, and the tour route is partially free because it is constrained by the layout of the thematic areas, placed in a specific order. The modules all require visitor participation but to varying degrees. Some modules engage the visitor with their hands or body, while others require only a button to be activated. The visits to the exhibition are not guided, which allows visitors to interact with modules autonomously. Next to each module there is an explanatory text in various colours: dark red, light red, and yellow. The text in dark red gives directions on how to interact with the exhibit; in light red are written some questions that the visitor is invited to try to answer; and finally in yellow is written the physical explanation of the observed phenomenon. The texts on the panels are exclusively in Portuguese, while along the room there are some sheets with English translations. Some examples of exhibits and texts are presented below.

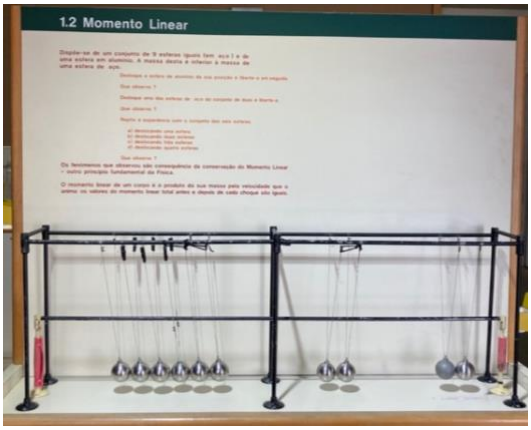


Figure 4 - "Linear Momentum"

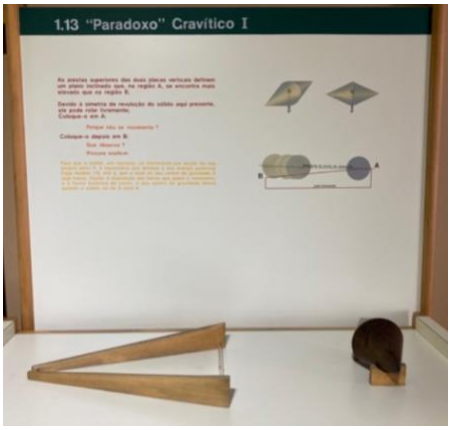


Figure 5 - "Gravity Paradox I"

In addition to the participatory modules, the exhibition presents historical objects displayed under a glass bell, and along with the explanatory texts of the modules, historical pieces of information are given regarding important scientists and discoveries of the past. This integrated approach seeks to contextualise the different scientific themes in a historical fashion.

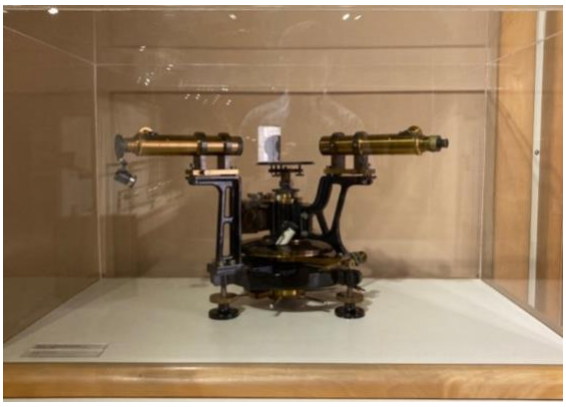


Figure 6- Goniometer/Spectroscope (19th century)

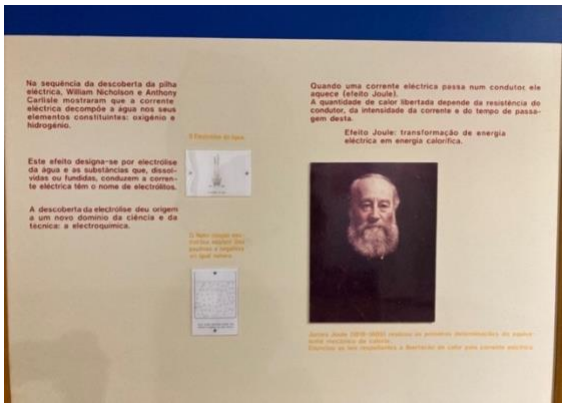


Figure 7 - Historical information on the discovery of the electric pile and the Joule effect

1.1.2 Pavilion of Knowledge

Figure 8 - Pavilion of Knowledge, Lisbon

The Pavilion of Knowledge is situated in the Park of Nations, Lisbon. It was constructed, along with several other facilities, for the 1998 Lisbon World Fair. The Pavilion of Knowledge is the largest science and technology centre in Portugal and has been open to the public since 25 July 1999. It is a part of the "Ciência Viva" circuit, which is a network of 21 Science Centres distributed throughout Portugal. "Ciência Viva" was founded in 1996 to foster education and scientific culture and was promoted by José Mariano Gago, who was then the Minister of Science and Technology. In 1998, it became part of an association of scientific institutions, and it was renamed "Ciência Viva - Agência Nacional para a Cultura Científica e Tecnológica" (Ciência Viva - National Agency for Scientific and Technological Culture). Since then, it has grown into a nationwide organization with a network of 21

science centres spread across the country. This organization supports a social movement promoting science and scientific culture, which includes hundreds of thousands of researchers and citizens, students, and teachers, young people, and adults (cienciaviva.pt).

The Pavilion of Knowledge is the largest Science Centre of the Ciência Viva network, and it hosts an interactive exhibition called "Explora". The "Explora" exhibition is located in a large room, and it consists of around 40 modules, which are scattered around the hall and divided into four thematic areas: Light, Vision, Perception, and Extremely Complex Systems. However, the division is not as distinct as at the National Museum of Natural History and Science and it is noticeable that the exhibition in general has a lower didactic character compared to the one at the Museum.

Most of the modules come from a collaboration with San Francisco's Exploratorium, featuring its science centre's logo. However, not all the modules are a replication of the ones at the Exploratorium. Some of them have been developed independently. Each module is accompanied by a text in Portuguese and English, which is split into two parts. The first part is titled "To do and notice" and explains how to interact with the module. The second part is called "What's going on?" and explains the phenomenon. The “Explora” exhibition does not include any historical scientific objects or historical information. Some examples of exhibits and texts are presented below.

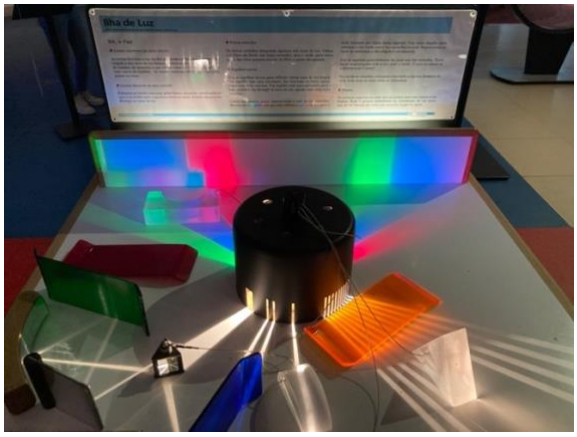


Figure 9 – “Island of Light”

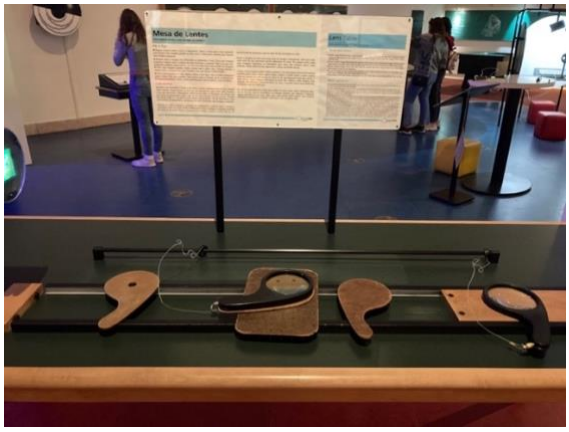
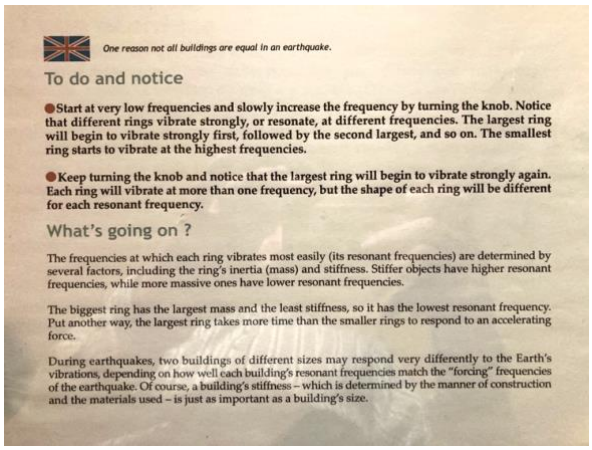


Figure 10 – “Lens Table”



One reason not all buildings are equal in an earthquake.

To do and notice

Start at very low frequencies and slowly increase the frequency by turning the knob. Notice that different rings vibrate strongly, or resonate, at different frequencies. The largest ring will begin to vibrate strongly first, followed by the second largest, and so on. The smallest ring starts to vibrate at the highest frequencies.

Keep turning the knob and notice that the largest ring will begin to vibrate strongly again. Each ring will vibrate at more than one frequency, but the shape of each ring will be different for each resonant frequency.

What's going on ?

The frequencies at which each ring vibrates most easily (its resonant frequencies) are determined by several factors, including the ring's inertia (mass) and stiffness. Stiffer objects have higher resonant frequencies, while more massive ones have lower resonant frequencies.

The biggest ring has the largest mass and the least stiffness, so it has the lowest resonant frequency. Put another way, the largest ring takes more time than the smaller rings to respond to an accelerating force.

During earthquakes, two buildings of different sizes may respond very differently to the Earth's vibrations, depending on how well each building's resonant frequencies match the "forcing" frequencies of the earthquake. Of course, a building's stiffness – which is determined by the manner of construction and the materials used – is just as important as a building's size.

Figure 11 – Text corresponding to the “Resonance rings”.

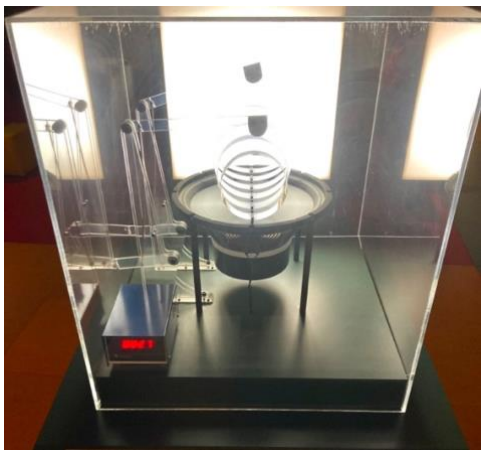


Figure 12 – “Resonance rings”

1.2 Interview protocol

To help answering the research questions posed, the chosen methodology was the development of direct interviews with visitors. Interviewing is the most practical way to learn about people's knowledge, thoughts, attitudes and behaviours on different topics and their causes (Patton, 2014). It was chosen to conduct semi-structured interviews as they are commonly used in qualitative research. These type of interviews allows for a degree of flexibility in collecting opinions and comments, making them ideal for capturing visitors' voices and interpreting their perceptions.

To verify that my interview questions were aligned with my research questions I created two matrices, one for each questionnaire, in which I could visualize the correlation between the two types of questions. The matrices can be found in the appendices A4 and A5.

To prepare for the interviews, an interview protocol that included both closed and open-ended questions was developed following many suggestions from Castillo-Montoya (2016).

To keep the interviews brief, the number of questions was limited to keep the duration under six minutes. The interview protocol had two versions with slight differences, one for the Museum and the other for the Pavilion. Although they both had the same core questions, the Museum interview protocol had more questions than the one for the Pavilion. The data collected at the Museum and not at the Pavilion were not presented in the findings because not very relevant to the study but they can be found in Appendix A6, while the two interview protocols can be found the Appendices A1 and A2.

1.4 Pilot test

A pilot test was conducted at the National Museum of Natural History and Science with six visitors. The interview protocol was applied, and the visitors were asked the questions included in the questionnaire.

