Understanding physics in museums: the role of interactivity

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Abstract

This thesis focuses on the understanding of physics in museums. The approach of the study considers the relationship between visitor and object/phenomenon presented in a museum as central, attempting to describe the role that sensory experiences play in the learning process. The intuitive understanding of reality is examined in the context of the theories of learning and interpretation. Visitor observation is carried out in two different science centres in the city of Gothenburg, Sweden, in order to describe the attracting and holding power of two exhibits. The results from a visitor survey are analysed, and interviews with people relevant to the topic are carried out with the aim of discussing interactivity and other aspects of physics learning in museums. The study concludes that multiple sensory experiences are an asset that can allow museums to cater meaningful learning experiences to a diverse audience. Evaluation should be carried out to asses the engagement of visitors as a measurement of the success of science exhibitions in promoting joyful understanding and contributing to the scientific literacy of societies.

1. Introduction

1.1. Aim and objectives

Aim

To study the role of the senses in the performance of museum exhibits displaying physics-related content.

Objectives

To explore the theoretical frameworks of learning theory, communication theory and interpretation theory and how they relate to the understanding of natural science.

To discuss the definition/s of interactivity in the museum context.

To explore the role of the senses in interactive experiences, with a special focus on the combination of multiple senses.

To explore different models of interactive experiences in museums and to identify their effectiveness in communicating scientific ideas.

To compare the role that different senses play in the engagement of the visitors interacting with displays exhibiting physics related content in two different science centre settings in Gothenburg.

1.2. Theoretical framework

> ‘Strange! I don’t understand how is it that we can write mathematical expressions and calculate what the thing is going to do without being able to picture it!’
>
> Richard Feynman, Physics Nobel Prize, 1965.

This quote from Richard Feynman, an outstanding character in the recent history of physics, points out one of the central aspects this work attempts to address. Our perception of the world, and more formally, the way in which we understand physics, is ruled by cognitive processes that deeply involve our use of the senses. Awareness of this fact can provide science museums with useful tools to effectively transmit knowledge, values, and attitudes to their visitors.

In order to explore this core question, this research piece will try to frame the topic in the theoretical frameworks of learning, communication and interpretation theory. The definition of interactivity and the role of the senses in it will be also discussed under the first part of this study, as an introduction to the analysis of fieldwork data carried out in two different science centres in the city of Gothenburg.

1.2.1. Approaches to learning

The theoretical insights of the learning processes have been extensively studied during the recent history of pedagogy (Csikszentmihalyi, 1990; Gardner, 1993). The way in which humans acquire knowledge and experience and adapt to different contexts has been analyzed and explained from different perspectives. From behaviourism, that set the basis for a long tradition of static, non-adaptive teaching, characterized by a unidirectional transmission of information, to the radical constructivism theories, researchers have been trying to understand and optimize learning experiences. The traditional academic methods constituting the formal education approach have failed to be universal and applicable in every situation (Gardner, 1991). Museums have found a niche in the education field that can be filled with new methodologies and activities based on active learning (Clarke, 2000; Hein, 1998, 1999; Hooper-Greenhill, 1999). The enthusiasm with which constructivist theories have been or are being adopted in many museums has allowed the creation of a new learning environment, also featuring new roles for educators and students (Hooper-Greenhill, 1999). As a facilitator for active learning, the museum educator has the opportunity to enhance the processes of constructing meaning driven by the learner (Hein, 1999). Acquiring the skills to ‘read’ objects in an effective way is one of the challenges that can be explored by educators willing to develop a set of new tools to connect with their audience. Rediscovering the fascination hidden in objects and phenomena can result in opening up new communication paths with the visitor and continuous self-education for the museum staff (Shuh, 1999).

1.2.2. Formal and informal learning environments

There is a continuing debate around whether there is a difference between formal and informal learning (Anderson *et al*., 2003). Constructivism approaches suggest that ‘learning is learning’ (Dierking, 1991), and Falk and Dierking (1992) have pointed out the importance of the physical, social, and personal contexts in which learning occurs. For the scope of this work, though, some special features of formal and informal environments will be considered and the tools they can both provide to enhance learning processes will be taken into account. Figure 1 exemplifies one of these characteristics. The time spent at formal educational settings (school, university, etc.) is much less than that spent in all other settings. It is in the last context in which museums have the opportunity to offer engaging experiences that can lead to learning outcomes. The time frame is obviously wide, as it is as well the number of other activities ‘competing’ with the museum.

Fig.1. Waking time spent in formal and informal learning environments (image provided by Sten Ljungström)

In his analysis of sources of informal learning and their influence in what we call ‘scientific literacy’, Lucas (1983) defines ‘accidental’ and ‘deliberate’ encounters with learning sources. Although museums obviously work within the frame of deliberate encounters, the experience of accidental sources can be a good source for reflection on the understanding of science.

Furthermore, a great deal of information can be extracted from the patterns in which young children acquire knowledge. The works of Howard Gardner (1991, 1999) are especially interesting when it comes to the learning processes in the natural sciences. According to him, the ‘intuitive understanding’ that small children acquire about the physical world around them is universal. This first approach to what physicists would translate into Newtonian physics is a good example challenging the established theories of conceptualization and abstract modelling still driving school curricula planning. The way in which we learn physics in formal settings, critically analyzed by many experiments (for a review, see Gardner, 1991), and comically modelled by Osborne (1984), has proven not to be highly efficient, according to the wide and deep misconceptions concerning the physical world which most adults hold, including physics students (Dussault, 1999; Gardner, 1999; Svanæs, 1999; Jimoyiannis & Komis, 2001). Research shows that conventional instruction is also ineffective in challenging these misconceptions once they are set in the student’s minds (Jimoyiannis & Komis, 2001). Gardner points out at least one reason for this failure. The teaching of theories is usually the first contact with new knowledge in formal learning environments. In the best case, this first contact will be followed by a practical application of the ‘learned’ content. However the order in this chain might be a barrier which is sometimes difficult to overcome. Nilsson (2008, personal communication) has noticed the greater improvement in learning outcomes in educational formal environments when the physical experience of phenomena precedes the teaching of physics theoretical content. Just as young children experiment newtonian physics without knowing the laws ruling it, and, from there, build their intuitive, mental models of the world, allowing students to experience natural phenomena might help in their later understanding of the theory explaining them. Hestenes (1992) describes ‘mental models’, representations of the physical phenomena constructed in the minds of students, and ‘conceptual models’ which originate from the first and are created by the cooperative activities of scientists. In order to engage with the last, learners must build solid mental models in agreement with their daily experiences, and the growing importance of informal learning settings (Wellington, 1990) can provide a niche for it.

Considering a wider frame of the same observable fact, and sharing most of its characteristics with constructivism, the socio-cultural learning model of education developed by Vygotsky (1978) frames knowledge within the culture in which the learning experience takes place. Knowledge cannot be isolated from language and its particular dialectics, and thus he defines some concepts as ‘spontaneous’, picked up in everyday life, and ‘systematically learned’, or scientific concepts, which are mainly learned at school. One could then discuss whether the broadening of ‘everyday life’ would enhance the easy, intuitive concept learning suggested by Gardner. In this same line, Halliday (1993) describes language as the process by which experience becomes knowledge. Science museums could then, provide a wider range of experiences that would, hopefully, result in an expanded number of learning opportunities.

1.2.3. Learning in museums

Furthermore, museums can have an important contribution to the development of a certain field of learning: the object-based approach (Leinhardt & Crowley, 2002). Objects have been identified as assisting learning (Groundwater-Smith & Kelly, 2003), giving educators the possibility to offer layers of information (Rice & Yenawine, 2002). On the one hand, there is the information that can be sensed from the object: by seeing it, touching it, or hearing it. On the other hand, museums and educators can provide new pieces of information (through labels, activities, etc.) contributing to modify what has been defined as the object’s aura. Wagensberg (2007) explains the power of objects in triggering scientific discovery in his vision of museums as holders of ‘condensed reality’. Real objects are pieces of this reality, rigorously compatible with natural laws. It is through manipulation (hands on), reflection (minds on) and connection to a personal or collective cultural identity (hearts on) of the real object, that the visitor establishes a unique dialogue with nature. Experiencing the object can be also understood under the light of Gardner’s hypothesis. Tactile, visual, hearing and other approaches to the objects can be explained as the result of different intelligence aspects interacting with the layers of information. The visitor can feel the objects (as in a fusion of cognitive and sensitive way) and extract an immediate knowledge. Through this active learning process, the learner’s ideas become ‘increasingly powerful and complex’ (Dara-Abrams, 2002). It is this building of links to previous knowledge and experiences, and setting the basis for further learning, which constitutes the core of education.

Since at least a part of the learning process takes place through interpretation under the light of the learner’s parameters, the construction of interpretations around objects cannot be detached from the observer’s personal biography and cultural context (what has been described by Fish (1980) as interpretive community). School, due to its structure and systematized curricular nature, has obvious constraints concerning the number of learning options available for each student. Museums can instead turn the particularities of interpretive communities into a strength, bringing in different voices and learning styles to try to suit a broader public, a challenge aiming directly at motivation.

Another key issue in the museum visit is the presence of co-visitors, mainly people belonging to a certain affective sphere (family, friends). As Hooper-Greenhill (2002) states, ‘cognitive knowledge (information, facts) cannot be separated from affective knowledge (emotions, values)’, and these last are deeply involved in family learning. In this matter, Clarke (2000) has explored another basic pillar of the socio-cultural model: the relationship between child and adult. Parents and educators can explore the kid’s zone of proximal development and must pay constant attention since this can be in constant expansion when the student is adequately stimulated. Based on Dewey, Hein (2006) draws an ‘educational cycle’, a feedback process in which new inquiries constantly arise from new interests, as a result of the reflection on previous inquiries. This expanding area offers virtually endless possibilities to the achievement of new skills and knowledge, and museums should aim to create an environment where these processes are facilitated.

1.2.4. Interpretation or ‘the joy of conversation’

Targeting the above mentioned feedback process is the declared aim of the science museum directed by Jorge Wagensberg in Barcelona, and the focus of some of his writings (Wagensberg, 2007). Stimuli, conversation and comprehension or intuition are, according to this researcher, the three fundamental phases of the acquisition of new knowledge. His definition of intuition is the ‘subtle touch between two states of mind’: the encounter between a solved question and an unsolved one, between what is understood and what is still to be discovered. Intuition, following Wagensberg, is located at the same cognitive level as understanding. To promote this state of comprehension, the author proposes in his museum (and through his writings) a ‘training technique’ for the mind: the conversation. Conversations with reality (i.e., to look, to experiment, to observe), conversations with others (i.e., colleagues, teachers, students) and conversations with one self (i.e., to think, to reflect) are his tools to confront reality with all possible comprehensions of it. In his vision of interpretation, Nature is constantly giving answers to our questions, in what we could call ‘science’ or ‘discovery’; comprehension is the compressing of reality (physics laws are a good example of this compressed information) that allows us to keep on asking questions, and facing new understandings. The joy of conversation, that takes the learner to the doorstep of understanding, can be illustrated by the metaphor of the first time one looks through the ocular of a microscope. A whole world of answers to questions not yet formulated! Museums, thus, can be regarded as providers of joy through conversation, the same as schools and other learning environments. Wagensberg points out as well that importance of the individual experimentation of the joy of conversation: the excitement inherent to discovery is much higher that that experienced when we are ‘taught’ something that has already been comprehended (and thus, compressed through the use of language or other codes) by another mind. Formal learning environments are in most cases forced to an extensive use of language to communicate ideas, while museums can explore a wider range of conversation types with their visitors.

There are some other reasons for which the informal learning setting provided by the museum might be considered to be key in its performance of education; the role of the museum educator, much freer from the academic constraints to which the school teacher is subject, can be that of a facilitator in the construction of knowledge. The vision of teachers as ‘guides’ and learners as ‘sense makers’ postulated by Mayer (1996) can be successfully cultivated in the good ground of the museum environment. Under the new conceptions of learning, a big part of the responsibility in the learning process is left to the learner. Individual and social knowledge construction cannot occur without motivation. The responsibility of the educator is not anymore the transmission of information, but devoting energy to stimulate motivation (Csikszentmihalyi, 1990). The flow that this author describes as driving the current in which pleasure leads to learning, is a ‘merging of action and awareness’ from which the dichotomy of daily acts and our vision on them is erased. The learner becomes the learning experience, in an intense involvement that can be just achieved when the challenges are in balance with the learner’s skills. It is the same phenomenon described by Wagensberg under the concept of ‘intellectual joy’ (Wagensberg, 2007). According to this author, teaching should not be the aim of a museum, given that the time frame of a single museum visit does not allow learning processes to take place. Instead, museums should provide an engaging experience, a series of ‘intellectual joy’ experiences that trigger further questions and long term, deep, understanding of phenomena. Surprisingly, the legitimacy of ‘fun’ as the main objective for science centres visitors seems to generate discomfort to some researchers (Anderson *et al.*, 2003).

Considering the issue from other perspectives, the non-formal education environment provided by the museum, offers the scenery for developing different aspects of intelligence, as suggested by Davies and Gardner (1999), especially those that are ignored by traditional schools. The limitations of formal education, for example in terms of the senses appreciated and devoted to learning, are well known. Linking Csikszentmihalyi’s (1990) concept of adequate challenges to Gardner’s conception of multiple intelligences, we could hypothesize that those people with strong musical or mathematical intelligences, would be attracted to playing instruments or listening to others play, while those with stronger language skills would easily engage in story telling and discussions, as an example. The museum environment can offer a customized experience to suit these different needs, under the context of a single visit. A virtually unlimited number of sensory and cognitive experiences, from which learners can voluntarily select and explore, sharpening their skills in a non-directed process.

Moreover, museums and non formal education environments can help dissolving physical and psychological barriers that prevent some people from enjoying learning, sharing and celebrating culture. Furthermore, they can play a key role in holistic approaches and lifelong learning experiences that are sometimes out of the scope of academic programs.