The feedback that was received allowed the improvement of the interview by changing a few questions. For example, the question “What motivated you to come to visit this exhibition?” was changed into “What motivated you to come to visit the museum?” because it appeared that nobody came there just for the physics exhibition. Another example is the question “What do you remember that you enjoyed?” that was changed into “What was the exhibit that you enjoyed the most?” since it was noticed that the visitors were a bit lost in identifying what they enjoyed in general.

Another pilot test was conducted at the Pavilion, and other changes were applied to the original interview protocol. The main problems encountered at the Pavilion were that there was no possibility of sitting, the flow of people was higher and there were mainly families with children. These circumstances made it difficult to ask people to stop for more than a couple of minutes. To solve this

problem, it was decided to reduce the length of the interviews by removing some of the questions that were not essential to answering the research questions. The omitted questions were:

1. Are you studying or did you study something related to one scientific area?
2. Are you working or did you work in something related to one scientific area?
3. Have you visited an interactive exhibition like this one before?
4. Did you notice that the exhibition is divided into four thematic areas?

Additionally, it was decided not to record any audio during the interviews to save time on requesting consent and because the acoustics of the room were not optimal. Nevertheless, it was possible to obtain all the responses on paper without sacrificing any information.

1.5 Study group

To participate in this research, individuals had to meet the following criteria:

1. Visit the exhibition within a reasonable time frame (not too short)
2. Aged 18 years or older
3. Be able to understand English or Portuguese languages

Fifty individuals who met the criteria were randomly selected and interviewed for each exhibition. The demographic characteristics of these interviewees are presented in Chapter 2, section 2.1.

1.6 Data collection

The process of data collection took place from mid-October to mid-November 2023. The first set of interviews was done at the National Museum of Natural History and Science between the 12th and 27th of October 2023. The interviews were done one visitor at a time at the end of the exhibition. The setting, with a desk and chair available at the exit of the hall where the interviewees could sit, created the perfect environment to conduct the interviews. Additionally, the flow of people was not too high, and there weren't many families with children present. Therefore, it was possible to conduct interviews as long as planned and to make all the questions planned within the interview protocol.

Before each interview, it was asked to the visitors if they would like to participate. If they agreed to participate, their signature on an informed consent form was requested so that the audio of the interview could be recorded to facilitate the gathering of information. The informed consent form can be found in Appendix A3.

The interview protocol was printed and used to mark the answers to the closed-ended questions during the interview. For open-ended questions, the responses were transcribed, at a later time, using the audio recording. The interviews were conducted in English, Portuguese, and, in a few cases, Italian.

The questions were phrased as similarly as possible between each language and the same questions were kept for each interviewee. If necessary, a clarification was provided without changing the question's meaning. At the Pavilion the same procedure was followed. As explained before, the only differences with the interviews conducted at the Museum were that some questions were omitted and no audio recording was used.

The interviews were all conducted by the same interviewer, i.e., the author of this dissertation. As previously mentioned, semi-structured interviews were conducted, meaning that the order of questions was not always the same. Instead, it was adapted to each conversation. During the interviews, the interviewees were allowed to speak freely and they were not interrupted, even if they strayed from the question. Instead, their digression was categorised as "additional comments."

If it was noticed that an interviewee was not articulating their answer sufficiently, it would either be asked for more detail or to move on to the next question, depending on the individual. There were not many difficulties in finding participants for this study. The main reasons for people not to participate were time constraints, language barriers, a quick passing through the museum, or having children to look after. Once the interviews were over, the answers obtained were inserted in two Google Forms, one for each exhibition, for further analysis.

1.7 Data analysis

All answers collected in the Google Forms were converted into Excel format to allow their analysis. The frequency of answers to close-ended questions was analysed to produce charts and tables. The open-ended questions helped gathering qualitative data and content analysis was used to extract relevant information. To analyse the qualitative data, first, all the answers were read to identify common themes, based on the words used by the interviewees in their responses. Afterwards, a list of themes was created, and their frequency of occurrence was counted. Two examples of the thematic analysis are presented below.

Theme	***Interviewees' answers***
Interesting	*It was **interesting** to see how rocks look in a different light* *I found **interesting** the fact of having the same thing represented form two different prospective* *It was **interesting** to see how the presence of light can turn a mirror into a window*
Funny	*It was **funny** to enter there and to look at each other* *It's like a **game*** *It was just **funny***

New/Surprizing	*They were showing something that **I've never seen** before that clear* ***I've never seen** it and it's interesting* ***I've never seen** something like that before. It's nice to see you and then the person in front of you*
Related to something personal	*I liked to see with my eyes what **I've always studied in theory*** *I enjoyed the most the ones that **I explained to my wife** because I was more involved* ***I like to see how objects move** depending on their weight and the material they are made of*
Visually impressive	*I liked the **image** that it creates* *I liked the **visual effect*** *The **visual effect**. When you touch it seems that a flash of lightning is created*
Beautiful/Fascinating	*I find **fascinating** the unpredictability of its evolution* *The one with the spring is really **fascinating** because I couldn't figure out how it is possible* *I was intuitive and **beautiful***
Body engaging	*You can **feel** the different weights and so you combine the visual understanding with the tactile* *That you can **feel** the experiment and puts you as a person to experience Physics. It's probably the most interactive exhibit* *You can study these things in books but here you can **feel** them*

*Table 1 – Example of thematic analysis of the answers to the question: **What did you like about that exhibit?***

Theme	***Interviewees' answers***
The principle	*The ball fluctuating is very cool but the **principle** behind is not very clear* *I didn't understand **why** the light is breaking in colours* *I didn't understand **how** the shadow remains there*
Text explanation	*You must carefully read the **explanation*** *The **text** in Portuguese is not very clear* *The **explanation** is very vague*
How to interact	*I didn't understand **what I was supposed to do*** ***How to create** the waves* ***How to use** the lens to create the image*
The purpose	*I didn't understand its **purpose*** *I didn't understand **how it was supposed to work*** *I used the filters but without understanding the **mechanism***
Didn't see the result expected	*I didn't understand the sense. The ball **always falls** inside the hole* *The ball was **never falling** inside the hole* *I turned on the volume, but **nothing happened***
Not intuitive	*It's more abstract and less **intuitive*** *It's not very **intuitive*** *Maybe I didn't understand it, but it **wasn't very clear***
Didn't put much effort to understand	*We **just stayed there 5 seconds** and then we moved on* *I **didn't read much** of the texts honestly* *It **didn't really capture my attention***

*Table 2 – Example of thematic analysis of the answers to the question: **What didn't you understand about that exhibit?***

CHAPTER 2 – Findings

This chapter presents the data analysed to help answering the research questions. The analyses of the quantitative data obtained from close-ended questions are presented in graphs followed by the corresponding tables. Regarding the qualitative data obtained from open-ended questions, tables showing the identified themes along with their frequencies are presented. The remaining data that is not directly relevant to the research questions are presented in Appendix A6.

The results are divided into three parts. First, the demographic data of the 50 visitors who were interviewed in each exhibition are presented. Second, the data collected to answer the first research question are shown. Finally, the data needed to answer the second research question are presented.

2.1 Demographic characteristics of the interviewees

2.1.1 Age

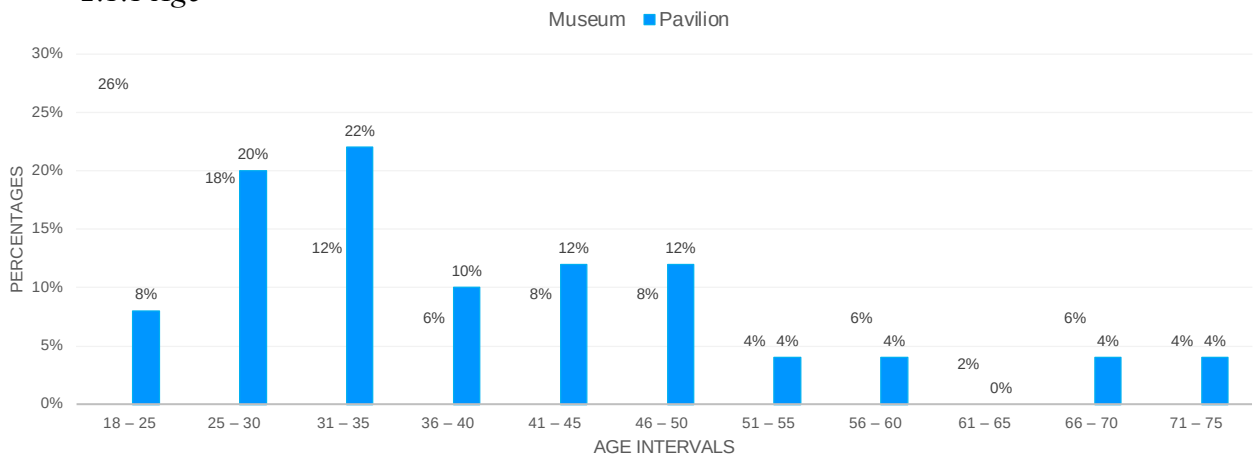


Figure 13 – Age distribution of the interviewees at the Museum and the Pavilion

Table 3 – Age distribution of the interviewees at the Museum and the Pavilion

Age intervals	***Museum***	***Pavilion***
18 – 25	13	4
25 – 30	9	10
31 – 35	6	11
36 – 40	3	5
41 – 45	4	6
46 – 50	4	6
51 – 55	2	2
56 – 60	3	2
61 – 65	1	-
66 – 70	3	2
71 – 75	2	2

According to data, the majority of visitors at the Museum were between 18 and 30 years old, which accounted for 44% of the total. On the other hand, at the Pavilion, most of the interviewees were aged

between 25 and 35 years old, representing 42% of the total. The reason for the high number of young people between 18 and 25 registered at the Museum is probably that it is part of the University of Lisbon and students are offered a discount. On the other hand, at the Pavilion, mainly families with young children were encountered, and several parents who were around 30 years old were interviewed.

2.1.2 Gender

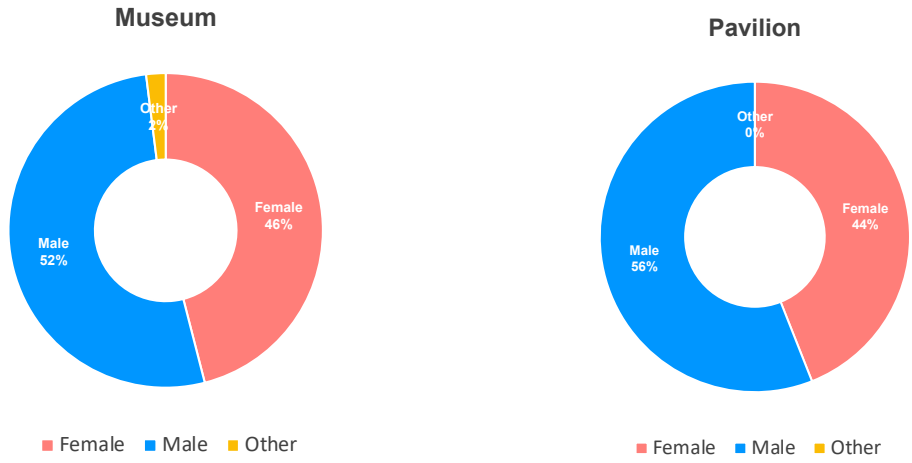


Figure 14 – Gender distribution of the interviewees at the Museum and the Pavilion

Table 4 – Gender distribution of the interviewees at the Museum and the Pavilion

Gender	***Museum***	***Pavilion***
Female	23	22
Male	26	28
Other	1	-

The gender distribution is quite balanced between males and females. However, in both exhibitions, the number of males interviewed exceeded the number of females.