1.2.5. Museums and interactivity

The American Heritage Dictionary of the English Language (Pickett, 2000) defines ‘interactive’ as ‘capable of acting on or influencing each other’. In the museum context, the practical definition of the term is not simple, describing a variety of experiences (Adams & Moussouri, 2002). ‘Hands-on/minds-on’, ‘participatory’, or ‘immersive’ are also terms used to refer to discovery activities in which the visitor plays a more active role than the mere observation. ‘Interactive’ is sometimes understood as ‘computer mediated’, and many times trivialized to simple menu selection or clickable objects in a screen (Sims, 1997). In radical opposition to this concept, the present work will attempt to explore the role of interactivity under Adams and Moussouri’s definition as ‘experiences that actively engage the visitor physically, intellectually, and emotionally’. Consequently, interactivity in learning is "a necessary and fundamental mechanism for knowledge acquisition and the development of both cognitive and physical skills" (Barker, 1994). A growing number of museums seem to have adopted working definitions in this direction. Art museums develop interactive galleries and exhibitions (Adams & Moussouri, 2002; Ciolfi & Bannon, 2002b; Bergseid, 2006) and handling sessions are becoming a popular strategy for family and school learning programming.

Adams & Moussouri (2002) point out the importance of multi-sensory experiences for a successful interactive museum experience. They describe the engagement of the visitor at a variety of levels, as ‘in an intellectual and sensory game’. This perspective recalls Wagensberg’s concept of ‘conversation’ and places it at a multi-sensory, multi-level dialogue, reflecting the human desire to communicate on a wide range of different levels. At the core of the experience, state the authors, resides a true and interesting challenge for the visitor.

The multi-sensory approach seems to be especially relevant in the children’s experience. The field work carried out by Adams & Moussouri (2002) shows how children focus in the kinaesthetic aspects of their visit. But the kinaesthetic experience does not warrant a rich or meaningful experience, as they warn museum practitioners. Responsible interactivity aims for an effective communication of content and targets outcomes directly connected to the mission statement. Finally, this connection needs to be ‘based on reliable data from visitor studies’.

Virtual reality environments can also be considered interactive spaces. But although from a cognitive perspective, virtual reality experiences might involve interaction, they can be regarded as lacking the real object experience, or as Adams & Moussouri (2002) express it, ‘interactive experiences need to focus on what makes the experience special or unique, to mine fully, as Howard Gardner expresses it, the ‘genius’ of the museum’. Nevertheless, several studies have shown the efficiency of simulations and computer models to communicate physics content (Jimoyiannis & Komis, 2001; Zacharia & Anderson, 2003), although there is a risk of losing the excitement of experiencing surprises in environments dominated by computer reconstructions and even being overwhelmed if the presence of technology is too strong (Zheng, 2005).

The role of interactivity will be further examined in this study, in order to discuss fieldwork results. This research piece will not try to assess the outcomes of learning processes in informal settings, but will rather try to focus in the degree of engagement and interaction of the visitor with science exhibits. Unfortunately, the unstructured and unpredictable learning processes that take place in informal settings such as museums makes it impossible to specifically measure or determine the knowledge ‘offered’ and acquired. Since informal settings provide audiences with the tools for continuous, life-long learning, assessing learning results in the same way we do in relation to formal settings such as school is a difficult task (Griffin, 1996). Thus, museums must be sensitive to more subtle indicators, such as the degree of involvement in activities, the enjoyment, the focusing capacity of the visitor, or the acquisition or reinforcement of certain skills. The performance of the learner is, of course, just a partial measure of the personal learning experience; the subjective meaning-making process can never be deeply analyzed.

2. Methods

In order to study the performance of museum displays, a wide range of different methods are used. Since assessing the degree of meaning making of the content displayed is a complex, difficult to achieve objective (Griffin, 1996), many studies target simpler measurements of the engagement of the visitor with the exhibition. Some of these methods don’t involve any interaction between researcher and visitor (visitor tracking and visitor observation in general), while other methods such as interviews and questionnaires are based in this interaction. Both types of techniques can be used to retrieve qualitative and quantitative information.

Visitor observation is a commonly used method for describing the behaviour of public visiting exhibitions (Sandifer, 1997; Ash, 2003, Ciolfi & Bannon, 2002a). Several different parameters can be recorded using this method, being time a recognised and powerful tool for measuring visitor behaviour (Falk, 1982; Serrell, 1995). Visitor tracking in general, and more specifically, features such as attracting power and holding power of the studied exhibits are commonly referred to in the literature (Umiker-Sebeok, 1994; Bailey *et al.*, 1998; Kelly & Bartlett, 2002, Sandifer, 2003). Attracting power is defined as the proportion of visitors that engage with a certain display, being the definition of this action subject to considerations such as the establishment of a cut-off time (the time the visitor needs to spend interacting with the display in order to be considered “engaged”). A cut-off of 5 seconds is a usual measure frequently used in previous studies (Sandifer, 1997).

Falk *et al.* (1985) defined three different factors affecting visitor’s holding time: visitor factors, setting or environmental factors, and exhibit factors. This study originally aimed to analyse the last one, although some quantitative data concerning the first factor were recorded, and during the course of the interviews some interesting data arose regarding environmental factors.

Interviews have as well been widely used in the assessment of museum exhibits (Bailey *et al.*, 1998; Dussault, 1999, Ash, 2003; Botelho & Morais, 2006, Woodruff *et al.,* 2001). This method can be time-consuming, but the results obtained can be very rich and detailed, providing qualitative information difficult to retrieve otherwise. Interviews can be structured by the researcher or, more commonly, and trying to avoid the preconceived notions of the interviewer, open to encourage the respondent to freely speak about their experience Woodruff *et al.,* 2001). Interview methods usually target a small number of people and aim instead for in depth, qualitative feedback.

The use of questionnaires is also a common method for exhibit assessment. It needs by definition a high-structured construction, and it presupposes that the researcher knows in advance the questions of interest (Woodruff *et al.,* 2001). On the other hand, questionnaires can provide large datasets that allow for quantitative analyses on the public's perceptions and experiences during museum visits.

In addition to the use of published literature, the three above mentioned data sources (visitor studies, questionnaires and interviews) were used for this study. The first source was a number of visitor's behaviour observations conducted in two different settings in the city of Gothenburg, Sweden. The second source was a series of interviews to people relevant to the studied field. The third and last source was the analysis of questionnaires answered by teachers and students visiting one of the centres being studied.

2.1. Visitor observation

Visitor's behaviour was observed at Universeum, a science centre located in central Gothenburg, and at Fysikaliska Leksaker, a centre for experimentation belonging to Chalmers University of Technology, in the same city. One display was selected in each place and the behaviour of visitors interacting with each of them was recorded. A customized form was designed for data collection in both locations (see Appendix).

The selection of the displays was made on the basis of their relevance for the central question of this study. Both displays appeal to the use of several senses and both demonstrate content and methods related to physics. In both exhibits, Physic-related content are immersed in a wider experience of the objects displayed, encouraging the visitor to interact with and reflect on them. Exhibits in which the visitor had to interact directly with the objects were selected, avoiding computer-based interactions. Although the complexity of the learning outcomes of both displays is dependent on the age group and circumstances of each visitor, they can be enjoyed by young children as well as by adults, and they both allow for individual and group interaction. In practical terms, both exhibits were easy to observe from a distance, being visitors not aware that they were being timed.

It was not the aim of this work to compare the exhibits with each other. The selection of two different science learning settings was an attempt to diversify and broaden the possibilities of information gathering. On the other hand, the public visiting Universeum do it mainly as an individual/family choice for leisure time, while the visitors attending Fysikaliska Leksaker are generally organized in groups (school, work, or any other association linking each group of visitors), offering the combination of both a wider range of data to be analyzed.

2.1.1. Visitor observation at Universeum

At Universeum, observations took place on Saturday, 5th of April 2008, from 10 am to 6 pm. The display observed was the theremin, located in a small room with glass walls within the “DiGit” exhibition. The theremin or aetherphone, is one of the first fully electronic musical instruments. It was invented by Russian inventor Lev Theremin in 1919, and it was the first musical instrument designed to be played without being touched. It consists of a box with two metal antennas to sense the relative position of the player's hands. These sensors control audio oscillators for frequency and amplitude. To play it, a right handed player would move the right hand around the vertical antenna, controlling the pitch (frequency), and the left hand around the handle-like antenna, controlling the volume (amplitude) (Fig.2).

Fig.2. Lev Theremin playing the instrument of his invention (source of the image: Wikipedia).

“diGit” is an exhibition about digital music with a focus on interactivity, clearly aiming to stimulate the creativity of the visitor (Ljungström, 2008). The area of the exhibition where the theremin is located is composed of a central glass corridor to which several small glass rooms open, each of them holding a different display. The theremin is thus visible when the visitor walks along the corridor. The glass wall facing the corridor holds a sign with the word “theremin” in a big font, and a label at around 100 cm height explaining how to use it and the principle that makes it work.

Observations were made from the end of the corridor, to ensure that visitors were not aware that they were being timed and observed. The data recorded for each visitor included sex, age group, accompanying visitor(s), and time spent interacting with the display. Sex and age group were visually assessed and recorded for each visitor walking by or interacting with the display. Age groups were defined as follows:
1: from walking age to 12 years old
2: 12 to 18 years old
3: 18 to 65 years old
4: from 65 years old

The attracting power of the display was calculated by relating the number of visitors reading the sign or entering the room to the number of visitors walking by the door in the corridor. Visitors that passed by the display and did not enter the room were counted just once in the analysis, even if they were walking the corridor several times. A glance at the display or the label was not considered interaction.

In order to calculate holding power, each visitor’s interaction with the display was timed, separately recording the time invested in reading the label, playing the instrument (using their hands or other parts of their body), and listening to someone else playing. A record was kept of whether the visitor interacting with the display was alone or with someone else, and of the data (sex and age group) of the accompanying person(s), as well as comments on the nature of the interaction amongst participants.

2.1.2. Visitor observation at Fysikaliska Leksaker

Fysikaliska Leksaker is a hall located within one of the buildings of Chalmers University of Technology, in Gothenburg. It contains more than 300 experiments that explain physics concepts and phenomena. All the experiments have been designed and homemade by Dr. Per-Olof Nilsson, who runs the centre. They are generally made with common materials and a very low degree of technology. All the displays are meant to be manipulated by the visitor in order to understand a certain process or phenomenon. Each display has a very simple label briefly describing what is happening. Sometimes the label consists of just drawings, sometimes of one or two explanatory sentences.

All kinds of groups of 10 to 30 people are welcome to visit the centre and try out the experiments. The visit is free and lasts for one and a half hours. The program of a normal visit includes a short introductory talk, about an hour to freely interact with the displays, while the two guides move around the displays demonstrating some of them, and a closing “show” in which Per-Olof Nilsson performs spectacular tricks to explain some physical laws and phenomena.

Fysikaliska Leksaker’s outreach program includes a weekly café-afternoon in which everyone is welcome to visit the hall. During these sessions, experiments are demonstrated, a book is recommended, and the visitor is given a small toy that helps understand a certain phenomenon. Some open-house days, special talks and programs and collaboration with the city’s Science Festival complete the program.

The display selected for observation at Fysikaliska Leksaker was one explaining atmospheric pressure. The display consists of three different parts. The first is a classic barometer, showing the current atmospheric pressure. The second part is a rubber squared layer with a holding point in its centre, resting on a table. Holding the central handle, the visitor can try to lift the rubber piece, and verify how firmly the square is attached to the surface, allowing the table to be lifted from the floor. Instead, letting a small amount of air beneath the rubber, by lifting one of its corners, the square is easy to lift from the table surface. The third part of the display is a thin piece of metal sitting on the same table, and half sticking out of it. On top of the part of the metal lying on the table, there is an open, flat, newspaper. A sign on the sticking part of the metal asks the visitor to hit it as hard as possible, in order to make the newspaper jump off the table. The atmospheric pressure on each square centimetre of the newspaper would require a 1000 kg push to actually lift it from the table. As in the rubber layer example, letting some air under the newspaper makes it possible to easily lift it. The display is completed with a simple label explaining how the three parts explain the same phenomenon (Fig. 3).

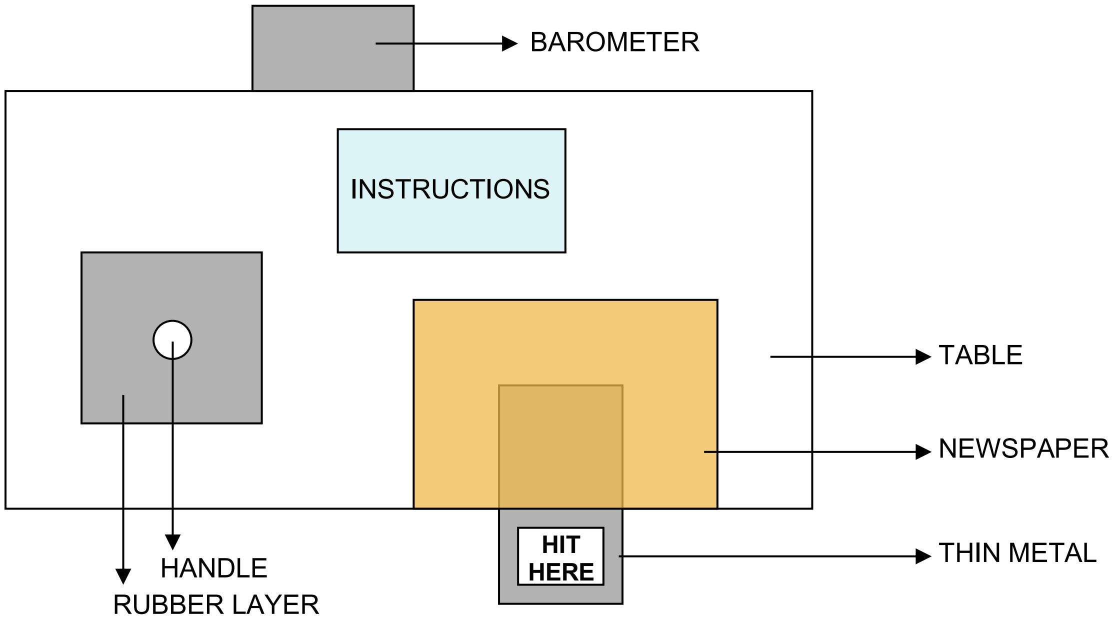

Fig. 3. Diagram of the disposition of the studied display at Fysikaliska Leksaker.

Observations were carried out during March and April 2008. Sixteen different groups of people were observed. Among the groups observed, 7 were high school groups (16-17 years), 3 were middle school groups (10-11 years), 3 were groups of adults, and 3 were mixed groups attending open house days. During the stay of each group, observations were made at intervals of 5 to 17 minutes (average: 8 minutes) and the number, sex and age of visitors interacting with displays on their own was recorded. Age or age group were inferred for school groups and visually assessed for adult visitors, grouping them with the same criteria used at Universeum. Visitors interacting with the selected display were timed, recording for how long they watched the barometer and physically interacted with the two touching displays (newspaper over thin metal and rubber square). The presence of other visitors or one of the guides was also recorded as a feature of the interaction. In the case of school groups, their physical attitude during both talks (their closeness to the speaker, whether they were sitting on the floor or standing, etc.) was also registered.

2.2. Questionnaires

During the period 2003-2004, Per-Olof Nilsson asked a number of teachers that had visited Fysikaliska Leksaker with their school groups to fill in a questionnaire. The teacher’s task was to orally ask the kids 10 questions about their experience at the experiment hall, and collect the answers for the questionnaire. Questionnaires were answered a week after the visit, and 26 of them were returned to Dr. Nilsson. These questionnaires were analysed for the purpose of the present study. Although the questionnaires were done long before this study and the questions were not designed specifically for it, they suit the purpose of answering the main questions this study attempts to address. A translation of the questionnaire questions can be found in the Appendix chapter of this work.

2.3. Interviews

During spring 2008 a number of people whose perspective could be relevant to the matter of this thesis were interviewed, with the aim of exploring qualitative aspects of the learning of physics. Some of them carry out their work in the field of physics teaching, while others have strong connections to the museum world. All interviews had some common questions and some other that were customized according to the respondent’s field or experience (see Appendix). Questions were designed to encourage respondents to elaborate in any topics they wanted to, leaving them in total freedom to drive the conversation to other questions of their interest. Interviews were digitally recorded. The following people were selected to be interviewed:

- Per-Olof Nilsson, PhD in physics, formerly professor at Chalmers University of Technology and currently director of Fysikaliska Leksaker.
- Sten Ljungström, PhD in physics, professor at Chalmers University of Technology and scientific director at Universeum.
- Sheila Gant, PhD in physics, professor at Chalmers University of Technology.
- Mathias Ohlson, former physics and Math high school teacher and currently Telecom Consultant, Mangement Systems at Ericsson AB.
- Torbjörn Eingren, guide at the Astronomic Observatory in Slottskogen, Gothenburg.
- Ole Ingolf Nyrén, PhD in Chemistry, exhibition developer, artist and writer.
- Mikael Andersson, physics high school teacher at the International School (IHGR), Gothenburg.
- Kuchi Prasad, Physician, Computering docent at Chalmers University of Technology.

2.4. Limitations of the fieldwork

During the course of the fieldwork, some unexpected issues arouse that fedback the method. People’s behaviour is complex and difficult to always fit into a tick box form. As a result, a large amount of qualitative notes complemented the visitor tracking variables recorded. Due to the nature of the studied displays and science centres, a slightly different set of data was obtained for each of the visitor observation studies. Consequently, the nature of the conclusions obtained from both experiences differ on some specific points.

Several unexpected questions arose as well during the performance of the interviews, but the open structure they were based on allowed for constant renegotiation of the content of the conversation. Due to time constraints and availability, some potential interviewees were unfortunately left out of the interview list. Given a different time frame, the author would have liked to include in that list researchers and practitioners linked to architecture and arts, in order to explore the influence of spaces and aesthetic elements in the understanding of physics in non-formal environments.

3. Fieldwork results

The present chapter summarizes the main findings of the visitor observation study and the answers to the questionnaires, with the aim of discussing it, in the following chapter, with published literature. The complete results of the visitor observations carried out at Universeum and Fysikaliska Leksaker are shown in tables 1 to 13 and figures 4 to 18 (sections 3.1.3 and 3.2.4), while the main findings are summarized in the text sections preceding the tables and figures. The decision of presenting all numerical and graphical data in independent sections was made with the aim of making the text easier to read. With the same purpose, no references are made in the text to tables and figures.

The findings from the questionnaire survey are presented as well in this chapter and summarized in table 14, while the more qualitative information obtained from the interviews is used in the discussion chapter, in connection with published sources.

3.1. Results from visitor observation at Universeum

A total number of 440 visitors (from which 52% were male) walked into the corridor of the selected display, that is, had the opportunity to interact with it. Most visitors were parents with small children (54% of the visitors were adults between 18 and 65 years, and 30% were children from walking age to 12 years). Very few adults (just 2%) over 65 years were part of the visiting public, showing that it is mainly parents, and not grandparents who take small children to the museum. Most of the visitors (76%) were accompanied by someone during their visit.

3.1.1. Attracting power

From the total number of visitors that walked beside the display, 59% had some kind of interaction with it. A glance at the display or its label was not counted as an interaction, and although no cut-off time was measured, and probably due to the physical configuration of the display on a corridor, it was very clear in every case were the visitor was interacting with the display or just passing by. Males (attracting power: 63 %) seemed to be slightly more attracted by the theremin than females (54%) although differences were not significant. In terms of age groups, adults between 18 and 65 years were the most attracted to the display (63%), followed by children under 12 years (56%) and the 12-18 age group (51%).

3.1.2. Holding power

The average total time spend by a visitor in interacting with the theremin was 32 seconds (range: 2-158). This time was divided into the time spent reading the label or (average 6%), listening to others playing (16%) and playing the theremin (78%). Holding time was significantly increased by the presence of accompanying visitors, but not by sex or age class. The ANOVA tests show that the number of accompanying visitors has also an effect on the holding time, although Post Hoc comparisons (Tukey tests) showed that difference between 0 and 1 accompanying visitor, but not among other categories (0 to 4 visitors).

The analysis of holding time devoted to the three studied aspects (reading, listening and playing) shows a significant effect of the presence of accompanying visitors in the listening time. This is most probably because people tend to listen to those they visit with (mean: 6 seconds), but they seldom stay and listen to visitors belonging to other families/visiting groups (mean: 0.4 seconds). Male visitors spent significantly more time playing than female visitors (28 and 21 seconds, respectively), but there were no differences in playing time among age groups or number of accompanying visitors. The time spent reading the label was different for those in different age groups and those accompanied by different number of visitors.

3.1.3. Tables and figures

This section shows the results obtained from the visitor observations conducted at Universeum.

	Age class					
	1	**2**	**3**	**4**	**Total N**	**%**
Male	72	28	125	3	228	52
Female	59	37	111	5	212	48
Total N	131	65	236	8	**440**	
%	30	15	54	2		

Table 1. Number of visitors walking the corridor beside the theremin. Age classes are defined as follows: 1: from walking age to 12 years; 2:12 to 18, 3:18 to 65; 4:more than 65 years.

	Age class					
	1	**2**	**3**	**4**	**Total N**	**%**
Male	8	4	3	0	15	28
Female	17	3	18	1	39	72
Total N	25	7	21	1	**54**	
%	46	13	39	2		

Table 2. Numbers of visitors interacting with the display.

	Age class				
	1	**2**	**3**	**4**	**Total %**
Male	61	39	71	0	**63**
Female	51	59	54	40	**54**
Total %	**56**	**51**	**63**	**25**	

Table 3. Attracting power (percentage of visitors interacting with the display from total visitors).

Attracting power (% of visitors interacting)		59%		
Shared interaction (more than 1 visitor interacting)		76%		
	Average	**Min**	**Max**	**%**
Number of accompanying visitors	1	0	4	--
Holding time (seconds spent interacting)	32	0	158	--
Reading label	2	0	20	6
Listening	5	0	60	16
Playing	25	0	158	78

Table 4. Descriptive statistics for some variables of the fieldwork at Universeum.

t-tests

Grouping variable: presence of accompanying visitors

Dependant variable	**Mean 1**	**Mean 0**	**t-value**	**df**	**p**	**Valid N 1**	**Valid N 0**	**Std. Dev 1**	**Std. Dev 0**	**F-ratio variances**	**p Variances**
Total holding time	*34.23858*	*22.70492*	*3.016433*	*256*	*0.002815*	*197*	*61*	*27.32157*	*21.60968*	*1.598508*	*0.034830*
Time spent listening to others	*6.025381*	*0.393443*	*3.717212*	*256*	*0.000247*	*197*	*61*	*11.77443*	*1.819145*	*41.89331*	*0.00*
Time spent playing	26.65990	20.22951	1.704023	256	0.089590	197	61	27.12934	20.63362	1.728731	0.014290
Time spent reading label	1.553299	2.081967	-0.937063	256	0.349609	197	61	3.620161	4.521412	1.559885	0.024913

Grouping variable: Sex

	Mean M	**Mean F**	**t-value**	**df**	**p**	**Valid N M**	**Valid N F**	**Std. Dev M**	**Std. Dev F**	**F-ratio variances**	**p Variances**
Total holding time	33.78472	28.64035	1.552550	256	0.121766	144	114	27.78568	24.60956	1.274778	0.178240
Time spent reading label	1.590278	1.789474	-0.412100	256	0.680611	144	114	3.733075	4.005469	1.151260	0.424536
Time spent listening to others	3.951389	5.631579	-1.26647	256	0.206496	144	114	9.994635	11.28258	1.274334	0.170377
Time spent playing	*28.24306*	*21.21930*	*2.183232*	*256*	*0.029927*	*144*	*114*	*27.26386*	*23.47914*	*1.348374*	*0.097678*

Table 5. t-tests for the evaluations of differences in means for the presence/absence of accompanying visitors (0: absence; 1: presence) and for sex (M: male; F: female). Results in italics show significant differences between means.

ANOVA results					
	Dependant variable: total holding time				
Grouping variable	**SS**	**Df**	**MS**	**F**	**p**
Age group	1665.9	3	555.31	0.78861	0.501215
Number of accompanying visitors	*6632.9*	*4*	*1658.22*	*2.4126*	*0.049579*
	Dependant variable: time spent reading label				
	SS	**Df**	**MS**	**F**	**p**
Age group	*463.551*	*3*	*154.5171*	*11.73403*	*0.000000*
Number of accompanying visitors	*185.012*	*4*	*46.25301*	*3.229668*	*0.013124*
	Dependant variable: time spent listening to others				
	SS	**Df**	**MS**	**F**	**p**
Age group	41.93	3	13.9754	0.123226	0.946341
Number of accompanying visitors	*4766.80*	*4*	*1191.701*	*12.51974*	*0.000000*
	Dependant variable: time spent playing				
	SS	**Df**	**MS**	**F**	**p**
Age group	867.5	3	289.17	0.42989	0.731765
Number of accompanying visitors	3496.0	4	874.01	1.31441	0.265051

Table 6. Results of the Analysis of Variance. Grouping and dependent variables are specified. Results marked in italics show significant differences among categories of the variable. The sign of these differences is shown in the Post Hoc tests in table 7.

Tukey tests						
Grouping variable	**Dependant variable: total holding time**					
Number of accompanying visitors	Error: Between MS = 729.26, df = 255					
	category	0	1	2	3	4
	0		*0.038456*	0.200629	0.463420	0.605229
	1	*0.038456*		0.998712	0.987453	0.987426
	2	0.200629	0.998712		0.975265	0.977613
	3	0.463420	0.987453	0.975265		0.999991
	4	0.605229	0.987426	0.977613	0.999991	
	Dependant variable: time spent reading label					
Age group	Error: Between MS = 13.168, df = 254					
	category	1	2	3	4	
	1		0.897206	*0.000023*	*0.000873*	
	2	0.897206		*0.034239*	*0.002343*	
	3	*0.000023*	*0.034239*		*0.020662*	
	4	*0.000873*	*0.002343*	*0.020662*		
Number of accompanying visitors	Error: Between MS = 14.321, df = 253					
	category	0	1	2	3	4
	0		0.998749	0.100395	0.586613	0.761400
	1	0.998749		*0.016128*	0.480111	0.690851
	2	0.100395	*0.016128*		0.999029	0.999579
	3	0.586613	0.480111	0.999029		1.000000
	4	0.761400	0.690851	0.999579	1.000000	
	Dependant variable: time spent listening to others					
Number of accompanying visitors	Error: Between MS = 95.186, df = 253					
	category	0	1	2	3	4
	0		0.068297	*0.001357*	0.120720	*0.000017*
	1	0.068297		0.349040	0.666603	*0.000017*
	2	*0.001357*	0.349040		0.985905	*0.000025*
	3	0.120720	0.666603	0.985905		*0.002186*
	4	*0.000017*	*0.000017*	*0.000025*	*0.002186*	

Table 7. Approximate probabilities for Post Hoc tests (Tukey tests) of those variables that showed significant differences among categories in the ANOVA tests.