2.1.3 Nationality

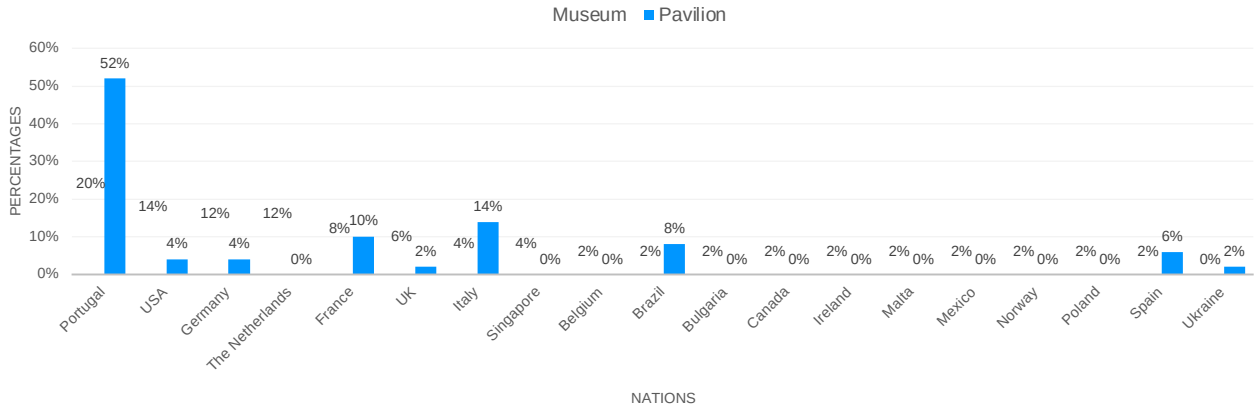


Figure 15 – Nationality of the interviewees at the Museum and the Pavilion

Table 5 – Nationality of the interviewees at the Museum and the Pavilion

Nationality	***Museum***	***Pavilion***
Portugal	10	26
USA	7	2
Germany	6	2
The Netherlands	6	-
France	4	5
UK	3	1
Italy	2	7
Singapore	2	-
Belgium	1	-
Brazil	1	4
Bulgaria	1	-
Canada	1	-
Ireland	1	-
Malta	1	-
Mexico	1	-
Norway	1	-
Poland	1	-
Spain	1	3
Ukraine	-	1

In both exhibitions, visitors' nationality was quite varied. However, at the Pavilion the number of Portuguese people exceeds much more the rest of the nationalities compared to the Museum, were visitors from more countries were interviewed. Moreover, it was noticed a significant difference in nationality between weekdays and weekends. During the weekdays, mainly non-Portuguese visitors attended the exhibitions, while on weekends, both Portuguese and non-Portuguese visitors were present.

2.2 Do interactive exhibitions effectively convey physics concepts and stimulate curiosity?

The data presented in this section are selected to answer the first research question stated in the title of this section. The data will be presented in the same order as it was done during the questionnaire.

2.2.1 Are you in general interested in physics?

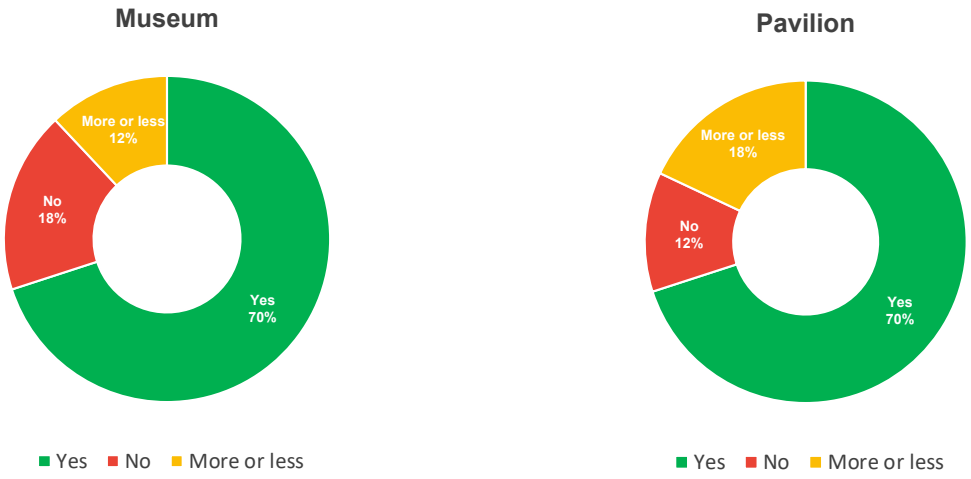


Figure 16 – Distribution of respondents on their general interest in physics

Table 6 – Distribution of respondents on their general interest in physics

Are you in general interested in physics?	***Museum***	***Pavilion***
Yes	35	35
No	9	6
More or less	6	9

Most of the people interviewed in both exhibitions answered that they were generally interested in Physics before the visit.

2.2.2 Do you feel more curious about Physics after this exhibition?

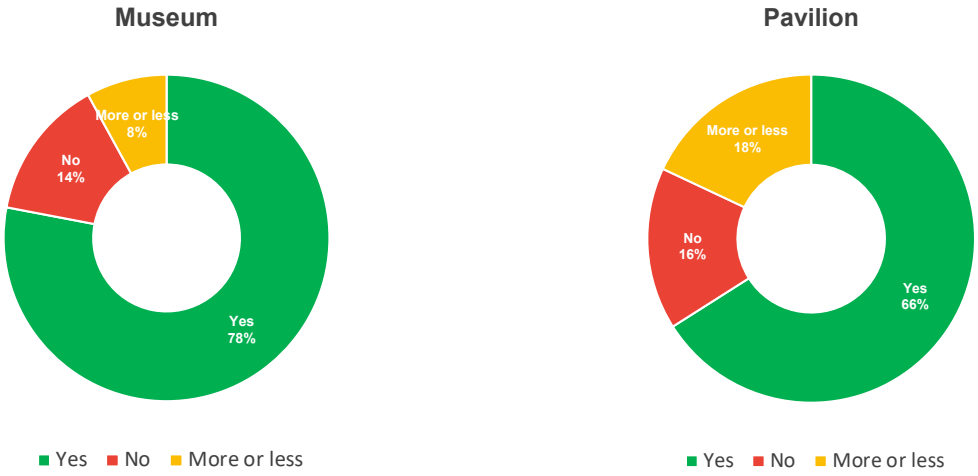


Figure 17 – Distribution of respondents on their possible increased curiosity after visiting the exhibitions

Table 7 – Distribution of respondents on their possible increased curiosity after visiting the exhibitions

Do you feel more curious about physics after this exhibition?	***Museum***	***Pavilion***
Yes	39	33
No	7	8
More or less	4	9

This question is significant because it highlights that the two exhibits sparked curiosity in Physics among the majority of visitors.

2.2.3 How much did you already know about the physics concepts presented?

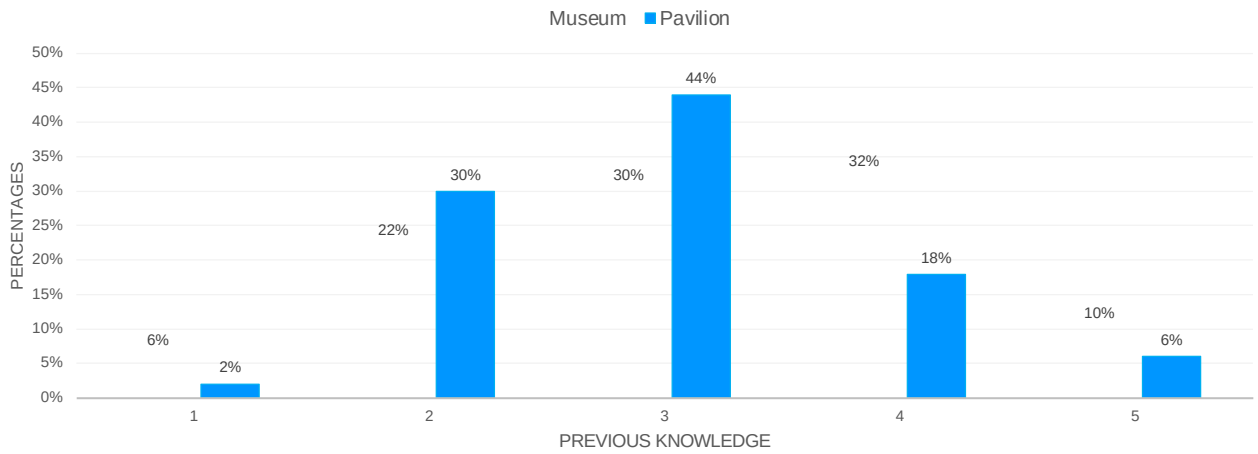


Figure 18 – Distribution of respondents on their previous knowledge about the physics concepts presented (1=nothing, 5=everything)

Table 8 – Distribution of respondents on their previous knowledge about the physics concepts presented (1=nothing, 5=everything)

How much did you already know about the physics concepts presented? 1 represents nothing and 5 everything	***Museum***	***Pavilion***
1 (nothing)	3	1
2	11	15
3	15	22
4	16	9
5 (Everything)	5	3

It is worth noting that in both exhibitions, the majority of visitors felt that they already had a good understanding of the presented concepts before visiting the exhibitions. However, these results should be considered with caution because there was no further investigation into the visitors' actual knowledge. Nevertheless, they provide a general idea that those who attend interactive physics exhibitions have typically already been exposed to a significant portion of the concepts presented.

2.2.4 Did you learn something new about physics today?

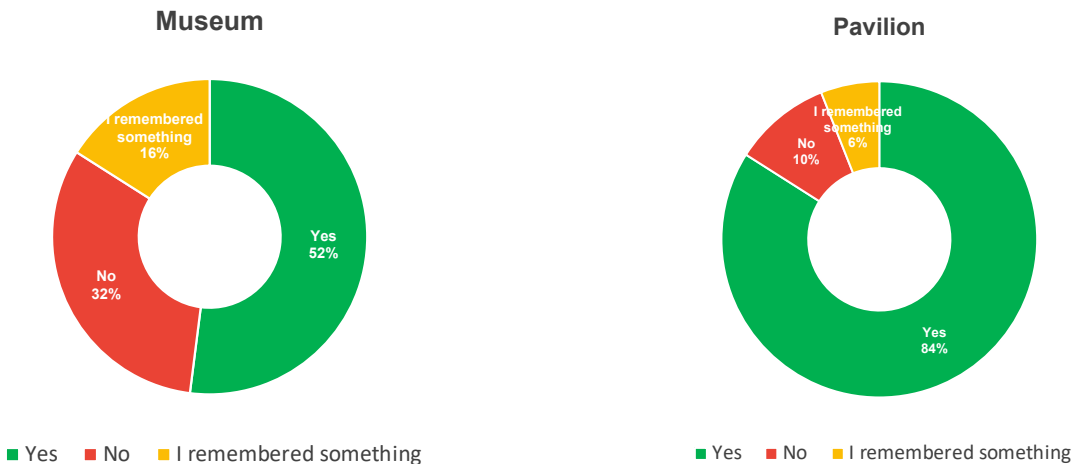


Figure 19 – Distribution of respondents on whether they learned something new about physics

Figure 9 – Distribution of respondents on whether they learned something new about physics

Did you learn something new about physics today?	***Museum***	***Pavilion***
Yes	26	42
No	16	5
I remembered something	8	3

As the data on the previous knowledge, the answers provided by visitors to the question "*Did you learn something new about physics today?"* may not necessarily indicate if they have actually learned something, but they do provide valuable insight into their feelings about their learning experience. The data suggests that significantly fewer visitors felt like they learned something new at the Museum compared to the Pavilion. This is most likely because the panels with explanatory texts at the Museum were only available in Portuguese, but only a fifth of visitors were of Portuguese nationality. This data highlights the importance of providing clear and accessible texts in interactive exhibition.

2.2.5 If you learned something, could you give an example of what you learned?

Table 30 – Distribution of respondents on examples of what they learned

Museum		***Pavilion***	
Name of the exhibit	***Frequency***	***Name of the exhibit***	***Frequency***
The part about Optics in general	5	Shadow box	6
The invisible light	4	Billiard	4
Pulleys	4	Lariat chain	4

When answering this question most interviewees did not really articulate an answer but they mainly mentioned the name of one or more exhibits from which they felt they had learned something. In the table are shown the names of the exhibits that were mentioned the most per exhibition. At the Museum, most of the visitors learned something from the last part about **Optics** and in particular the exhibit called "**The invisible light**". Also, the "**Pulleys**" from the part about mechanics were

mentioned. Meanwhile, at the Pavilion the most cited exhibit name was the "**Shadowbox**", followed by "**Billiard**" and the "**Lariat chain**". All these exhibits are quite intuitive and easy to understand. The following two questions regarding the texts were asked in a slightly different manner in the two exhibitions. At the Museum, participants were asked if they had read the text in general, while at the Pavilion, they were asked if they had read the instructions on how to interact with the exhibits. This variation in questioning was because, at the Museum, texts in the main panels were only available in Portuguese, while English texts were written on some sheets spread across the exhibition but not very visible. By asking if they had read the text in general first, the researcher could avoid asking any other questions regarding the texts.