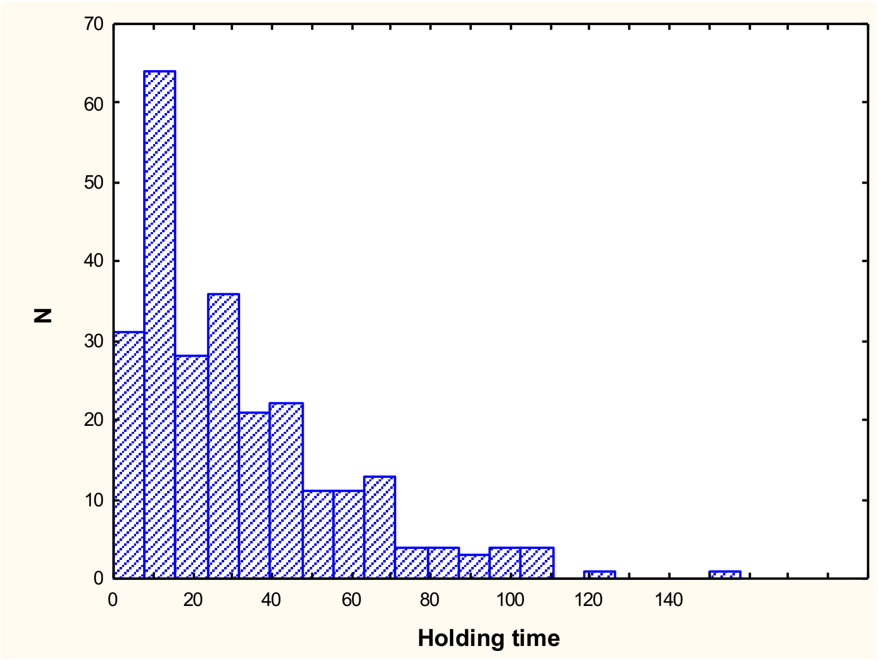

Figure 4. Frequency distribution of holding time (seconds) for visitors interacting with the theremin (N=258).

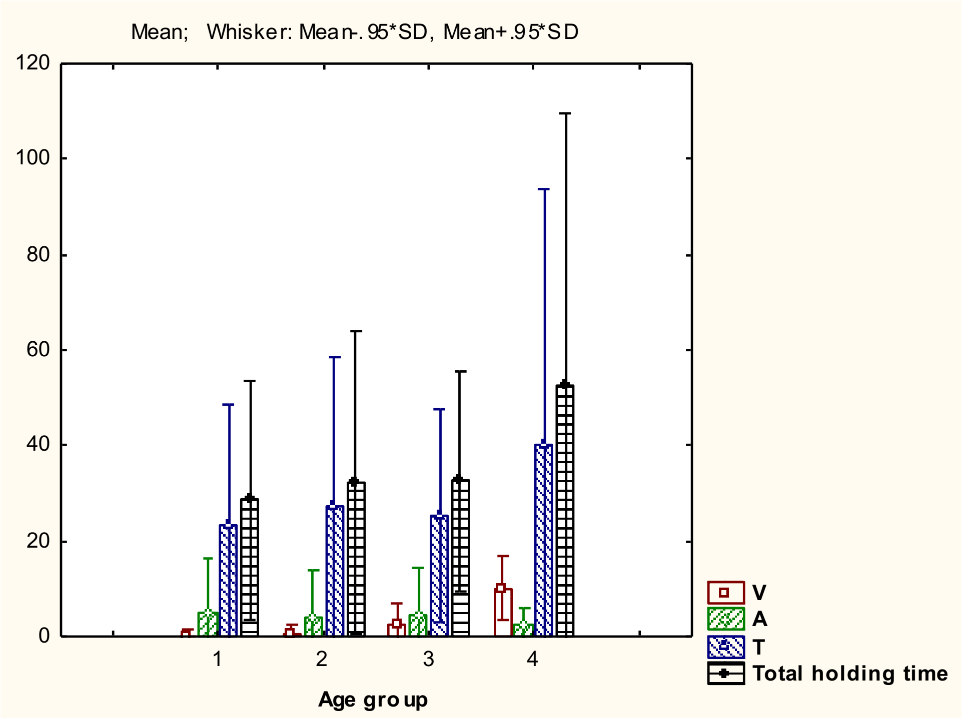

Figure 5. Holding time (seconds) for each age group. V (visual): time spent reading the label; A (audio): time spent listening to other visitors playing and T (touch): time spent playing the theremin. Histograms show mean measurements and whiskers show 95% of the standard deviation.

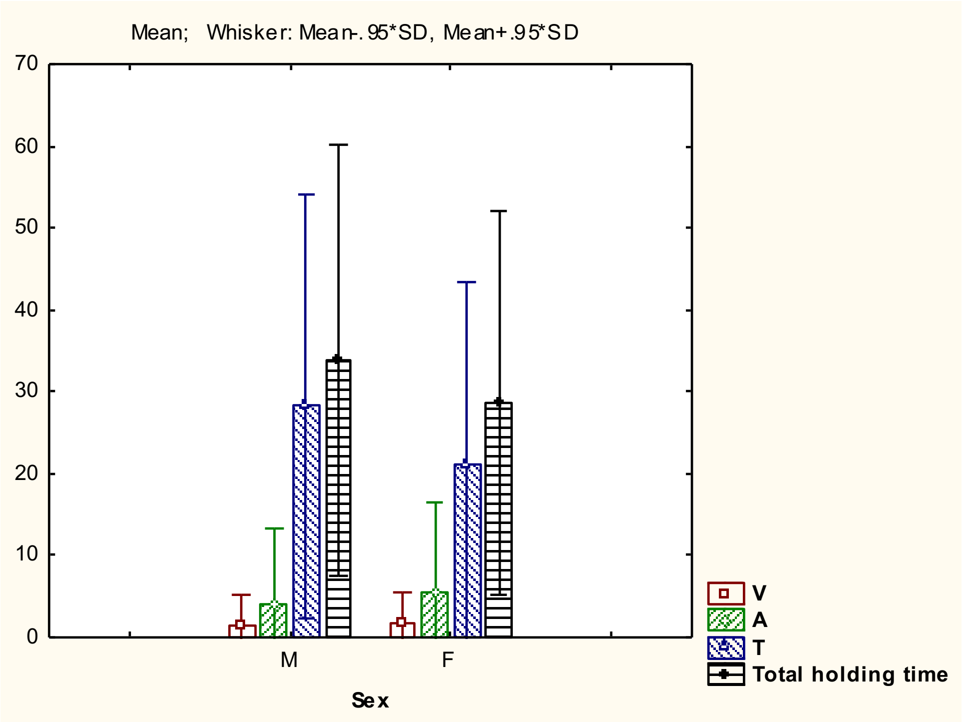

Figure 6. Holding time (seconds) for male and female visitors. V (visual): time spent reading the label; A (audio): time spent listening to other visitors playing and T (touch): time spent playing the theremin. Histograms show mean measurements and whiskers show 95% of the standard deviation.

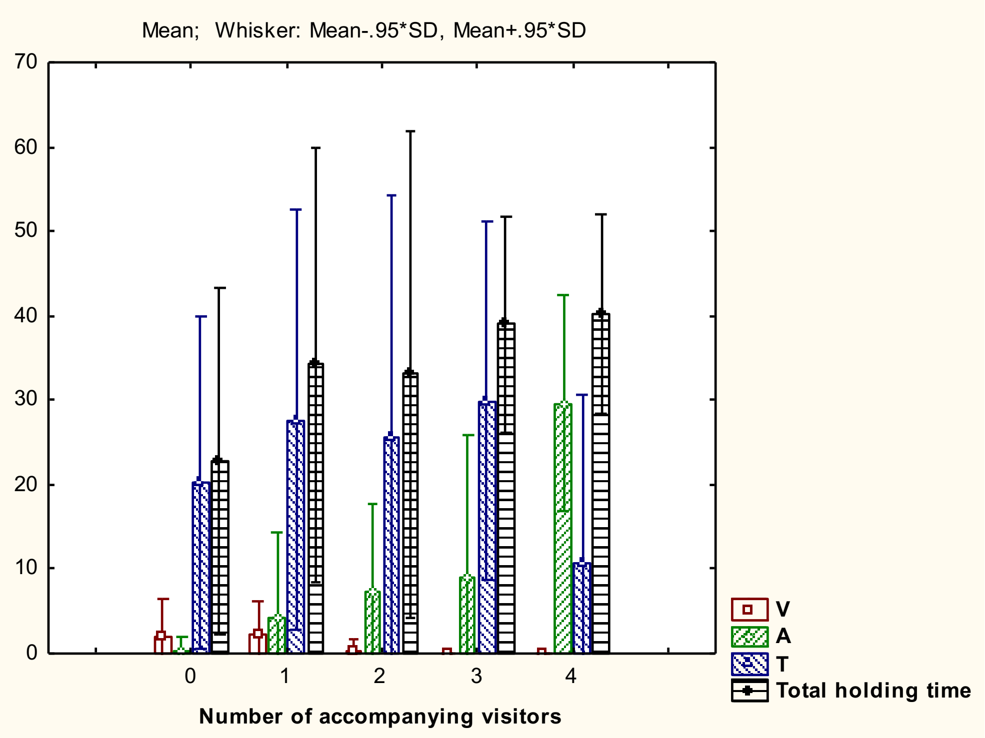

Figure 7. Holding time (seconds) in relation to the number of accompanying visitors. V (visual): time spent reading the label; A (audio): time spent listening to other visitors playing and T (touch): time spent playing the theremin. Histograms show mean measurements and whiskers show 95% of the standard deviation.

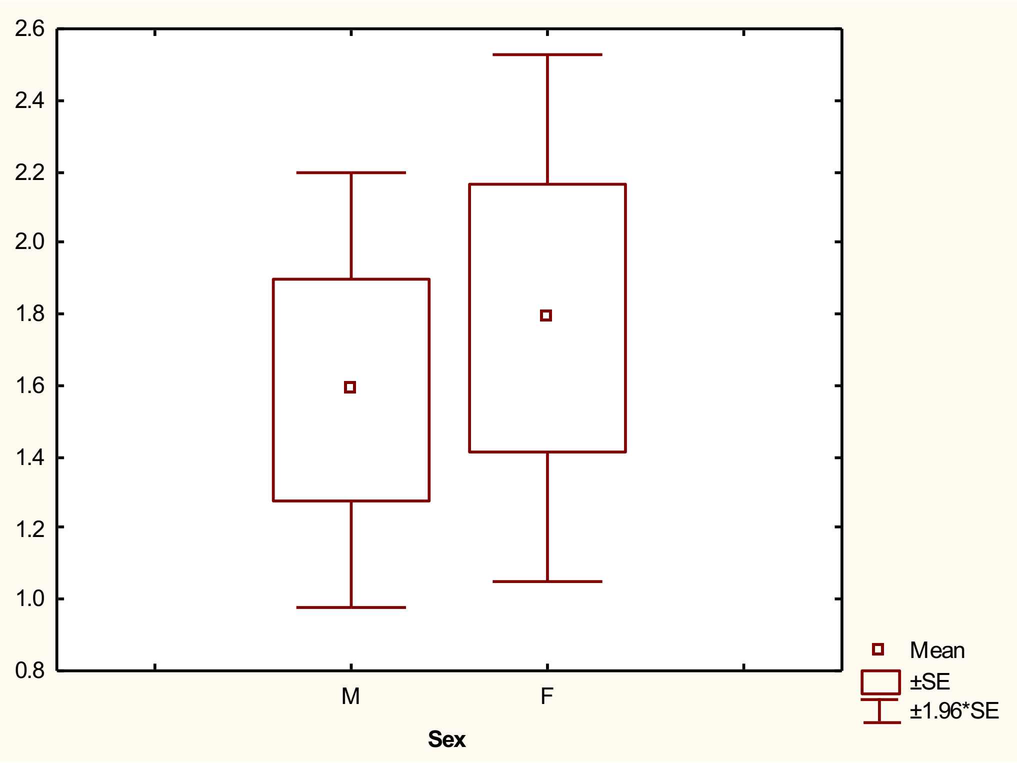

Figure 8. Time (seconds) spent in reading the label for male and female visitors. Markers represent mean, blocks show mean standard error, and whiskers show +/-1.96SE.

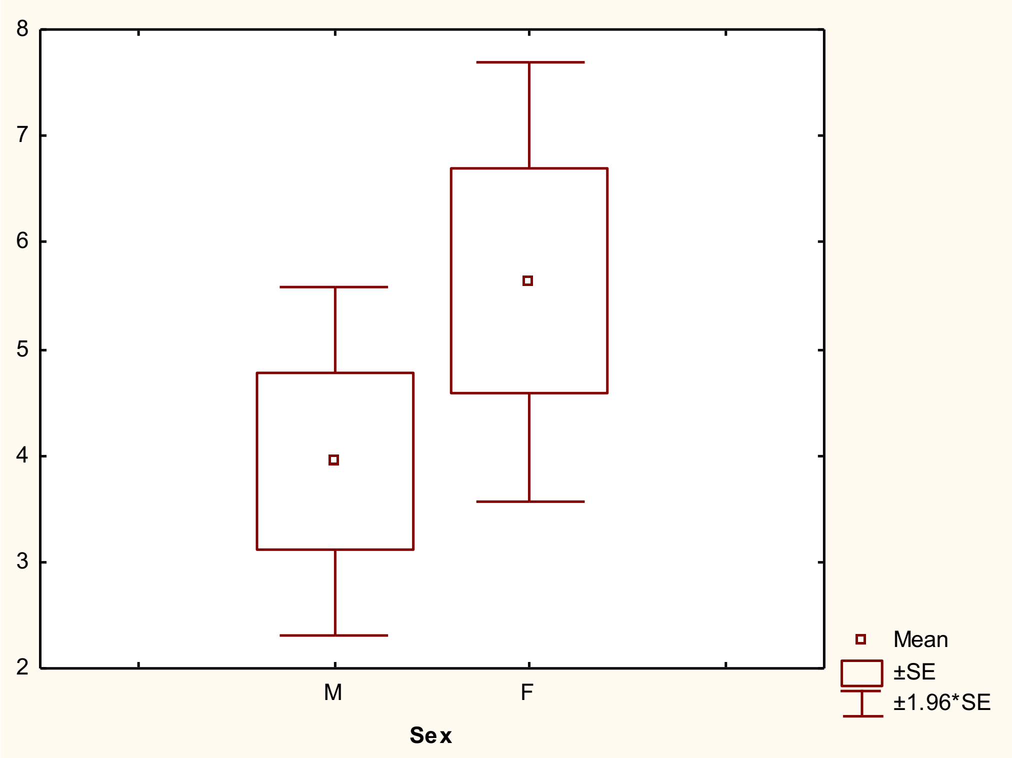

Figure 9. Time (seconds) spent in listening to other visitors playing for male and female visitors. Markers represent mean, blocks show mean standard error, and whiskers show +/-1.96SE.