2.2.6 Did you read the texts?

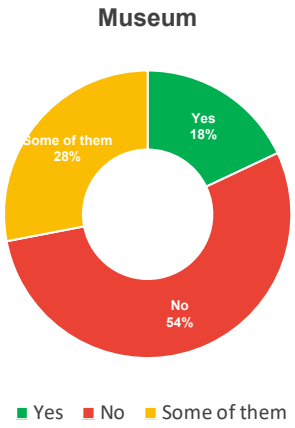


Figure 20 – Distribution of respondents on whether or not they read the texts

Table 11 – Distribution of respondents on whether or not they read the texts

Did you read the texts?	***Museum***
Yes	9
No	28
Some of them	13

As seen before, the majority of visitors at the Museum were not Portuguese and that explains the high percentage of people that didn't read the texts.

2.2.7 Did you read the instructions on how to interact with the exhibits?

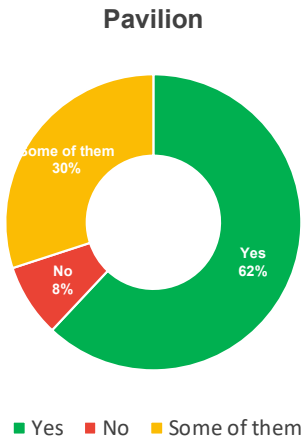


Figure 21 - Distribution of respondents on whether or not they read the instructions on how to interact with the exhibits

Table 12 – Distribution of respondents on whether or not they read the instructions on how to interact with the exhibits

Did you read the instructions on how to interact with the exhibits?	***Pavilion***
Yes	31
No	4
Some of them	15

At the Pavilion the vast majority of visitors interviews read the instruction on how to interact with the exhibits.

2.2.8 Did you read the instructions before or after touching the exhibits?

Figure 22 – Distribution of respondents on whether they read the instructions before or after touching the exhibits

Table 13 – Distribution of respondents on whether they read the instructions before or after touching the exhibits

Did you read the instructions before or after touching the exhibits?	***Museum***	***Pavilion***
Before	19	34
After	4	8
Sometimes before sometimes after	-	4
TOT	23	46

The data indicates that most visitors engaged with exhibit texts before interacting with the exhibits. Some of them read the instructions after touching the exhibits and only at the Museum some did it sometimes before others after.

2.2.9 Did you read the physics explanations?

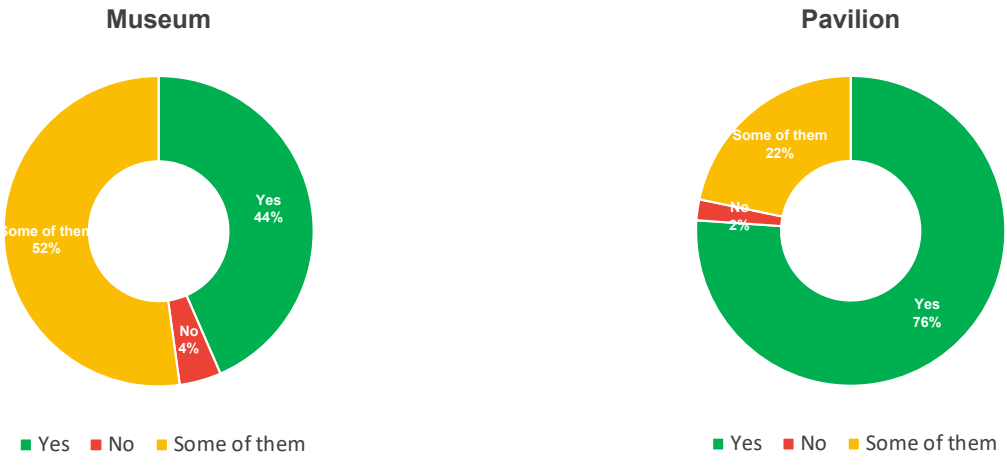


Figure 23 – Distribution of respondents on whether or not they read the physics explanations

Table 14 – Distribution of respondents on whether or not they read the physics explanations

Did you read the physics explanations?	***Museum***	***Pavilion***
Yes	10	35
No	1	1
Some of them	12	10
TOT	23	46

Most people who read the texts in both exhibitions also read the explanations and not just the instructions.

2.2.10 If you read the explanations, did you find them easy to follow?

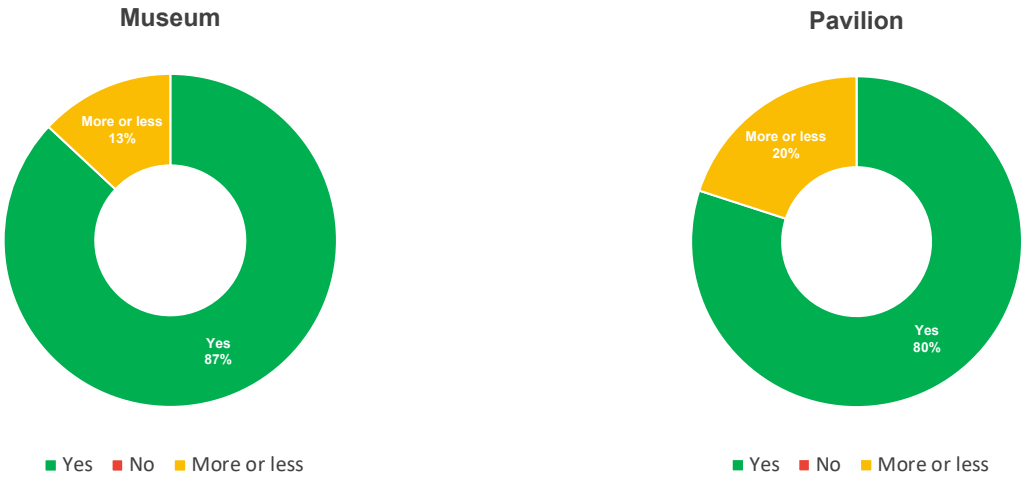


Figure 24 – Distribution of respondents on whether they found the physics explanations easy to follow

Table 15 – Distribution of respondents on whether they found the physics explanations easy to follow

If you read the explanations, did you find them easy to follow?	***Museum***	***Pavilion***
Yes	19	36
No	-	-
More or less	3	9
TOT	22	45

It is interesting to see that nobody among the ones who read the explanations found them difficult to follow.

In the two exhibitions, two questions regarding the presence of guides were asked differently. At the Museum, there were no guides available, whereas, at the Pavilion, 2-3 guides were always present. Therefore, visitors to the Museum were asked if they would recommend the presence of a guide, while visitors to the Pavilion were asked if they had spoken to any of the available guides.

2.2.11 (Museum) Would you suggest the presence of a guide?

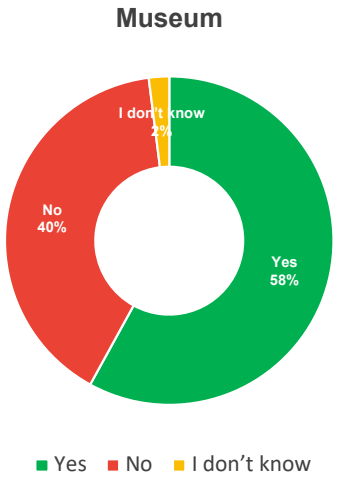


Figure 25 – Distribution of respondents on whether they would suggest the presence of a guide at the Museum

Table 16 – Distribution of respondents on whether they would suggest the presence of a guide at the Museum

Museum	
Would you suggest the presence of a guide?	Frequency
Yes	29
No	20
I don't know	1

2.2.12 (Pavilion) Did you talk with one of the guides in the room?

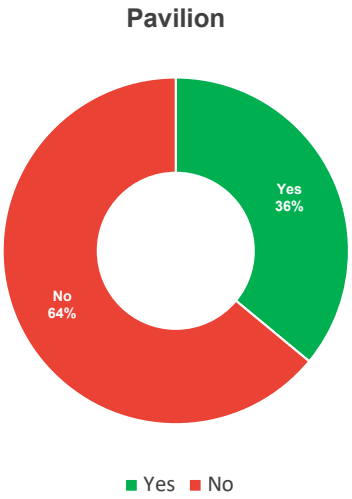


Figure 26 – Distribution of respondents on whether they talked with at the Pavilion?

Table 17 – Distribution of respondents on whether they talked with at the Pavilion

Pavilion	
Did you talk with one of the guides in the room?	Frequency
Yes	18
No	32

The data indicates that over 50% of the visitors to the Museum who explored the exhibits on their own expressed the desire for expert assistance. However, the remaining half felt that it was unnecessary. On the other hand, at the Pavilion, which has 2-3 guides present at all times, less than half of the interviewed visitors actually interacted with one of them.

2.3 What are visitors' preferences in an interactive Physics exhibition and how would be possible to improve it?

The data presented in this section are the ones selected to answer the second research question stated in the title of this section. Answer to the open questions were analysed by thematic analysis and the

frequency of the themes emerged was counted. The data will be presented in the same order as the questionnaire.

2.3.1 What exhibit did you enjoy the most?

Table 18 – Distribution of respondents on their favourite exhibit

Museum		*Pavilion*	
Name of the exhibit	Frequency	Name of the exhibit	Frequency
The invisible light	6	Shadow Box	7
Playing with air current	5	Plasma sphere	5
Windows or mirror?	5	Tornado	5

Figure 27 – "The invisible light"

Figure 28 – "Shadow Box"

Figure 29 – "Playing with air current"

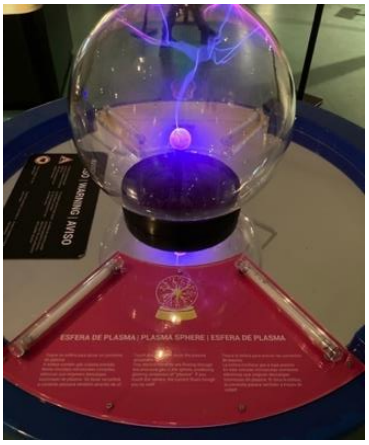


Figure 30 – "Plasma sphere"

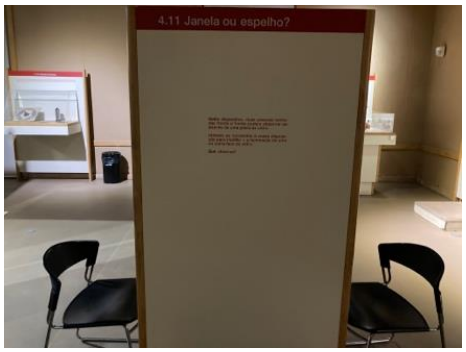


Figure 31 – "Windows or mirror?"

Figure 32 – "Tornado"

At the Museum it was found that the most appreciated section of the exhibition was the last part about Optics. In that section, there were two exhibits particularly popular that were "**The Invisible Light**" and "**Windows or Mirror?**". The first one, the most appreciated one, consists of a collection of rocks that, after pressing a button, get lighted by an ultraviolet light. They are made of a particular material that captures the light and reemits it making the rocks shine after the light turns off. The "Windows or Mirror" consist of a table with two chairs separated by a panel of glass. From each side, there is a light pointing to the face of the person sitting. When the light is off the two persons see each other through the glass. When the light is on, in place of the other person's face they see their face as the glass turned from a window to a mirror. Another exhibit that people enjoyed a lot was "**Playing with air current**", where a stream of air keeps a ball suspended.