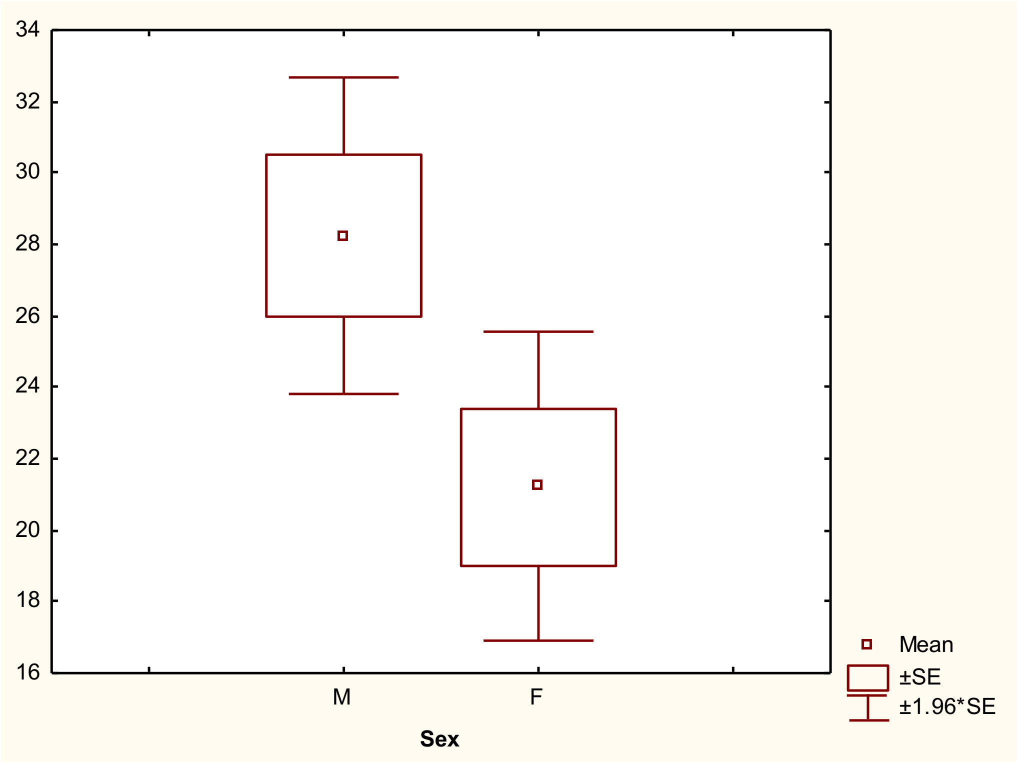

Figure 10. Time (seconds) spent in playing the theremin for male and female visitors. Markers represent mean, blocks show mean standard error, and whiskers show +/-1.96SE.

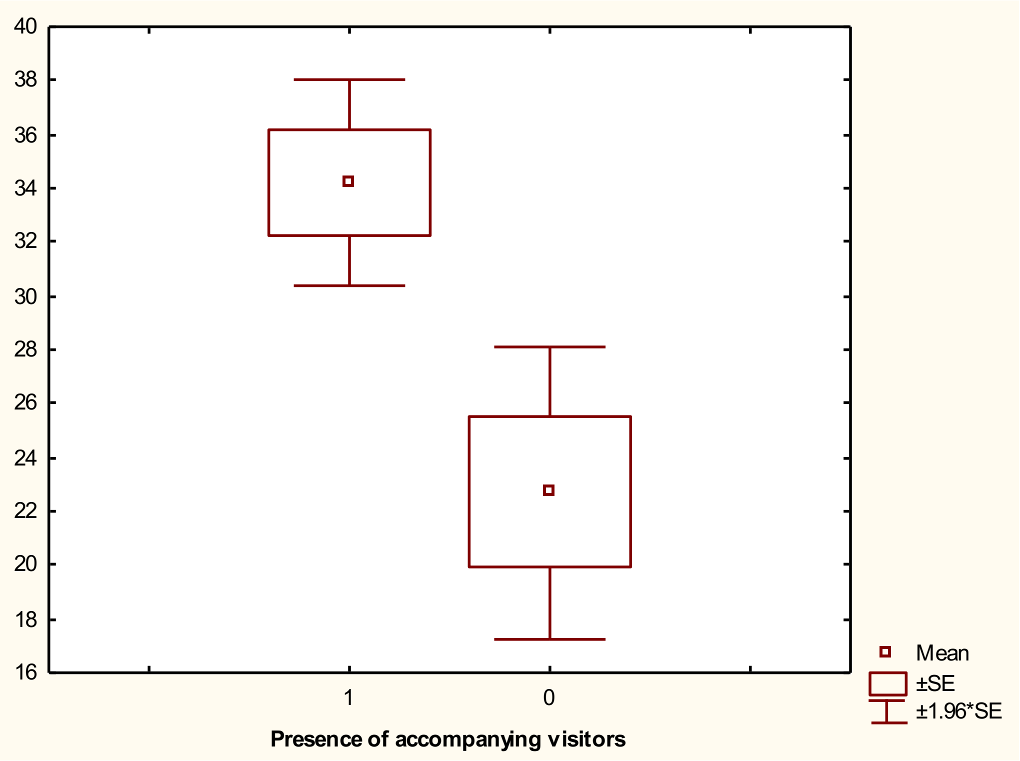

Figure 11. Holding time (seconds) in relation to the presence/absence of accompanying visitors (0: absence; 1: presence). Markers represent mean, blocks show mean standard error, and whiskers show +/-1.96SE.

3.2. Results from visitor observation at Fysikaliska Leksaker

A total number of 319 visitors were observed at Fysikaliska Leksaker, from which 53% were male visitors. In terms of age groups, most of the visitors were under 18 years (22% up to 12 years, and 52% 12-18 years), representing the visitors between 18 and 65 years, 22% and just being 4% over 65 years.

3.2.1. Attracting power

From the total number of visitors observed, 30% interacted with the studied display, 35% of the male visitors and 25% of the females. In relation to age, the highest attracting power was observed in the younger visitors (42% of the children under 12 years and 44% of the 12-18 years), while adults were less attracted to interact with it (12% and 21% for 18-65 years and over 65 years, respectively).

Not all visitors of those interacting with the exhibition had physical contact with it. 15% of the visitors counted as ‘attracted’ by the display did not actually touch it, but they looked at it, read the instructions, or heard the guide’s or their accompanying visitor’s explanation without trying it out. Male visitors physically interacted more frequently than females with the display. A significant difference was also observed in relation to age groups, being physical interaction more frequent in the two younger classes. The presence of the guide also had a significant effect on this variable, decreasing the frequency of physical interaction.

3.2.2. Holding power

The average holding power of the display was 54 seconds (range: 5-147 seconds). In relation to the three parts of the exhibit, 31 seconds were spent on average on the newspaper display, 12 on the rubber square, and 1 second on the barometer. No differences were found in holding time that related to the sex or age group of the visitors, but the presence of the guide significantly increased the holding power of the display. The time spent in each of the three parts observed (newspaper, rubber square and barometer) didn’t show any relation to sex, age groups or the presence and number of accompanying visitors.

3.2.3. Interaction among visitors

A high percentage (79%) of the visitors that interacted with the display were not alone, but the interaction was shared with one or more accompanying persons, or with one of the guides.

During the visit of each group to the hall, observations were made every few minutes to record how many people were interacting with any displays on their own, and how many were sharing the interaction with at least one other person. Only 14% of the visitors were alone during those observations (range: 0 to 33%). Male visitors seemed to interact more in the presence of other visitors (only 11% were alone during observations, range: 0-36%), while female visitors seemed to be alone more frequently (16%, range: 0-67%). The high degree of interaction among visitors could also be registered by qualitative observations. A very common behaviour was that of a visitors 'discovering' an exhibit and immediately calling one or more members of the group to call their attention on to what they had just experienced.

3.2.4. Tables and figures

This section shows the results obtained from the visitor observations conducted at Fysikaliska Leksaker.

	Age class					
	1	**2**	**3**	**4**	**Total N**	**%**
Male	35	87	40	7	169	53
Female	32	94	17	7	150	47
Total N	67	181	57	14	319	
%	21	57	18	4		

Table 8. Number of visitors observed at Fysikaliska Leksaker. Age classes are defined as follows: 1: from walking age to 12 years; 2:12 to 18, 3:18 to 65; 4:more than 65 years.

	Age class					
	1	**2**	**3**	**4**	**Total N**	**%**
Male	20	33	2	3	58	61
Female	10	21	6	0	37	39
Total N	30	54	8	3	95	
%	32	57	8	3		

Table 9. Number of visitors interacting with the display.

Attracting power (% of visitors interacting)	30%
Frequency of physical interaction	85%
Shared interaction (more than 1 visitor interact	79%

	Average	Min	Max	%
Number of accompanying visitors	2	0	9	--
Holding time (seconds spent interac	54	5	147	--
Newspaper	37	0	120	69
Rubber square	15	0	68	28
Barometer	2	0	12	4

Table 10. Descriptive statistics for some variables of the fieldwork at Fysikaliska Leksaker.

t-tests

	Dependent variable: physical interaction										
Grouping variable	**Mean M**	**Mean F**	**t-value**	**df**	**p**	**Valid N M**	**Valid N F**	**Std. Dev M**	**Std. Dev F**	**F-ratio variances**	**p Variances**
Sex	*0.717949*	*0.960000*	*-3.95248*	*112*	*0.000136*	*39*	*75*	*0.455881*	*0.197279*	*5.340006*	*0.000000*
	Dependent variable: holding time										
	Mean M	**Mean F**	**t-value**	**df**	**p**	**Valid N M**	**Valid N F**	**Std. Dev M**	**Std. Dev F**	**F-ratio variances**	**p Variances**
Sex	50.00000	56.44828	-0.987356	93	0.326030	37	58	25.67424	33.99544	1.753260	0.074548
	Mean 1	**Mean 0**	**t-value**	**df**	**p**	**Valid N 1**	**Valid N 0**	**Std. Dev 1**	**Std. Dev 0**	**F-ratio variances**	**p Variances**
Physical interaction	51.88889	65.78571	-1.55874	93	0.122455	81	14	32.61135	15.58687	4.377434	0.005009
	Mean 0	**Mean 1**	**t-value**	**df**	**p**	**Valid N 0**	**Valid N 1**	**Std. Dev 0**	**Std. Dev 1**	**F-ratio variances**	**p Variances**
Presence of accompanying visitor or guide	40.05882	48.33333	-0.769503	42	0.445901	17	27	37.25666	33.08032	1.268436	0.573425

Table 11. t-tests for the evaluations of differences in means for sex (M: male; F: female); presence/absence of accompanying visitors or guide (0: absence; 1: presence), and presence/absence of physical interaction (0: absence; 1: presence). Results in italics show significant differences between means.

ANOVA results

	Dependent variable: total holding time				
Grouping variable	**SS**	**Df**	**MS**	**F**	**p**
Age group	6552.76	3	2184.25	2.36653	0.076044
Presence of accompanying visitor or guide	*7062.0*	*2*	*3531.0*	*3.8913*	*0.023863*
	Dependent variable: physical interaction				
	SS	**Df**	**MS**	**F**	**p**
Age group	*3.229035*	*3*	*1.076345*	*13.0802*	*0.000000*
Presence of accompanying visitor or guide	*1.05413*	*2*	*0.52706*	*5.2112*	*0.006868*

Table 12. Results of the Analysis of Variance. Grouping and dependent variables are specified. Results marked in italics show significant differences among categories of the variable. The sign of these differences is shown in the Post Hoc tests in table 13.

Tukey tests					
Grouping variable	**Dependent variable: total holding time**				
Presence of accompanying visitors or guide	Error: Between MS = 907.41, df = 92				
	category	0	1	G	
	0		0.649794	*0.033475*	
	1	0.649794		0.162306	
	G	*0.033475*	0.162306		
	Dependent variable: physical interaction				
Presence of accompanying visitors or guide	Error: Between MS = 0.10114, df = 111				
	category	0	1	G	
	0		0.856959	0.112666	
	1	0.856959		*0.009453*	
	G	0.112666	*0.009453*		
Age group	Error: Between MS = 0.08064, df = 110				
	category	1	2	3	4
	1		0.975607	*0.009147*	*0.026816*
	2	0.975607		*0.000140*	*0.003247*
	3	*0.009147*	*0.000140*		0.996558
	4	*0.026816*	*0.003247*	0.996558	

Table 13. Approximate probabilities for Post Hoc tests (Tukey tests) of those variables that showed significant differences among categories in the ANOVA tests.

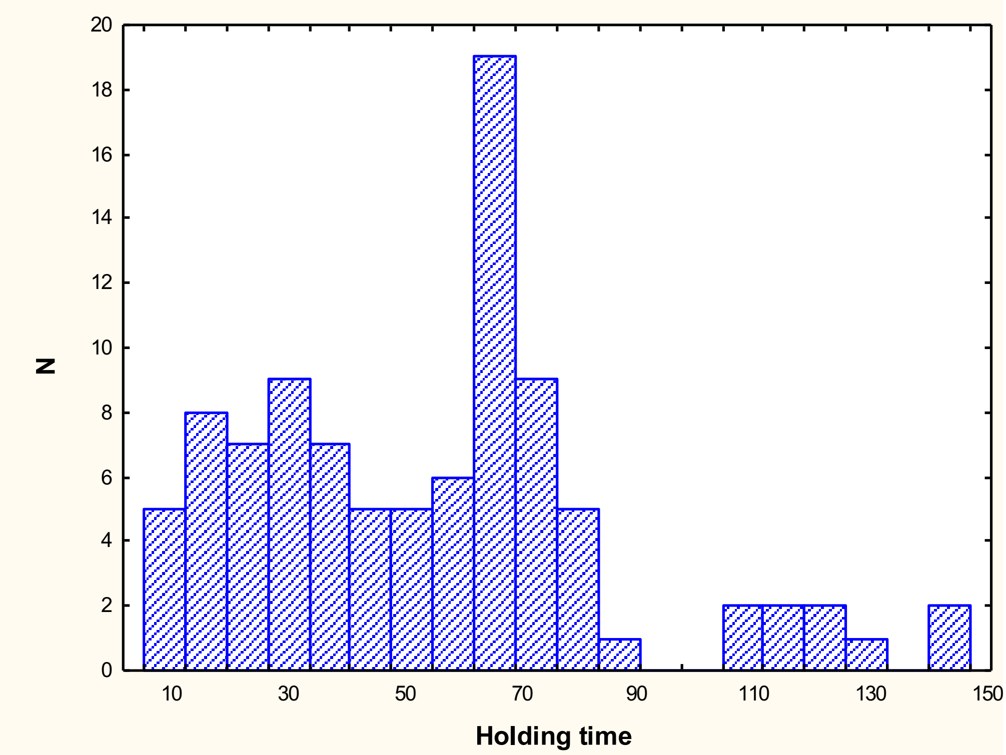

Figure 12. Frequency distribution of holding time (seconds) for visitors interacting with the atmospheric pressure display (N=95).

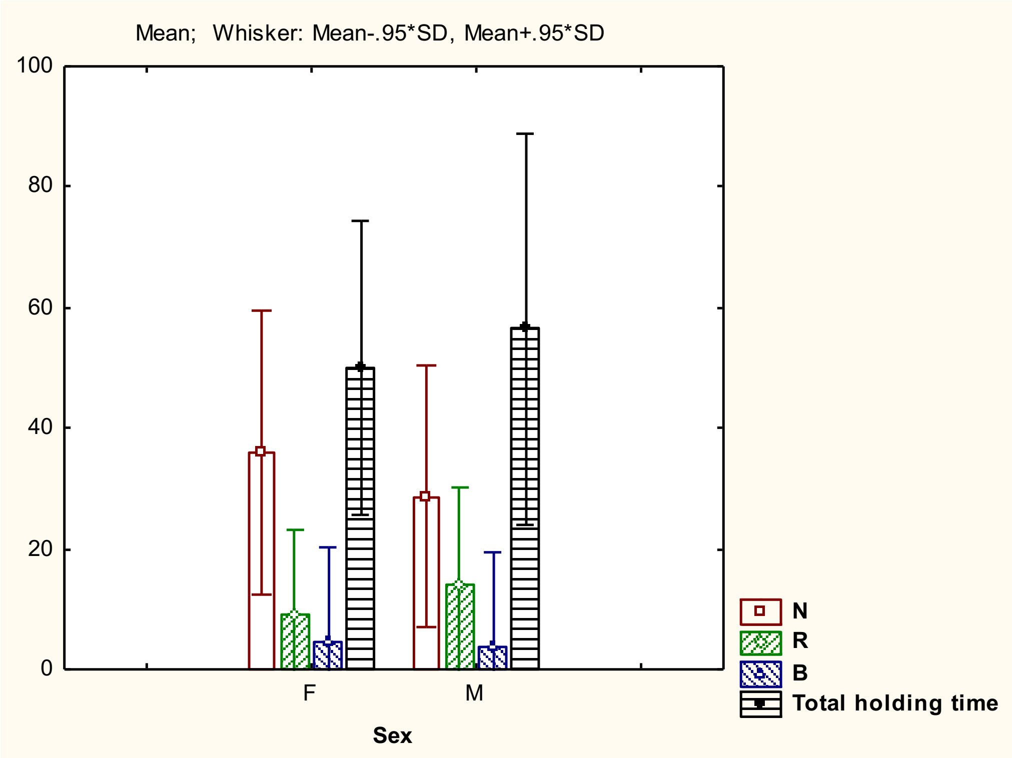

Figure 13. Holding time (total and for each of the parts of the display; seconds) for male and female visitors. Histograms show mean measurements and whiskers show 95% of the standard deviation.

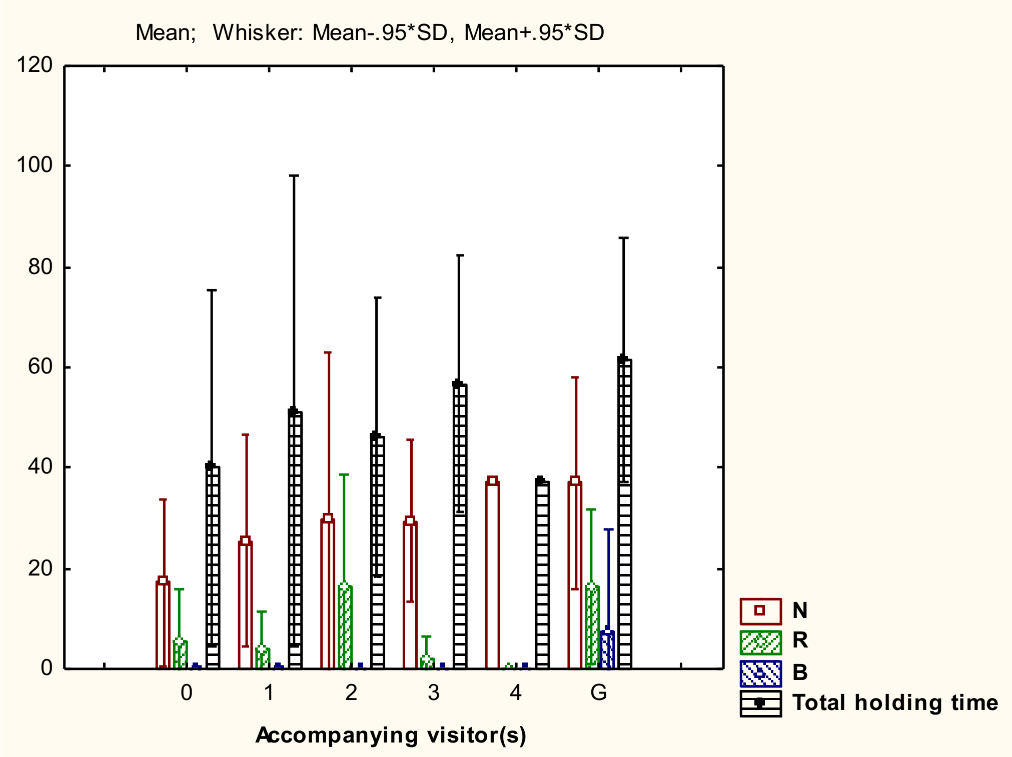

Figure 14. Holding time (total and for each of the parts of the display; seconds) for visitors accompanied by 0, 1, 2, 3, 4 visitors or by a guide (G). Histograms show mean measurements and whiskers show 95% of the standard deviation.

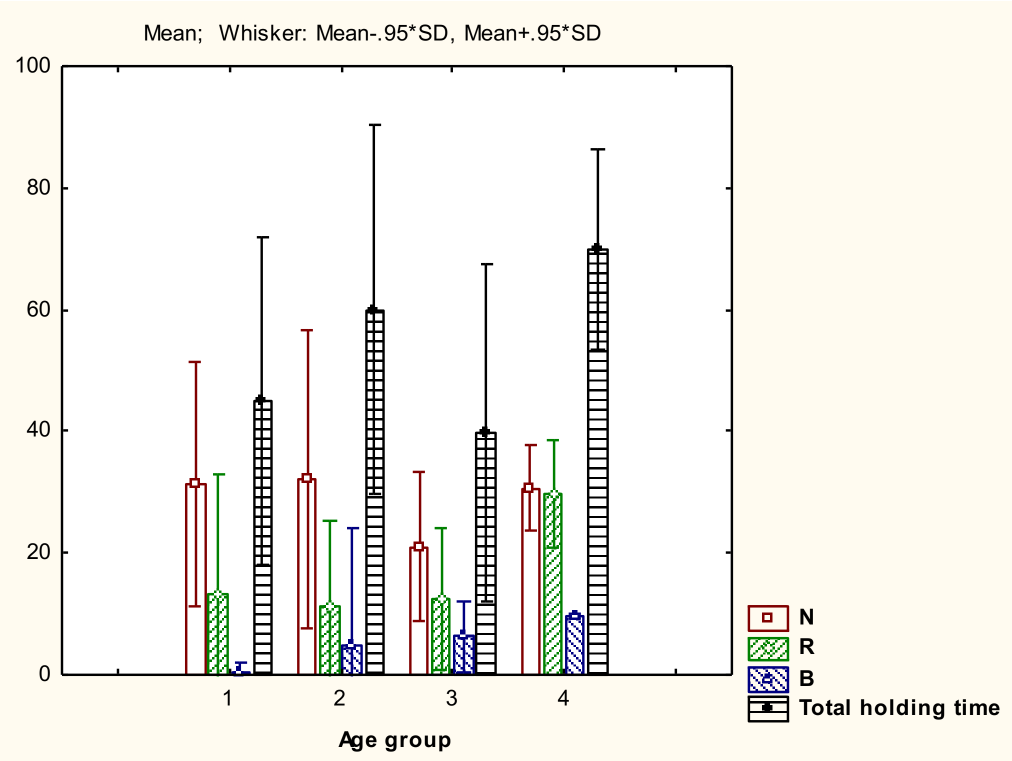

Figure 15. Holding time (total and for each of the parts of the display; seconds) for the different age groups (1: visitors under 12 years; 2: 12 to 18 years; 3: 18 to 65 years; 4: more than 65 years). Histograms show mean measurements and whiskers show 95% of the standard deviation.

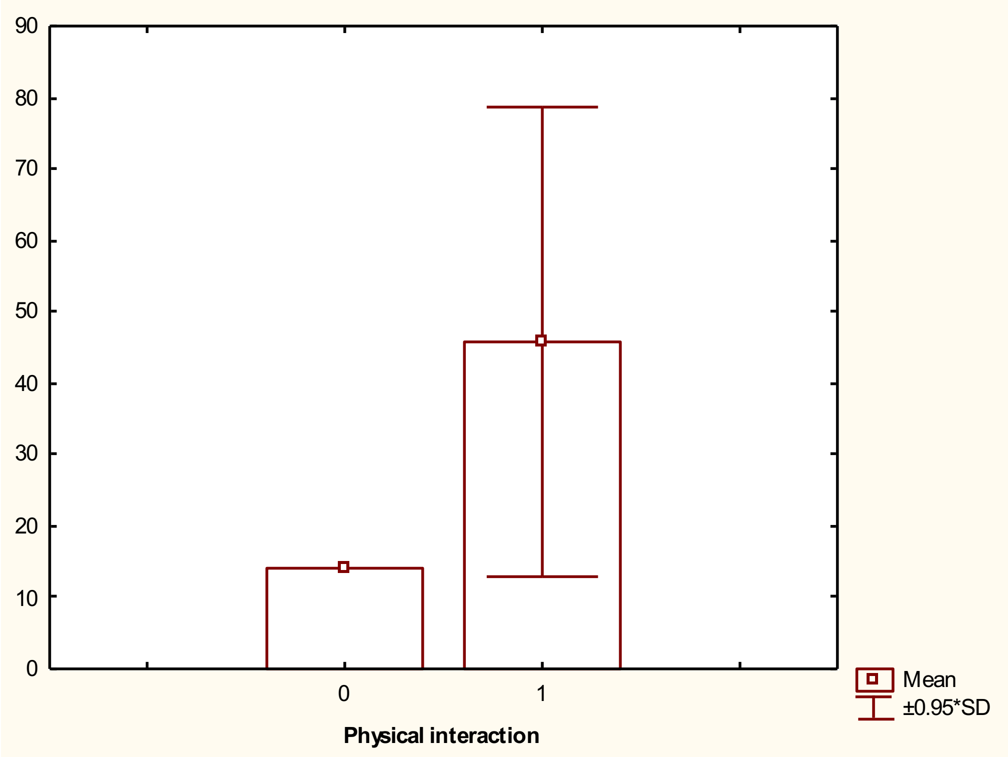

Figure 16. Total holding time (seconds) for visitors that physically interacted with the display (1) and that didn't (0). Histograms show mean measurements and whiskers show 95% of the standard deviation.