At the Pavilion the module that visitors enjoyed the most was the "**Shadow Box**". In the exhibit at the touch of a button, a flash of light appears, and people can see their shadow imprinted on the wall for a while. This happens because the wall is made of zinc sulphide crystals that continue to glow even after the light has stopped shining on them. The other two most appreciated exhibits were the "**Plasma Sphere**" and then the "**Tornado**". The first one consists of a sphere with a rarefied gas inside. By establishing a potential difference between the central region of the sphere and its surface, a spark appears which ionises part of the gas: the ions formed by the light rays form a plasma. Hand or finger contact favours this process making people impressed when they touch it. The second one recreates a tornado on a small scale. In nature, this phenomenon forms due to temperature differences that cause changes in atmospheric pressure. Tornadoes form from above and they go down, but in the exhibition, a fan pulls the circulating air upwards.

2.3.2 What did you like about it?

Table 19 – Distribution of respondents on what they enjoyed of their favourite exhibit

Theme	***Museum***	***Pavilion***
Interesting	4	3
Beautiful/fascinating	4	-
Visually impressive	3	7
Funny	2	2
New/Surprizing	2	3
Related to something personal	1	1
Real-life application	-	1

When asked why they found a particular exhibit enjoyable, visitors gave some adjectives of features to describe why they liked it. The data shows that the visual effect is particularly effective in making a module attractive, more than its engagement. That is especially true at the Pavilion where the most

appreciated feature of the exhibits was how much they were visually impressive. Along with the visual effect also how much a module is beautiful, funny and original makes it attractive to people.

2.3.3 What was the exhibit most difficult to understand?

Table 20 – Distribution of respondents on the most difficult exhibit

Museum		***Pavilion***	
Name of the exhibit	**Frequency**	**Name of the exhibit**	**Frequency**
Holography	4	Island of Light	11
Playing with air current	3	Visible Effects of the Invisible	5
Magnetism	3	Billiard	4
No one	18	No one	5

Figure 33 – "Holography?"

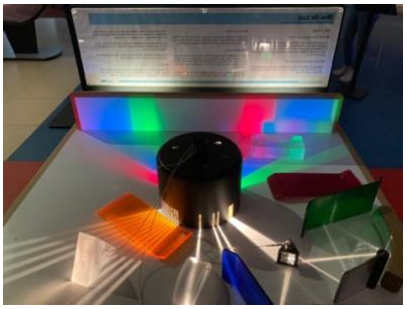


Figure 34 – "Island of Light"

Figure 35 – "Playing with air current

Figure 36 – "Visible Effects of the Invisible"

Figure 37 – "Magnetism"

Figure 38 – "Billiard"

It noticeable that at the Museum 18 persons said that they did not find any exhibit that was difficult to understand while at the Pavilion only five persons said that. At the Museum, among the ones that found it, the most challenging module to understand was the one about "**Holography**", followed by "**Playing with air current**" and "**Magnetism**" in general. The first one shows the image of a car created as a hologram, while "Magnetism" comprehends a series of exhibits that show and explain phenomena like electromagnetic induction or alternative and continuous current. It is interesting to notice that "Playing with Air Current" is also one of the most appreciated, which means that it is enjoyable, but at the same time, people do not understand how it functions.

At the Pavilion more people found a module difficult to understand and the three most cited were: the "**Island of Light**", "**Visible Effects of the Invisible**" and the "**Billiard**". In the first exhibit, visitors can explore light using mirrors, lenses, prisms or filters. Mirrors reflect light and allow you to superimpose lights of different colours. Lenses allow light rays to be brought together or pulled apart, depending on convergence or divergence, and prisms work separating white light into the colours of the rainbow. In the second one, the vibration of the loudspeaker creates sound waves, vibrations of compressed air that travel through the tube, touch the sealed end and return. At certain frequencies, the waves travelling through the tube reinforce those already being reflected, forming a stable pattern known as a "standing wave". Finally, "Billiard" consists of three billiard tables shaped as a parabola, a hyperbole and an ellipse. This exhibit wants to show visitors the mathematical properties of the focus of these three curves through the use of a billiard ball.

All these three require a high level of interaction. Especially the "Island of Light" is made of several components that are meant to be touched and handled by visitors.

2.3.4 What did you not understand about it?

Table 21 – Distribution of respondents on the main difficulties encountered

Theme	***Museum***	***Pavilion***
The principle	5	3
The purpose	-	1
Didn't see the expected result	1	4
Text explanation	2	2
Didn't put much effort to understand	-	7
How to interact	-	2
It was not intuitive	2	1

Visitors had trouble understanding the principle behind the module, which refers to the physical explanation of how the exhibit functions. Additionally, many people at the Pavilion did not see the expected results from the exhibits, and some others did not put in much effort to understand them.

2.3.5 Do you have any suggestions for future improvement?

Table 22 – Distribution of respondents on their suggestions for future improvement

Theme	***Museum***	***Pavilion***
Add text in other languages	*26*	*1*
A guide in the room	*8*	*-*
Add more explanatory pictures/videos	*6*	*4*
Indicate a clear path to follow	*6*	*-*
Make it more for children	*4*	*2*
Reduce the number of exhibits	*1*	*-*
Add new exhibits	*1*	*4*
Simplify the texts	*2*	*8*
Others	*2*	*5*
Explain some real-life applications of what exposed	*-*	*1*
None	*4*	*30*

More than half of the people interviewed at the Museum said that they would like to see texts in the main panels also in English or other languages. Other frequent suggestions were to add more pictures or videos that support the text, to make the understanding easier and to help those who do not speak the language of the text. Some people suggested making the exhibition more for children and at the Museum a guide to which ask for help would be appreciated.

To summarise, the main suggestions on how to improve the interactive exhibitions were:

- Simple texts in Portuguese and in English.
- Some pictures and videos that explain with images what the text says in words. People do not like to read much.
- A mix of very simple exhibits more for children and others more complex for adults.
- The presence of a guide to help visitors and provide more information is needed

CHAPTER 3 – Discussion

3.1 Summary of key findings

In this section, a list of key findings from the collected data is presented. The interpretations of the results will be discussed in the following section.
Key findings from both the exhibitions:

1. The data show that most visitors were generally interested in Physics and already familiar with most of the presented concepts.
2. Based on the data, many visitors reported gaining new knowledge from interactive Physics exhibits, but only a few were able to articulate what they had learned.
3. Most of the interviewees answered affirmatively when asked if they were feeling more curious about Physics after the visit.
4. From the data, it emerges that visitors who read the texts mostly read the instructions and explanations in the order they are presented and physics explanations are usually considered easy to follow.
5. The results indicate that the visual effect is one of the key features that makes an exhibit attractive. All the most appreciated modules share this feature, along with being funny, beautiful, and surprising.
6. The data suggests that a module requiring a high level of interaction may not necessarily get people engaged with it. Almost all the most appreciated exhibits did not require much interaction.
7. Moreover, the exhibits that visitors found most challenging are those that require prior knowledge or higher levels of interaction. It also emerges that many visitors didn't put much effort into understanding what was not immediately clear or required more reasoning to understand.
8. The feedback given by visitors indicates that the following factors could help improve the effectiveness of Physics interactive exhibitions:
    - Simplify texts in the local language of the country and English, reducing the number of words and using bigger font sizes and colours to make it more appealing.
    - Add pictures and videos that explain the text with images, to avoid visitors reading too much.
    - Include a mix of simple exhibits for children and more complex ones for adults, to allow people of different ages to share the same space and enjoy the exhibition.
    - Hire guides to help visitors understand the exhibits if asked. They could also provide brief lessons about Physics through guided experiments.

3.2 Discussion of results

Do interactive exhibitions effectively convey Physics concepts and stimulate curiosity among visitors?

Aiming to answer this question, the study addressed the following sub-questions:

3.2.1 Do visitors learn something new while visiting an interactive physics exhibition?

According to the survey, 50% of the visitors to the Museum and 84% of the visitors to the Pavilion claimed to have learned something new about Physics. However, when asked to provide an example of what they had learned, most of them failed to articulate an answer and just mentioned the name of one or two modules. This suggests that the visitors might have gained some new knowledge, but not to a significant extent. This is in line with expectations since most of the people who visit a science centre or a museum, do it for entertainment and fun, not necessarily to acquire new knowledge. It is difficult to expect visitors to make an effort to understand a Physics concept. Nonetheless, many of them felt that they had learned something new or that the visit had refreshed their memory of concepts they had studied in school.

The same conclusion was reached by Laçin-Şimşek & Öztürk (2021a) in their research on visitors' opinions and understanding of exhibits and labels in a science centre in Turkey. They found that most visitors stated that they understood what was aimed to be explained in the exhibit. However, when asked what they understood, it was determined that most of them could not give the expected answer, made incorrect explanations, and described how the exhibit worked or their observations.

It is important to consider these results when thinking about the role of science centres and museums in society. To improve their educational value, it is necessary to enhance the effectiveness of conveying Physics concepts through interactive exhibitions. It would be useful to focus on creating exhibits that not only engage visitors but also encourage a deeper understanding of Physics principles. Guides who can clarify complex exhibits and explain the underlying theories of those phenomena can be a great help in achieving this goal. As Caulton stated (1998), most interactive centres have educational goals, and mediation by staff can enhance the learning process by guiding parents to help their children learn more from their interactions with the exhibits.

Another crucial factor in improving visitors' understanding of Physics is visual explanations. According to several interviewees, using explanatory videos or images would be more effective for conveying Physics concepts than a lengthy paragraph of text.

3.2.2 Do visitors feel more curious about physics after visiting an interactive exhibition?

Based on the answers provided by the interviewees, it was found that most of them felt more curious about physics after visiting an interactive exhibition, which was in line with expectations. This could be attributed to the fact that interactive exhibitions allow people to see and touch things that they may not have seen before or only studied in books. This is perhaps the biggest potential of interactive exhibitions, as they provide a new perspective and integrate difficult concepts into accessible activities, which can provoke a sense of wonder in front of science, something that is not commonly found in scholastic environments. Moreover, curiosity is the driving force that encourages people to interact with the exhibits and that leads them to learn. As Csikszentmihalyi & Hermanson (2016) stated, after the individual's curiosity is aroused, the exhibit must engage sustained interest for learning to take place. Allen (2004) explains how curiosity drives the inquiry cycle leading to learning. He discusses how exhibits' designs play a fundamental role in stimulating curiosity. Visual effects, small competitions, and group engagement are just a few features that can enhance engagement and curiosity among visitors. Text design also plays an important role in stimulating curiosity. Providing instructions on what to do and then asking questions is an effective way to help people wonder what to expect.

This is the approach adopted by the two exhibitions examined and is a standard setting for this type of exhibition. Another feature that emerged from the interviews and that could make a difference in stimulating interest is presenting some real-life applications of the physics concepts explained in theory. This can help people realize how much science is structurally integrated into our society and present in our everyday lives.

3.2.3 How do visitors engage with texts?

Understanding how visitors engage with exhibit texts is crucial to determine the significance of texts in exhibitions and how to use them in the most effective way possible. To understand how visitors interact with exhibits, it is important to know whether they follow instructions or prefer to do it themselves before reading the text. Based on the interview results, it appears that most visitors read texts, usually, they read the instructions before touching and then the explanations. However, specific conditions must be met, like easily available English translations.

A similar result was found as well by Laçin-Şimşek & Öztürk (2021a) who reported that visitors mostly noticed and read the labels in a science centre. In the study of McManus (1990), it was also determined that the majority of the visitors read the labels. Caulton (1998) stated that people are more

likely to read the labels in the first part of their visit, namely before they get tired. In his research, it was also found that most visitors who read the labels stated that they understood the information on the labels and just a few of them did not understand them. Therefore, according to the data and other previous studies, it can be inferred that visitors read the labels and they usually do it in the intended order. So, they read the instructions before interacting with the modules, and the scientific explanations afterwards.

From the data emerges also that in general, visitors found the physics explanations to be easily understandable. As reported also by Laçin-Şimşek & Öztürk (2021a) most visitors interviewed, reported that they found the labels sufficient and some stated that they were superficial. Visitors said that the labels could be more colourful and noticeable and suggested that they could be written more clearly and with large fonts. Moreover, some of the visitors stated that the labels can be supported with visual items, tablets, photographs, and videos. (Laçin-Şimşek & Öztürk, 2021a)

This result highlights the fundamental role played by exhibits' texts. Therefore, it is important to organize the labels in a way that is understandable and appealing to all ages. Caulton (1998) gives four simple stages that could help ensure that labels are effective:

1. The target audience should be clearly defined.
2. The proposed text should be analysed for grammatical content and reading level. The educational context.
3. The proposed text should be evaluated by teachers specialising in the language development of the target age group.
4. Lastly, and most importantly, the text should be evaluated with children (preferably alongside the prototype exhibit and associated graphic images).

What are visitors' preferences in an interactive physics exhibition and how would be possible to improve it?

Aiming to answer this question, the study addressed the following sub-questions:

3.2.4 Which specific exhibits do visitors find most enjoyable, and what factors contribute to their enjoyment?

The data show that the three most appreciated exhibits at the Museum were: "Invisible Light", "Windows or Mirror?" and "Playing with Air Current". At the Pavilion the most appreciated exhibits were: "Shadow Box", "Plasma Sphere" and "Tornado". One characteristic that all these exhibits share is that they require minimal interaction by the visitors. This means that visitors, to interact with the

exhibits, had to either simply press a button, as in the case of the "Shadow Box" or “Invisible light”, or simply touch it without any particular action, as in the case of the "Plasma Sphere" or just to look at it as in the case of the “Tornado”. Moreover, from visitors’ feedback, it emerged that one of the most important features that makes these exhibits enjoyable is their visual effects, along with being beautiful, funny, and surprising. This contrasts with the belief that exhibits that require high interaction are the most popular.

For example, according to Laçin-Şimşek & Öztürk (2021b), the most popular exhibits are those that involve high levels of interaction between visitors and the exhibit (the use of pistons, handles, buttons, or tools, the necessity of taking an action in the exhibit, the occurrence of a clear reaction to the action visitors take, etc.), are open to manipulation, contain easily observable situations, and have a fun aspect.

In a similar study on the relationship between exhibit characteristics and attraction, holding power, and visitor engagement levels, Boisvert and Slez (1994) found that attraction levels were highest for exhibits with concrete presentations. Holding power was highest for exhibits with high interaction and concrete presentations and engagement levels were highest for high-interaction exhibits.

Sandifer (2003) found that, between the four exhibit characteristics that he identified (technological novelty, user-centeredness, sensory stimulation, and open-endedness) two of these characteristics, technological novelty and open-endedness have positive correlations with the amount of time spent by visitors at exhibits. An exhibit was considered to be technologically novel if it met at least one of the following criteria: 1. The exhibit contained visible state-of-the-art devices. 2. The exhibit, through the use of technology, illustrated phenomena that would otherwise be impossible or laborious for visitors to explore on their own. Instead, it was considered to be open-ended if it met at least one of the following criteria: 1. The exhibit allowed for the achievement of multiple visitor-set goals. 2. The exhibit allowed for one goal to be achieved in multiple ways.

It seems that the only characteristic that the most appreciated exhibits, found in this study, share is the technological novelty, while the open-endedness is completely absent. However, it is important to notice that the study conducted by Sandifer (2003) was in a different interactive exhibition and he used a different methodology consisting of visitors’ tracking and observation, instead of direct interviews.

Nevertheless, this finding suggests that high interaction does not always mean more visitor engagement. Therefore, improving the visual appeal of an exhibit while maintaining its complexity can be an effective way to draw visitors and present them with scientific concepts.

3.2.5 Which exhibits do visitors find most challenging to understand, and what factors may contribute to these challenges?

The data indicate that the three most challenging exhibits at the Museum were "Holography", "Playing with air current" and "Magnetism". At the Pavilion the most challenging exhibits were: "Island of Light", "Visible Effects of the Invisible" and "Billiard". These exhibits present phenomena that are not very intuitive and that compared to other exhibits need more prior knowledge to be understood. Moreover, the ones at the Pavilion require more complex interaction compared to the remaining exhibition. Therefore, these results suggest that exhibits that require more prior knowledge and complex interaction are usually the most difficult to understand. Additionally, from visitors' feedback emerged that the most challenging thing to understand was the principle of the exhibits but also many admitted that they didn't put much effort into understanding it.

Laçin-Şimşek & Öztürk (2021b) also said that visitors quickly gave up on exhibits that were not easily understood or could not be observed clearly and easily even if they were open to interaction. In addition, exhibits that require prior knowledge were less frequently preferred. Therefore, it's important to consider that visitors may not invest much effort in understanding complex or unclear concepts. That suggests the development of exhibits that can convey simple physics concepts to a fundamental level and the design of exhibits that prioritise visitor experience over the complexity of interactions. Integrating text with multimedia elements to explain better concepts otherwise difficult to digest, can be a winning choice for this purpose.

3.3.6 What suggestions do visitors provide to enhance and improve the overall exhibition experience?

A common suggestion was to make the text more reader-friendly, by increasing the font size and possibly replacing text with multimedia elements such as videos or images. Other suggestions were for example adding some new exhibits occasionally, making the exhibitions more for children and indicating a clear path to follow. Remarkably, nobody suggested more complex exhibits or more details in the physics explanations. On the contrary, visitors mostly asked for easier texts and less complex exhibits. This helps to understand better the mental attitude that visitors usually have when they enter an interactive exhibition, which is not really learning-oriented.

At the Museum, it was evident that the main panels lacked an English translation. Therefore, it is crucial to consider that visitors come from diverse backgrounds and providing text in English, in addition to the local language, is necessary.

In general, collecting feedback from visitors is a constructive way to enhance an exhibition. It is highly recommended that curators include a section at the end of the exhibition where visitors can

provide their feedback. This could be done through a QR code, a book or a tablet with an open questionnaire. There are several ways to gather people's opinions, and it should not be underestimated how valuable those opinions can be.

3.3 Limitations of the study

The data obtained from this study provide several useful recommendations that could be implemented to enhance the two exhibitions that were analysed, as well as other interactive exhibitions in general. However, it is important to recognise the limits of this study to evaluate the validity of the findings presented. Some factors that may have affected the generalizability of the sample data analysed and the results obtained from it were identified. Recognizing the limitations of this study is not only crucial for critical awareness of the findings but also guides future researchers interested in investigating the same area.
The limitations identified are listed below:

1. **Limited sample size:**

Fifty people were interviewed per exhibition. Although it is not a small number, it is recognized that a larger sample size could have allowed for a greater representativeness of the museum's visitor population.

2. **Language barrier and text accessibility:**

The language barrier was particularly evident at the National Museum of Natural History and Science, where the texts on the panels were only available in Portuguese, with just some sheets with English translations around. Non-Portuguese-speaking visitors who did not find or read the translations might have had a different experience compared to those who did. This affected the depth of understanding and engagement with the exhibits of foreign visitors.

3. **Exhibition-specific factors:**

The findings are specific to the two interactive Physics exhibitions that were studied. It should be noted that extrapolating the results to other interactive exhibitions without considering the unique characteristics of those exhibits could be a limitation.

Final remarks

This thesis aimed to provide valuable insights into visitors' experiences in interactive physics exhibitions. The objective was to gain an understanding of the effectiveness of two exhibitions in conveying physics concepts to visitors and stimulating curiosity in the subject. Additionally, the study analysed visitors' personal preferences, challenges faced, and suggestions regarding the exhibits. The central questions for this research were as follows:

1. Do interactive exhibitions effectively convey Physics concepts and stimulate curiosity among visitors?
2. What do visitors like the most in an interactive Physics exhibition and what suggestions would they give to improve it?

Based on the feedback provided by the visitors, it appeared that most of them had gained new knowledge or recalled information from their prior studies. However, when asked to articulate what they had learned, the majority struggled to answer, and instead only remembered the name of one or two exhibits. Despite this, many visitors expressed feeling more curious about Physics after attending the exhibition. It was also found that most of the visitors were generally interested in Physics before the visit and already quite familiar with the concepts presented. Additionally, data shows that visitors who read the texts mostly read the instructions and explanations in the order they were presented and physics explanations were usually considered easy to follow.
Similar results were obtained in other studies. According to a study conducted by Laçin-Şimşek & Öztürk (2021a), most visitors claimed to have understood the information presented in the exhibit. However, when questioned about their understanding, it was discovered that most of them were unable to provide the correct answer. Instead, they gave incorrect explanations, described how the exhibit worked or shared their observations. They report that visitors mostly noticed and read the labels. In the study of McManus (1990), it was also determined that the majority of the visitors read the labels. In his research, Caulton (1998) stated that people are more likely to read the labels in the first part of their visit, namely before they get tired.
These findings are valuable resources for defining visitors' attitudes when entering an interactive exhibition, managing their expectations, and understanding the educational role of interactive exhibitions. The study suggests that people primarily visit interactive exhibitions to enjoy and discover, rather than to learn. Therefore, interactive exhibitions may serve as a place for people to increase their curiosity about Physics, rather than to gain in-depth knowledge about it. However, it

clear that labels are a fundamental factor in understanding the exhibits and it has been determined that they are mostly read. Therefore, it is important to organize them in a way that is appealing to all ages and understandable.

This study didn't go further than asking visitors if they had learned something or if they had read the exhibit labels. Therefore, while the findings are certainly valuable in terms of understanding visitors' opinions, they may not necessarily be an accurate reflection of how much they have actually learned. To gain a more comprehensive understanding of visitors' grasp of the physics concepts presented in interactive exhibits, future studies could delve deeper and ask more detailed questions about their comprehension of the exhibits. This would provide greater insight into the visitors' overall learning experiences.

Regarding the second research question, data showed that one of the most important features that make these exhibits enjoyable is their visual effects, along with being beautiful, funny, and original. This contrasts with the belief that exhibits that require high interaction are the most popular. For example, according to Laçin-Şimşek & Öztürk (2021b), the most popular exhibits are those that involve high levels of interaction between visitors and the exhibit, are open to manipulation, contain easily observable situations, and have a fun aspect. Additionally, from visitors' feedback, it emerged that the exhibits most difficult to understand were the ones that required more prior knowledge or that involved complex interaction. Finally, some suggestions for improvements were collected. The most common one at the Museum was adding English text to the main panels, while in both exhibitions people suggested using more pictures and videos, simplifying text content, and improving text readability.

Overall, these results provide important insights into visitors' experiences, difficulties, and suggestions for an interactive Physics exhibition. They can be used to improve exhibits in interactive exhibitions, ensuring visitors appreciate them more and can understand them better.

This study is particularly significant for the two exhibitions examined since no previous similar study was conducted there, but it can be useful as well for other interactive exhibitions. The findings could benefit curators looking to create or renew interactive exhibitions. Enhancing the visual effects of exhibits and including the exhibits that resulted as the most appreciated ones from this research. The study also highlights some of the limits of interactive Physics exhibitions, as complex exhibits may be too difficult to understand or ignored by most visitors. The importance of requesting feedback from visitors after their visit cannot be overstated, as it can provide highly precious insights that can be used to improve interactive exhibitions.

Future studies could explore in more detail the features that distinguish the most popular exhibits from the most challenging ones. Other studies could categorise exhibits based on their level or type of interaction, rather than simply asking visitors what they liked. This approach can help to gain a deeper understanding of visitors' engagement with exhibits, going beyond just their preferences.