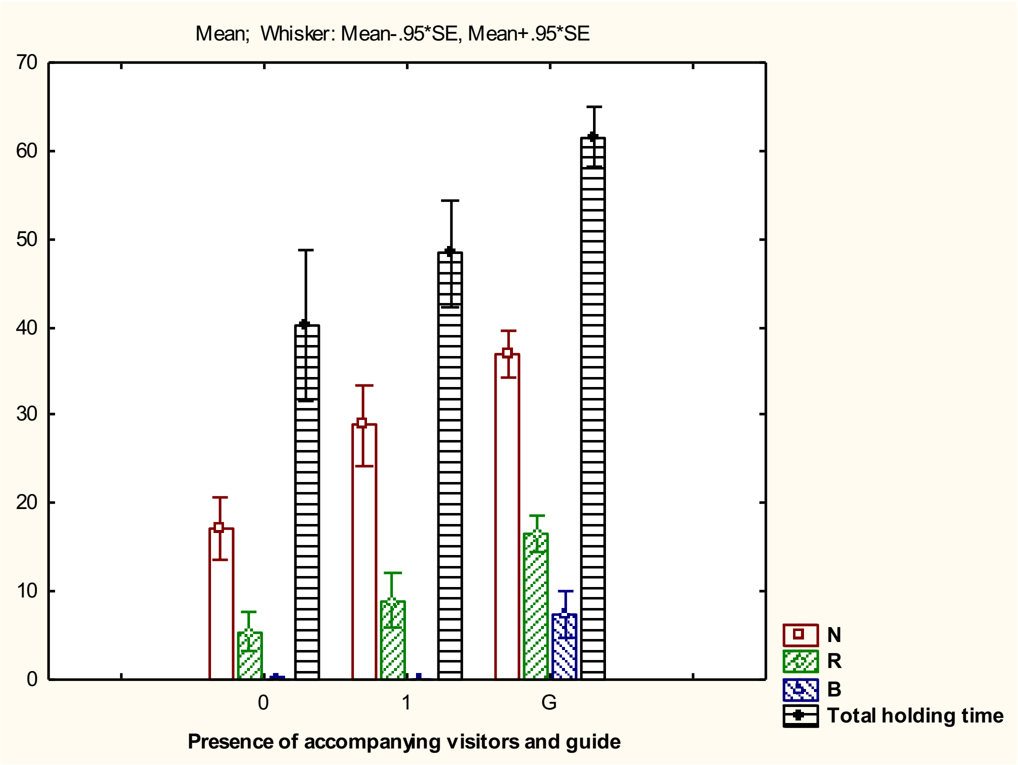

Figure 17. Holding time (total and for each of the parts of the display; seconds) for visitors on their own (0), accompanied by other visitors (1) and by the guide (G). Histograms show mean measurements and whiskers show 95% of the standard deviation.

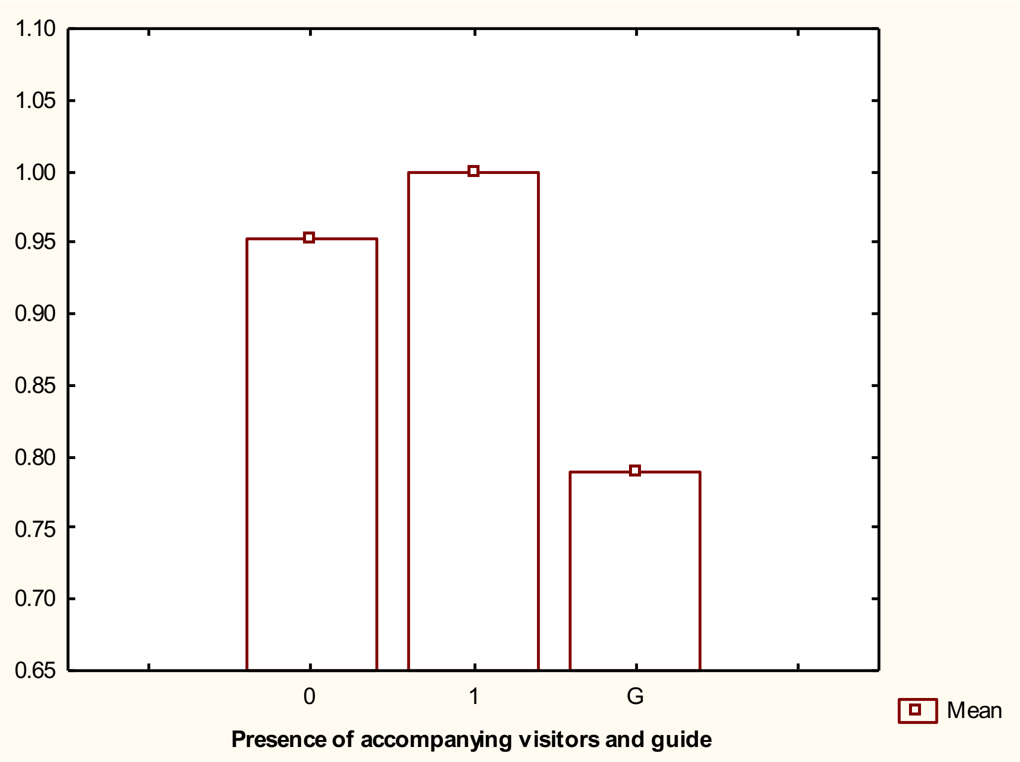

Figure 18. Proportion of visitors having physical interaction in relation to the presence of accompanying visitors or guide (0: visitors on their own; 1: presence of accompanying visitors; G: presence of the guide). Histograms show mean measurements and whiskers show 95% of the standard deviation.

3.3. Results of the questionnaires

A total number of 476 students answered the questionnaires after their visit to Fysikaliska Leksaker. Not all the students answered every question, so the number of answers is shown for each question, together with the results, in table 14. No ‘no’ or ‘other’ answers were computed, since some of the questionnaires included just ‘yes’ answers.

Question	**N**	**Yes (N)**	**Yes (%)**
Do you think now, after the visit, that it was a good idea to go to Fysikaliska Leksaker?	455	435	96
Did you think before the visit that it was a good proposal?	436	305	70
Do you think it was a fun visit?	455	434	95
Do you think the visit should have been longer?	455	370	81
Did you learn something during the visit?	437	361	83
Would you like to make another visit for example in one year (when there will be new experiments)?	437	398	91
Do you like now Physics and Technology more than you did before the visit?	437	249	57
Would you also like to do other visits to Chalmers (for example, to research laboratories)?	437	362	83
Did the visit make you think of going to Chalmers to study engineering (in case you hadn’t considered it before)?	392	95	24

Table 14. Answers to the yes/no questions asked in the questionnaire developed by Dr. Per-Olof Nilsson. N: number of students answering each question. Total numbers and percentages of positive answers are shown for each question.

According to these results, most students enjoyed the visit and thought there was a good idea to visit the hall. A large proportion of the students state there has been a personal learning outcome derived from the experience, and the feel positive about visiting other science settings within Chalmers. Most students would as well like to repeat the visit after some time. Although not many students felt inspired to the point of starting to consider the possibility of studying at Chalmers, more than half of them express an increased interest in physics and technology after the experience.

The last question (not included in table 14) was an open one, and invited both students and teacher to express their general opinions on the visit, or those on particular aspects that were left out of the previous question set. The only negative aspect repeatedly pointed out by the answers of this open question was the length of the visit, which appeared too short for most students. Several students state that they didn't have time to try out all the experiments, and therefore they would have liked to stay longer. Recurrent comments refer to particular experiments with which visitors seem to especially engage, such as the demonstrations with liquid air, and certain experiments that involve daily life objects. Many of the answers reveal the importance of guidance during the experience, explicitly talking about Per-Olof Nilsson and his engagement with his job. Several visitors mention the quality of the guidance and help, although others suggest that increasing the number of guides would enhance the experience. Adjectives like 'fun', 'playful', and 'engaging' are commonly repeated throughout the answers, and sentences such as 'I learned a lot' frequently written by the students. Another commonly mentioned asset of the experience was that 'doing things on your own is fun'. This last sentence tells about the desire of learning in ways that might be different from those, unfortunately limited, offered by the tools that many schools can use for their daily teaching.

4. Discussion

Data obtained from the visitor observation experiences at Universeum and Fysikaliska Leksaker show some interesting facts. The present chapter will discuss these results together with those of the questionnaires and the qualitative information obtained from the interviews, in relation to published sources.

4.1. Social interaction in the museum

People visit in pairs or in groups, museum visits are social activities. However, not only people come with company to the museum, they as well involve those people accompanying them in their interaction with the exhibits. Sandifer (1997) observed longer holding times for those visitors visiting in family groups than for those visiting alone. Tracking data for both settings studied in this thesis point out the importance of sharing the museum experience with others. This is especially clear with young children, who often call the attention of their parents onto what they have just discovered. A common scene during these observations was that of a kid pulling an adult's arm towards a certain display with which the kid had previously been interacting.

In every case, shared interactions took place within the context of a dialogue between or among the group of visitors. Comments and information exchange on the experience while it is taking place is probably an important source for the understanding of the exhibited contents. Ohlson (2008, personal communication) points out the need for reflecting time during museum visits in order to reach a targeted level of meaning making. Most probably, the dialogue during shared interactions allows for and enhances that reflection to take place, sometimes accelerating understanding processes.

As Ohlson describes, the nature of physics makes it difficult to compare the success of certain sensory experiences with that of the performance of mathematical models. For example, a child that has never experienced holding a piece of lead, would quickly understand weight and density by simply lifting a lead object, rather than looking at a number of values describing the density of different substances. In this way, the museum can take advantage of the power of the real object. As Wagensberg (2005) suggests: 'In a museum, there is no ban on using simulations, models, graphic images or new technologies, but only as accessories of reality, not to take its place'. Even though the sensory experience of the real object can be considered a very personal one, the role of sharing that experience seems to be important. After all, it is impossible to know how others understand phenomena, what are their mental images like when trying to transmit science contents and models (Ohlson, 2008, personal communication), so constant dialogue and exchange of the transmissible part of those experiences are probably a human tool to improve understanding.

In the case of Fysikaliska Leksaker, the presence of guides and the structure of the group visits added some interesting information about the interaction patterns among visitors. The presence of the guide while the visitor was interacting with the display prolonged the holding time of the studied display. The presence of accompanying visitors did not have the same effect, showing the importance of guidance in the experience. However, a longer holding time does not necessarily involve a better outcome in terms of learning, but it most probably reflects a deeper engagement with the display. Carlisle (1985), describes sharing and cooperative behaviours predominating in students visits in a science centre in Canada, stating that ‘social interaction was pleasurable, and held the potential for learning scientific facts and principles’. Under the contextual model of learning in the museum postulated by Falk and Dierking (2000), within-group social mediation and facilitated mediation by others are parameters of the sociocultural context that affect learning experiences.

Devoting resources to intensive guiding is also a strategy that takes place at Universeum. Ljunström (2008, personal communication) explains it as a way of dealing with time constraints during school groups visits. An educator and five high school interns guide each group in their visit. This is a double learning experience: high school students facilitate the learning of younger children while they learn themselves. This strategy of using a student to teach another student is also mentioned by Nilsson (2008, personal communication) when comparing the learning outcomes of reading a book (after which the average learner remembers around 10%), listening to someone explaining it (20%), doing experiments (70%) and teaching someone else (95%).

Surprisingly, at Fysikaliska Leksaker the frequency of physical interaction with the exhibit decreased in the presence of the guide. There might be several reasons explaining this behaviour, but the fact of seeing someone demonstrating a certain display might discourage visitors to try themselves, devoting their time, instead, to some other of the numerous stations.

In the case of Fysikaliska Leksaker, there is another peculiarity that enhances the effectiveness of guiding. Dr Nilsson runs a short explanation with some demonstrations at the beginning of the visit, and a second show with some spectacular tricks at the end of the session. His charisma and enthusiasm in communicating science is one of the main reasons of the success of the experience, as many of the questionnaire answers reflect. A common feature to all school groups observed during the fieldwork at Fysikaliska Leksaker, was a certain pattern of physical display during those two meetings with Per-Olof. During the second show, students tried to get closer to the guide, almost closing a circle around him. In some cases, especially in the younger school groups, children tried to reduce their physical distance to the speaker to almost that typical of a conversation between two people. Nilsson (2008, personal communication) explains that the most efficient transmission of knowledge through the spoken word occurs when the distance between speaker and listener is around 40 cm. He also quotes Charles Henderson (2007), a researcher on physics education, who has empirically tested a significant increase in the efficiency of learning at University level when the students are placed in a circle around the speaker, rather than in the classical disposition of all students facing the same direction. Wagensberg (2005) also reflects on the spatial configuration of lecture halls and classrooms, the height of speaker and audiences, and its effects on the transmission of information.

4.2. Time aspects of the museum visit

According to the questionnaire answers, most students believed that the time spent at Fysikaliska Leksaker was not enough. Visitors observed at Universeum showed a tendency to rush through the exhibits, sometimes not allowing for the consequences of their actions to take place. Non formal observations during the fieldwork revealed that, in those cases in which the exhibit ‘reacted’ to the visitor, the effect was sometimes lost because the visitor had already stepped out and moved into a different display. A whole discussion opens at this point about whether an interaction is still taking place or not. By definition, the system still reacts to the visitor’s action, although the visitor is not there anymore to extract whatever gain was to be extracted from it. If we define interactivity as Adams and Moussouri (2002), one could question if the active engagement is still present. During the visitor observation session, it was in some cases very obvious that the learning outcome apparently targeted with the display of the theremin, was not achieved. Some people left the room without understanding how the instrument worked. This rushing through the displays may be due to the impression of not having enough time to visit the whole museum and reinforced by the need to extract as much as possible of the visit, after having paid the entrance fee. Museum management policies that encourage revisiting (for example, with yearly entrance fees) might contribute to decrease this tendency, as suggested by Ohlson (2008, personal communication).

4.3. Attracting and holding power

The number of visitors that are attracted to a certain display should be referred to the context of the whole exhibition to which they belong. The attracting and holding power calculated for the displays observed in this study loose some of their value due to the impossibility to compare those data with similar displays within the same exhibitions. Furthermore, the behaviour of visitors might be different in the context of different exhibitions, for example by being selective and focusing in a few exhibits during longer periods of time. The number of displays in an exhibition, or even in the whole museum, might as well affect the time spent at each station. In both sites studied the visitor is probably overwhelmed by the amount of information accessible, reducing as a consequence holding time in order to have the chance to get in contact with a larger number of exhibits.

Nevertheless, the published literature shows values of over a minute of holding time for successful science stations that could be compared to the ones studied in this thesis (Bailey et al., 1998). Although Sandifer (1997) reports an average time of 1.4 minutes for the displays in a natural science museum, sensibly longer than the usually reported values of 30 seconds for this kind of museums (Falk, 1991), 60% of the interactions lasted less than 1 minute. In the same study, Sandifer measures engagement in two different ways. Firstly, by checking, at intervals of three minutes, how many of the visitors are engaged with any of the displays. Secondly, by setting a cut-off time of 5 seconds when measuring holding time. In the fieldwork presented in this thesis no cut-off time was set, but engagement was present (even if for a short while) in all visitors counted into the holding time statistics. In the very few cases in which visitors interacted for periods of time shorter than 5 seconds, there was a reason for it that did not exclude engagement. For example, after a few seconds of interaction, an accompanying visitor called the attention to a different display, sometimes pulling the first visitor away from the exhibit. Other cases include visitors who, for a short while, observe other visitors (not belonging to their visiting group) while they interact with the display.