Bibliography

Allen, S. (2004). Designs for learning: Studying science museum exhibits that do more than entertain. *Science Education*, *88*(S1), S17–S33. https://doi.org/10.1002/sce.20016

Allen, S., & Gutwill, J. P. (2009). Creating a program to deepen family inquiry at interactive science exhibits. *Curator: The Museum Journal*, *52*(3), 289–306. https://doi.org/10.1111/j.2151-6952.2009.tb00352.x

Ayar, M. C. (2016). Examining the Effect of our World Exhibit on student visitors: A Science Center case. *Science Education International*, *27*(3), 419–436. http://files.eric.ed.gov/fulltext/EJ1118424.pdf

Baniyamin, N., & Rashid, M. Z. A. (2016). Understanding science centre engagement in nurturing visitor interest and curiosity. *Procedia - Social and Behavioral Sciences*, *222*, 235–243. https://doi.org/10.1016/j.sbspro.2016.05.152

Barriault, C., & Pearson, D. (2010). Assessing Exhibits for Learning in Science Centers: A Practical tool. *Visitor Studies*, *13*(1), 90–106. https://doi.org/10.1080/10645571003618824

Beiers, R., & McRobbie, C. (1992). Learning in interactive science centres. *Research in Science Education*, *22*(1), 38–44. https://doi.org/10.1007/bf02356877

Boisvert, D. L., & Slez, B. J. (1995). The relationship between visitor characteristics and learning-associated behaviors in a science museum discovery space. *Science Education*, *78*(2), 137–148. https://doi.org/10.1002/sce.3730780203

Castillo-Montoya, M. (2016). Preparing for interview research: The Interview Protocol Refinement Framework. *The Qualitative Report*. https://doi.org/10.46743/2160-3715/2016.2337

Caulton, T. (1998). *Hands-On Exhibitions: Managing interactive museums and science centres* [Book]. http://ci.nii.ac.jp/ncid/BA37857435

Chang, E. (2006). Interactive experiences and contextual learning in museums. *Studies in Art Education: A Journal of Issues and Research in Art Education*, *47*(2), 170–186. https://doi.org/10.1080/00393541.2006.11650492

Colinvaux, D. (2005). Museus de ciências e psicologia: interatividade, experimentação e contexto. *Historia Ciencias Saude-manguinhos*, *12*(suppl), 79–91. https://doi.org/10.1590/s0104-59702005000400005

Csikszentmihalyi, M., and K. Hermanson. 2016. “Intrinsic motivation in museums: Why does one want to learn?”

Dorph, R., Cannady, M. A., & Schunn, C. D. (2019). What drives visitor engagement in exhibits? The interaction between visitor activation profiles and exhibit features. *Curator: The Museum Journal*, *65*(2), 399–416. https://doi.org/10.1111/cura.12324

Eiró A. M., & Lourenço M. C. (2010). *Fernando Bragança Gil Colectânea de textos sobre museus e museologia* [Book].

Erätuuli, M., & Sneider, C. (1990). The experiences of visitors in a physics discovery room. *Science Education*, *74*(4), 481–493. https://doi.org/10.1002/sce.3730740408

Falk, J. H., & Dierking, L. D. (1992). *The museum experience*. http://ci.nii.ac.jp/ncid/BA24556618

Falk, J. H., & Storksdieck, M. (2005). Using the contextual model of learning to understand visitor learning from a science center exhibition. *Science Education*, *89*(5), 744-778. https://doi.org/10.1002/sce.20078

Falk, J. H. (1997). Testing a museum exhibition design assumption: Effect of explicit labeling of exhibit clusters on visitor concept development. *Science Education*, *81*(6), 679–687. https://doi.org/10.1002/(sici)1098-237x(199711)81:6

Gilbert, J. K., & Stöcklmayer, S. (2001). The design of interactive exhibits to promote the making of meaning. *Museum Management and Curatorship*, *19*(1), 41–50. https://doi.org/10.1080/09647770100401901

Haywood, N., & Cairns, P. (2007). Engagement with an Interactive Museum Exhibit. In *Springer eBooks* (pp. 113–129). https://doi.org/10.1007/1-84628-249-7_8

Hooper-Greenhill, E. (1994). *The educational role of the museum*. http://ci.nii.ac.jp/ncid/BA39917050

Jeffery-Clay, K. R. (1998). Constructivism in Museums: How museums create Meaningful learning Environments. *Journal of Museum Education*, *23*(1), 37. https://doi.org/10.1080/10598650.1998.11510362

Laçin-Şimşek, C., & Öztürk, M. (2021a). Opinions and understandings of science center visitors about exhibits and labels. Participatory Educational Research, 8(1), 232–247. https://doi.org/10.17275/per.21.13.8.1

Laçin-Şimşek, C., & Öztürk, M. (2021b). An Examination of Science Center Visitors' Interactions With Exhibits. Museum Management and Curatorship, 37(3), 266–286. https://doi.org/10.1080/09647775.2021.1891560

McManus, P. M. (1990). Watch your language! People do read labels. ILVS Review, 1, 2. http://kora.matrix.msu.edu/files/31/173/1F-AD-331-8-VSA-a0b1m2-a_5730.pdf

Oppenheimer, F. (1968). A rationale for a science museum. *Curator: The Museum Journal*, *11*(3), 206–209. https://doi.org/10.1111/j.2151-6952.1968.tb00891.x

Oppenheimer, F. (1975). The Exploratorium and other ways of teaching physics. *Physics Today*, *28*(9), 9–13. https://doi.org/10.1063/1.3069149

Oppenheimer, F. (1972b). The Exploratorium: a playful museum combines perception and art in science education. *American Journal of Physics*, *40*(7), 978–984. https://doi.org/10.1119/1.1986726

Patton, M. Q. (n.d.). *Qualitative Research & Evaluation Methods: Integrating Theory and Practice*. SAGE Publications.

Pedretti, E., & Iannini, A. M. N. (2020). Towards Fourth-Generation Science Museums: Changing goals, changing roles. *Canadian Journal of Science, Mathematics and Technology Education*, *20*(4), 700–714. https://doi.org/10.1007/s42330-020-00128-0

Rennie, L. J., & Williams, G. F. (2006). Adults' Learning about Science in Free-choice Settings. *International Journal of Science Education*, *28*(8), 871–893. https://doi.org/10.1080/09500690500435387

Rennie, L. J., & McClafferty, T. (1996). Science centres and science learning. *Studies in Science Education*, *27*(1), 53–98. https://doi.org/10.1080/03057269608560078

Sandifer, C. (2003). Technological novelty and open-endedness: Two characteristics of interactive exhibits that contribute to the holding of visitor attention in a science museum. *Journal of Research in Science Teaching*, *40*(2), 121–137. https://doi.org/10.1002/tea.10068

Schwan, S., Grajal, A., & Lewalter, D. (2014). Understanding and engagement in places of science experience: science museums, science centers, zoos, and aquariums. *Educational Psychologist*, *49*(2), 70–85. https://doi.org/10.1080/00461520.2014.917588

Screven C. (1992). Motivating visitors to read labels. *ILVS Review*, 2 (2), 183–221.

Semper, R., Diamond, J., & St John, M. (1982). Use of interactive exhibits in college physics teaching. *American Journal of Physics*, *50*(5), 425–430. https://doi.org/10.1119/1.13072

Sjøberg, S. (2010). Constructivism and learning. In *Elsevier eBooks* (pp. 485–490). https://doi.org/10.1016/b978-0-08-044894-7.00467-x

Voase, R. (2002). Rediscovering the imagination: investigating active and passive visitor experience in the 21st century. *International Journal of Tourism Research*, *4*(5), 391–399. https://doi.org/10.1002/jtr.390

Wareath, O. a. E. (2022b). The role of educational museums in the development of education. *International Journal of Humanities and Language Research*, *5*(1), 36–48. https://doi.org/10.21608/ijhlr.2023.215796.1011

Wellington, J. (1990). Formal and informal learning in science: the role of the interactive science centres. *Physics Education*, *25*(5), 247–252. https://doi.org/10.1088/0031-9120/25/5/307

Sitography

ECSITE | the European Network of Science Centres and Museums. (n.d.). https://www.ecsite.eu/

EdTech Books. (n.d.). *About*. https://edtechbooks.org/about

Exploratorium. (n.d.). Exploratorium. https://www.exploratorium.edu/

Pavilhão do Conhecimento - Ciência Viva - Pavilhão do Conhecimento. (n.d.). Pavconhecimento.pt. https://www.pavconhecimento.pt/

Todo o Universo na cidade | Museu Nacional de História Natural e da Ciência. (n.d.). https://www.museus.ulisboa.pt/

Appendix

A1 Questionnaire *(National Museum of Natural History and Science)*

Code:_____

Matteo Giacomelli Master's Degree in Physics University of Bologna

Physics Interactive Exhibition – Visitor Questionnaire

1. Nationality: _____
2. Age: _____years old → ◯ 18 – 25 ◯ 36 – 40 ◯ 51 – 55 ◯ 66 – 70 ◯ 26 – 30 ◯ 41 – 45 ◯ 56 – 60 ◯ 71 – 75 ◯ 31 – 35 ◯ 46 – 50 ◯ 61 – 65 ◯ 76 – 80
3. In which gender do you identify?
   ◯ Female ◯ Male ◯ Other ◯ I prefer to not answer
4. Are you studying or did you study something related to one scientific area?
   ◯ Yes ◯ No If yes, which one? _____
5. Are you working or did you work in something related to one scientific area?
   ◯ Yes ◯ No If yes, which one? _____
6. Is this your first time at this museum? → 6.1. If not, did you already visit this exhibition?
   ◯ Yes ◯ No ◯ Yes ◯ No
7. What motivated you to come here today?
   _____
8. Did you know about this exhibition before visiting the museum?
   ◯ Yes ◯ No
9. Have you visited an interactive exhibition like this one before?
   ◯ Yes ◯ No If yes, which one? _____
10. Are you in general interested in Physics?
    ◯ Yes ◯ No ◯ More or less
11. Do you feel more curious about Physics after this exhibition?
    ◯ Yes ◯ No ◯ More or less
12. Did you notice that the exhibition is divided into four thematic areas?
    ◯ Yes ◯ No
13. From 1 to 5 how much did you already know about the physics concepts presented?
    Nothing ① ② ③ ④ ⑤ Everything
14. Did you learn something new about Physics today?
    ◯ Yes ◯ No ◯ I remembered something
    14.1. If yes, could you give me an example of what you learned?
    _____

15. Did you read the texts?

◯ Yes ◯ No ◯ Some of them

Yes

16. Did you read the instructions **before** or **after** touching the exhibits?

16.1. Did you read them all along the exhibition or at the end you didn't read them much?

◯ Beginning ◯ Middle ◯ End ◯ All along _____

17. Did you read the physics explanations?

◯ Yes ◯ No ◯ Some of them _____

17.1. If yes, did you find them easy to follow?

◯ Yes ◯ No ◯ More or less _____

18. Did you read the historical information about important physicists and discoveries?

◯ Yes ◯ No ◯ Some of them _____

No

19. Was it intuitive to figure out how to interact with exhibits?

◯ Yes ◯ No ◯ More or less

19.1. If not, which ones were not intuitive?

_____

20. Did you pay attention to the historical scientific instruments exposed?

◯ Yes ◯ No ◯ Some of them _____

21. Would you suggest the presence of a guide to help visitors understand the activities?

◯ Yes ◯ No ◯ I don't know _____

22. Which exhibit did you enjoy the most?

_____

22.1. What did you like about that exhibit?

_____

23. What was the exhibit most difficult to understand?

_____

23.1. What didn't you understand about it?

_____

24. Do you have any suggestions for future improvement?

_____

A2 Questionnaire *(Pavilion of Knowledge)*

Code:_____

Matteo Giacomelli Master's Degree in Physics University of Bologna

Physics Interactive Exhibition – Visitor Questionnaire

1. Nationality: _____
2. Age: _____years old → ◯ 18 – 25 ◯ 36 – 40 ◯ 51 – 55 ◯ 66 – 70 ◯ 26 – 30 ◯ 41 – 45 ◯ 56 – 60 ◯ 71 – 75 ◯ 31 – 35 ◯ 46 – 50 ◯ 61 – 65 ◯ 76 – 80
3. In which gender do you identify?
   ◯ Female ◯ Male ◯ Other ◯ I prefer to not answer
4. Is this your first time at the Pavilhão? → 4.1. If not, did you already visit this exhibition?
   ◯ Yes ◯ No ◯ Yes ◯ No
5. Are you in general interested in Physics?
   ◯ Yes ◯ No ◯ More or less
6. Do you feel more curious about Physics after this exhibition?
   ◯ Yes ◯ No ◯ More or less
7. From 1 to 5 how much did you already know about the physics concepts presented?
   Nothing ① ② ③ ④ ⑤ Everything
8. Did you learn something new about physics today?
   ◯ Yes ◯ No ◯ I remembered something
   8.1. If yes, could you give me an example of what you learned?
   _____
9. Did you read the instructions on how to interact with the exhibits?
   ◯ Yes ◯ No ◯ Some of them
10. Did you read them **before** or **after** touching the exhibits?
    10.1. Did you read them all the exhibits you interacted with or more in first ones?
    ◯ Firsts ◯ Middle ◯ Finals ◯ All _____
11. Did you read the physics explanations?
    ◯ Yes ◯ No ◯ Some of them _____
    11.1. If yes, did you find them easy to follow?
    ◯ Yes ◯ No ◯ More or less _____
12. Did you talk with one of the guides in the room?
    ◯ Yes ◯ No _____
13. If yes, was it useful to understand the physics concept behind the exhibits?
    ◯ Yes ◯ No ◯ more or less _____

14. Which exhibit did you enjoy the most?

_____

14.1. What did you like about that exhibit?

_____

15. What was the exhibit most difficult to understand?

_____

15.1. What didn't you understand about it?

_____

16. Do you have any suggestions for future improvement?

_____

A3 Interview Consent Form *(National Museum of Natural History and Science)*

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

INTERVIEW CONSENT FORM

Thank you for agreeing to be interviewed as part of a master's degree research project conducted by Matteo Giacomelli at the University of Bologna. The project aims to assess the engagement of visitors in Physics interactive exhibitions. To achieve this goal, Matteo Giacomelli will collect and analyze interviews with visitors. Participation in this study is entirely voluntary and involves answering some closed- and open-ended questions about your experience within the physics exhibition hosted at the National Museum of Natural History and Science of Lisbon. You have the right to stop the interview or withdraw from the research at any time, without specific notice or reason. You also have the right to request information about the results and outcome of the research. This consent form is necessary for us to ensure that you understand the purpose of your involvement and that you agree to the conditions of your participation. Therefore, please read the attached information sheet and sign this form to certify that you agree to the following:

- The interview will be recorded in audio format, and a transcript will be produced.
- The transcript of the interview will only be analyzed by Matteo Giacomelli as research investigator and his advisors.
- Access to the interview transcript will be limited to Matteo Giacomelli and his advisors.
- Any summary interview content, or direct quotations from the interview will be anonymized so that you cannot be identified, and care will be taken to ensure that any information in the interview that could identify yourself is not revealed.
- The actual recording will be destroyed within one month from when it is recorded.

I, _____, have read and understood the information provided in this consent form. I voluntarily consent to the recording of the interview, for the purpose of the research project conducted by Matteo Giacomelli. I understand that the data collected will be anonymous, and my identity will not be revealed.

Signature: _____ Date: _____

If you have any questions or concerns about this study or the processing of your interview, please feel free to contact me.

Sincerely, matteo.giacomelli5@studio.unibo.it
Matteo Giacomelli +39 3455687316

A4 Interview Protocol Matrix *(National Museum of Natural History and Science)*

(MUSEUM) – Interview Protocol Matrix	MAIN QUESTIONS	Do interactive exhibitions effectively convey Physics concepts and stimulate curiosity among visitors?			What are visitors' preferences in an interactive Physics exhibition and how would be possible to improve it?		
Interviews questions ↓	Background information	Do visitors learn something new about Physics?	Do visitors feel more curious about Physics after the visit?	How do visitors usually engage with texts?	Which exhibits do visitors enjoy the most?	Which exhibits did visitors find most difficult to understand?	What do visitors suggest to improve in the exhibition?
1. 2. 3. Nationality, Age, Gender	X						
4. Are you studying in the scientific area?	X						
5. Are you working in the scientific area?	X						
6. Is this your first time at the museum?	X						
7. What motivated you to come here today?	X						
8. Have you visited an interactive exhibition like this one before?	X						
9. Are you in general interested in Physics?	X						
10. Do you feel more curious about Physics after this exhibition?	X						
11. Did you notice that the exhibition is divided into four thematic areas?		X		X			
12. From 1 to 5 how did you already know about the physics concepts presented in this exhibition?	X	X					
13. Did you learn/remember something new about physics during your visit?		X					
14. Did you read the texts?				X			
15. Did you read them before or after touching the exhibits?				X			
16. Did you read them all along the exhibition or the end you didn't read that much?				X			
17. Did you read the physics explanations next to each module?				X			
18. Did you find them easy to follow?				X			
19. Did you read the historical information about important physicists and discoveries?		X		X			
20. Was it intuitive to figure out how to interact with modules				X			X
21. Could you give me an example of a module that was very intuitive?					X		
22. Do you think that the presence of a guide would be necessary to improve visitors' understanding?							X
23. Which exhibit did you enjoyed the most?					X		
24. What did you like about that?					X		
25. What was the exhibit most difficult to understand?				X		X	X
26. What didn't you understand about it?						X	
27. Do you have any suggestions for future improvements?							X

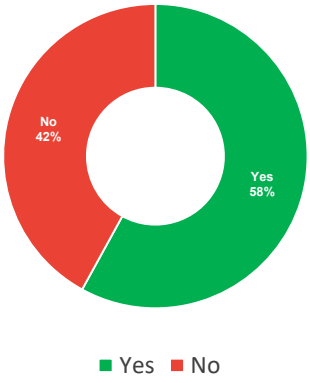
A5 Interview Protocol Matrix *(Pavilion of Knowledge)*

(PAVILION) – Interview Protocol Matrix	MAIN QUESTIONS	Do interactive exhibitions effectively convey Physics concepts and stimulate curiosity among visitors?			What are visitors' preferences in an interactive Physics exhibition and how would be possible to improve it?		
Interviews questions ↓	Background information	Do visitors learn something new about Physics?	Do visitors feel more curious about Physics after the visit?	How do visitors usually engage with texts?	Which exhibits do visitors enjoy the most?	Which exhibits did visitors find most difficult to understand?	What do visitors suggest to improve in the exhibition?
1. Nationality, Age, Gender	X						
2. Is this your first time at the Pavilhão?	X						
3. If not, did you already visit this exhibition?	X						
4. Are you in general interested in Physics?	X						
5. Do you feel more curious about Physics after this exhibition?			X				
6. From 1 to 5 how much did you already know about the concepts presented?	X						
7. Did you learn something new about Physics during your visit?		X					
8. If yes, can you give me an example of something you learned?		X					
9. Did you read the instruction reported in the texts?				X			
10. Did you read them before or after touching the exhibits?				X			
11. Did you read the physics explanations?				X			
12. Did you find them easy to follow?				X			
13. Did you talk with one of the guides in the rooms?				X			
14. Was it useful to understand the physics concept behind the exhibits?				X			
15. Which exhibit did you enjoy the most?					X		
16. What did you like about that exhibit?					X		
17. Which was the exhibit most difficult to understand?						X	
18. What didn't you understand about it?						X	
19. Do you have any suggestions for future improvement?							X

A6 Data collected but not presented in the Findings Chapter

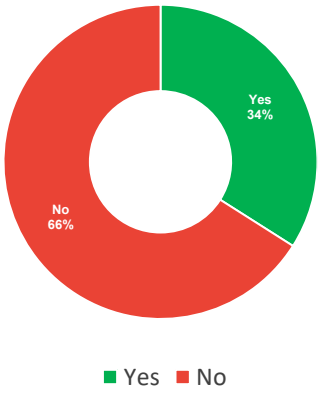
Museum

1. Are you studying or did you study something related to one scientific area?



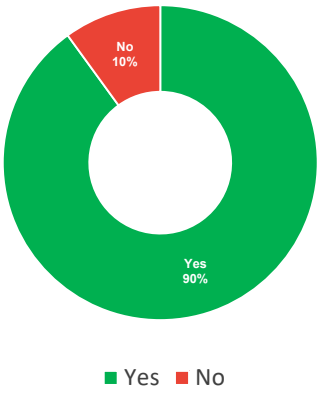
Are you studying or did you study something related to one scientific area?	*Museum*
Yes	29
No	21

2. Are you working or did you work in something related to one scientific area?



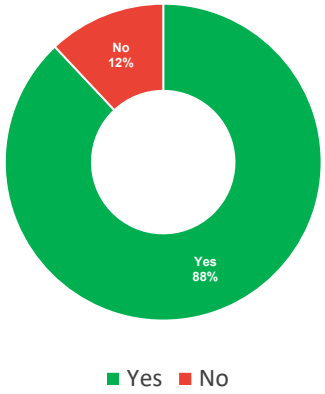
Are you working or did you work in something related to one scientific area?	*Museum*
Yes	17
No	33

3. Is this your first time at this museum?



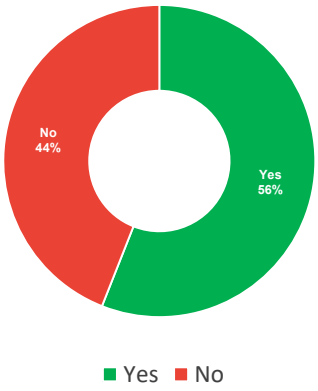
Is this your first time at this museum?	*Museum*
Yes	45
No	5

4. Have you visited an interactive exhibition like this one before?



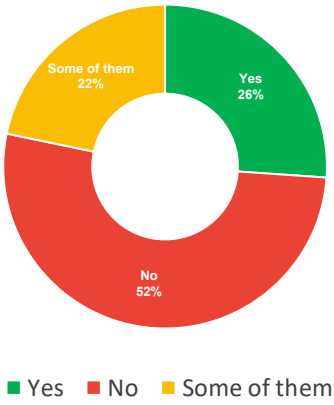
Have you visited an interactive exhibition like this one before?	*Museum*
Yes	44
No	6

5. Did you notice that the exhibition is divided into four thematic areas?



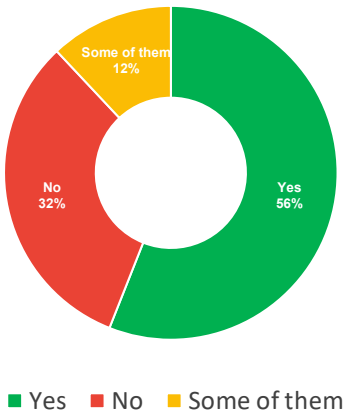
Did you notice that the exhibition is divided into four thematic areas?	*Museum*
Yes	28
No	22

6. Did you read the historical information about important physicists and discoveries?



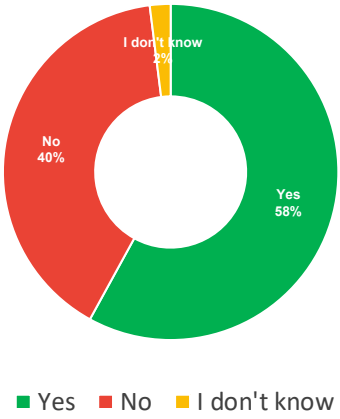
Did you read the historical information about important physicists and discoveries?	*Museum*
Yes	6
No	12
Some of them	5

7. Did you pay attention to the historical scientific instruments exposed?



Did you pay attention to the historical scientific instruments exposed?	*Museum*
Yes	28
No	16
Some of them	6

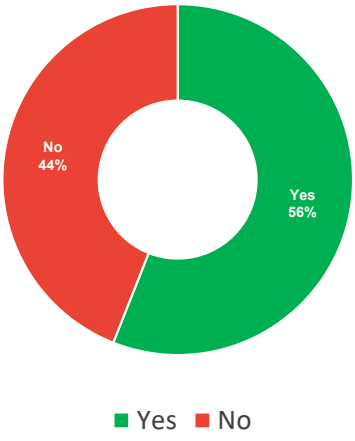
8. Would you suggest the presence of a guide to help visitors understand the activities?



Would you suggest the presence of a guide to help visitors understand the activities?	*Museum*
Yes	29
No	20
Some of them	1

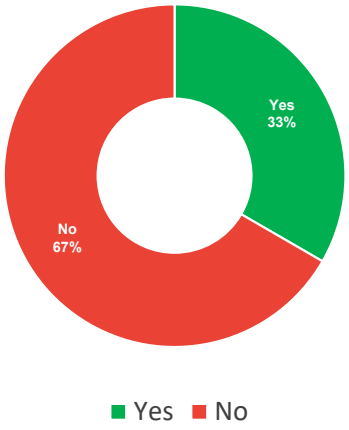
Pavilion

1. Is this your first time at the Pavilion?



Is this your first time at the Pavilion?	*Pavilion*
Yes	28
No	22

2. Did you talk with one of the guides in the room?



Did you talk with one of the guides in the room?	*Pavilion*
Yes	18
No	36