Falk (1991) suggests that the mean holding time is not a useful measurement, given that nobody spends the ‘average time’ interacting with the exhibit. Instead, he proposes the use of histograms showing the real distribution of the frequencies for the different holding times, which appear to fit to binomial distributions. Figures 4 and 12 show these suggested histograms. In the case of the present study, the mean seems to be a good indicator of visitor behaviour, although the ranges of both distributions are wide.

Observations were made during a weekend in Universeum and during weekdays at Fysikaliska Leksaker. For the last, no other choice was possible, considered that the hall opens just for school groups under school hours. In the case of Universeum, fieldwork was carried out on a weekend after the suggestion of the scientific director, and due to the higher number of visitors susceptible to be tracked during this period. Sandifer (1997) observed no differences in holding time between weekdays and weekends, but suggests the possibility of different visitors’ agendas and their behavioural reaction to crowded exhibits during weekends.

The tracking of partial holding times for both field studies carried out had the aim to explain visitor behaviour into detail. The decision of measuring how long time did people spend in activities that involved mainly one of the senses was an attempt to obtain deeper information about the contribution of different perceptions to the full experience of the content offered by a certain exhibit. The results of these observations show that holding time was longer for those interactions involving physical contact (or the use of the hands in the case of the theremin) than for those involving looking. In both science centres, reading (labels, instructions, or looking at the barometer) caught the attention of visitors just for a few seconds.

At Fysikaliska Leksaker, the newspaper display was the one with a longer holding time, followed by the rubber square. In both displays the sense of touch is dominant over others, and both of them involve a certain degree of ‘controlled violence’ to experience the desired outcomes. In some cases, visitors softly pushed the metal piece instead of hitting it, thus making it difficult to reach the goal of understanding the magnitude of atmospheric pressure targeted by the display. This could have been solved by spending three or four seconds reading the label that stands beside the exhibit. In most of these cases, if a guide was not present to facilitate the experience, the visitor left without fulfilling any of the learning outcomes, and most probably with a certain degree of frustration.

In the case of the observations at Universeum, playing the instrument was what visitors spent a longer time doing, followed by listening to others playing. Sandifer (1997) observed that young visitors spent 53% of the time interacting, while adults just 27%. Watching others while they are interacting showed, in the same study, the reverse tendency (29% of the children's time and 44% of the adults' time).

In the case of the theremin, whenever the visitor is playing, the sense of hearing is as well involved, making it difficult to separate the engaging effect of each of them. The visitor can create a sound and simultaneously listen to it. Most probably, this combined action triggers a special interest. Paradoxically, the sense of touch involved in playing most of the existing musical instruments is not present in this experience in the same way. The visitor does not need to touch the object to play it, being the movement of a hand or any other body part around it, enough the produce sound. This paradoxical 'playing without touching' triggered immediate curiosity and engagement in many visitors. This fact was enhanced by the surprise factor, given that most of the visitors did not know what the object was and were, thus, shocked by the sudden hearing of a sound without 'having touched' anything in the room. In a few cases, the visitors did not even realise there was sound production involved in the exhibit, because they constantly held the volume antenna, 'turning it down' to zero. This illustrates how used visitors are to using their sense of touching when they enter the doors of a science centre.

4.4. Reading labels

Botelho & Morais (2006) make a short review of the literature about the behaviour of visitors regarding labels. Some researchers conclude that meaning is partially lost because people don't read the labels accompanying exhibits, while Falk's (1997) comparison of two exhibitions, one with and one without labels shows that people stay longer and seem to learn more about the content when labels are provided.

In the fieldwork carried out within this thesis, time spent in reading labels was very short, if any. Most visitors did not read the labels or instructions at all, although in both cases the amount of text was very small. The little time spent reading the label contributed in the case of the theremin display to enhance the surprise in either direction (sudden unexpected sound or unexpected silence), but had the counterpart of some visitors leaving without understanding the exhibit. This result suggests the need for evaluation of the performance of exhibitions and, when appropriate, a change in the strategy for communicating the information held in labels.

4.5. The tools of the museum

All subjects interviewed for this study agreed in the importance of the experimental nature of physics in its learning processes. Although some of them develop their work in formal learning environment such as schools and universities, their ideal set of tools for the teaching of physics included in all cases experimentation. Ohlson (2008, personal communication) suggests the use of physics labs without steering for an efficient learning process. The opportunity to get in contact with ‘a cupboard of objects and tools’ and learn how to design their own experiments and to formulate their own questions is also pointed out by Gant (2008, personal communication) as key for discovery learning. Museums can offer the visitor an even more relaxed version of these experimental labs, although some constraints such as time frames and guidance must be considered.

In the deep essence of the question, the idea of museums as holders of concentrated reality (Wagensberg, 2005) places these institutions in a privileged position for achieving their goals through experimental learning. Physics is a human tool developed to understand reality (Andersson, 2008, personal communication), it is not reality itself. Physics theories can be understood as ‘best guesses’ of a simplified model of reality (Eingren, 2008, personal communication). The benefit of museums, their advantage over schools and other formal education settings, is in fact the possibility of showing (and not recreating) reality. Ohlson relates, in the course of the interview, his trips to Liseberg (an amusement park in the city of Gothenburg) with his physics students. After several rides in the different attractions, students were asked to explain, in a report, the physics models explaining what they had already bodily experienced. Linking into Nilsson’s appreciation (2008, personal communication) of the precedence of physical experiences to the learning of theory, this is a very good example of the role of informal settings in the effective understanding of natural science. Moreover, reality brings in another asset of learning about the world. Prasad (2008, personal communication) identifies some of the constraints of the formal experimentation used in schools and universities. As he explains, in our approach to reality we can intuitively design procedures to describe and understand the physical world, but the nature of the scientific method sets some limitations to our capacity to discern what is real when it does not produce the approved, expected results. The way in which we set our criteria about the accuracy of experimental procedures is most of the times determined by the prestige of science, and not by our own intuitive feelings about the world. Since reality, due to its complexity, does not always match the simplified models we construct to describe it, formal experimentation provides ‘cooked up’ situations in which the model would work (Prasad, 2008, personal communication).

Andersson’s experience with high school students show that most teenagers don’t question models and laws (Andersson, 2008, personal communication). This is probably a measurement of the power of what we could call ‘the image of science’ in modern societies. Science itself, as Prasad (2008, personal communication) reminds us, should be built on doubt and scepticism. Reality, and museums that are prepared to show it, are the best tools to trigger natural curiosity, sincere discovery and, consequently, meaning making. If school had the chance to be student centred, as Prasad (2008, personal communication) suggests, taught concepts could more easily be translated into the student’s own understanding. Instead, the repetition of meaningless procedures to achieve the approved result, that are never deeply interiorized as actual learning, removes self confidence from the learner (Gant, 2008, personal communication). The real ‘aha! experience’, as Prasad (2008, personal communication) refers to the intellectual joy described by Wagensberg (2007) should be the aim of those museums targeting the understanding of our physical world, and requires, in most cases, a certain degree of self confidence to open a dialogue with reality. After all, intuitive learning is inherent to animal brains. We, the same as a dog has the ability to catch a ball in the air intercepting its trajectory, are good at predicting, says Prasad (2008, personal communication). We are required to, in order to survive; predicting the behaviour of the physical world is a tool evolution has equipped our brains with. When a baby sees the bouncing of a ball for the first time, the experience is probably surprising and calls for attention. When the same phenomenon has been repeated a hundred times, surprise leads to automatic prediction (Nilsson, 2008, personal communication). Several processes in our daily life need to build

in using this automatism, showing the effectiveness of intuitive learning through the simple contact with reality.
Although classical learning theories set pre-puberty as the moment in which the building of abstract models can start taking place (Ljungström, 2008, personal communication), there are obvious processes of conceptualisation of nature occurring before. Sheila Gant (2008, personal communication) refers her scepticism about the division between abstract and non abstract models. The same reality, she explains, can be simplified in a series of mathematical formulae, but also building physical models with everyday objects with which people can relate to. It is by using daily objects and through experiencing surprise, as reflected in the answers to the questionnaires analysed in this study, that people remember. Both Nilsson (2008, personal communication) and Andersson (2008, personal communication) recall learning experiences that exemplify this phenomenon. Accordingly, Sten Ljungström (2008, personal communication) states that Universeum, rather than 'teaching' the visitor, tries to provide an experience that will be remembered.

4.6. Understanding with the body

The implications of sensory experiences in the intuitive learning of physics might be obvious after a brief reflection, but school and other learning settings seem to have failed to widely incorporate them as educational tools. In some cases in the museum world, a similar phenomenon with totally different roots can be observed: systematic touching (of computer keys, buttons that activate displays and screens) can fall as well in the ground of the meaningless in terms of learning outcomes. Torbjörn Eingren (2008, personal communication) manages to introduce senses through the spoken word in his guided tours at the astronomic observatory in Gothenburg. He uses sensory references ('moon dust feels like sugar powder, although it doesn't taste like it') when talking to children, overcoming the constraints of learning sessions based in the oral transmission of content (Eingren, 2008, personal communication). He also uses simple theatre plays involving the students to show, for example, the behaviour of particles. Kids enjoy pretending to be atoms, and through that body experience, they understand the meaning of physical forces.

It is difficult to separate the role of senses from the definition of interaction. In a classical lecture, seeing and hearing are not only dominant, but mainly one-way communication tools (Gant, 2008, personal communication). Interaction claims for information bouncing, for a constant modification of the perceived and the emitted. What is learned through the body is difficult to forget, because it has become part of our automatic tools to react to the world. To illustrate this, keeping the balance when learning to skate has a number of inherent integration processes that help us construct models to predict future interactions with the physical world. Prasad (2008, personal communication) explains this fact through a personal lecture of Lakoff and Núñez's (2000) concept of metaphor: bodily experience builds new circuits that are reused when predictions are necessary.

Reading and writing, the mean tools used at school, are learned ones. Senses are built in naturally, so most probably their role in understanding and acquiring new concepts is more important than we are aware of, as Nilsson suggests (2008, personal communication). An incredible amount of information bytes are constantly perceived by our senses, processed by our brains, and forgotten or disregarded by our consciousness, but most probably kept alive in the form of unconscious memories, argues Nilsson (2008, personal communication). These are recalled when dreaming or making 'unconscious' decisions, making survival possible without a constant, conscious thinking about everything. Furthermore, sensory experiences can help building self-confidence. Prasad (2008, personal communication) brings up the importance of the trust in oneself in learning processes. However, he adds, just a few fields, such as native language, provide that awareness on one's knowledge. Bodily experiences are an example of the same nature, and museums could take advantage of it to build up new knowledge on the self-confidence basis they provide.

A common issue that arose in most of the interviews conducted in this study was the individuality of learning processes. Real understanding of the natural world is a matter of sense making of a particular brain. This makes it difficult to think of knowledge as transmittable units to be incorporated in a novice's reasoning. Carl Wieman, awarded the Nobel Prize of physics, analyses the failures of physics teaching at school and university. He locates the roots of some of the poor achievements of physics teaching in quite basic mechanisms (Wieman, 2007): 'the brains of novices in a subject are activated quite differently from those of experts when confronted with a problem. As mastery is achieved, the brain literally changes; different links are formed and there are different activation patterns during problem solving'. This mismatch between teacher and student's perceptions originates a gap where transmission of knowledge becomes almost impossible. It is as if learner and instructor were speaking different languages, without even noticing. Perceptual differences about the quality and clearness of teaching are tested by Wieman, who warns about the dangers of thinking of student learning based on what appears ‘best to faculty members’ (Wieman, 2007). Mastery is much more than concept transmission; it is a delicate process of restructuring that cannot be fed just by the transference of content. Wieman proposes the use of intuition and motivation to improve understanding. Although this process is probably common to all fields of knowledge, the mentioned gap can be bridged in the learning of physics by the intensive use of sensory experiences. Nilsson (2008, personal communication) suggests that this should be the case with any other school subject, although practical reasons make it difficult to teach, for example, history, through recreations that involve multiple senses.

When the interviewed subjects were asked to reflect on Wieman’s statements and about the tools that could be used to bridge the gap between learner and content provider (schoolteacher, curator, etc), several different thoughts surfaced. Ohlson (2008, personal communication) reveals the need for empathy in the teaching process together with the use of ‘detective work’ strategies of learning. The use of analogies occupies also a relevant place among the respondents, encouraging learners to move their questions into fields in which they have intuitive understanding (Eingren, 2008, personal communication). Sheila Gant (2008, personal communication) uses MUD (most unclear discussions) cards where students note keywords about points that remain unclear during lectures. Cards are collected at the end of the lesson and questions clarified at the beginning of the following class. This technique would also be applicable in the museum context, where most of the evaluation targets the learning outcomes of visitors, remaining those contents that have not been understood, hidden. The use of non steered labs is another way of providing a customized experience that could be enjoyed both at school and in a museum environment.

4.7. Catering for a diverse audience

Not only physical perception might decrease the distance among brains, but it can as well become a tool to be efficiently used with young children. School classes put together people born in a certain period of time, being this a quite artificial procedure that, on the other hand, might minimize the differences in levels of conceptualization during long instructional processes. Museums, instead, cater for heterogeneous audiences, and the profuse use of sensory experiences can provide customized understanding that can be shared by an infinite number of visitor categories. As previously pointed out by the fieldwork results obtained in this thesis, the high frequency of shared interactions should be relevant to museum practitioners. Ljungström (2008, personal communication), explains how Universeum brings this need into exhibition design, projecting stations that aim for shared interactions or allow, at least, to participate in or overlook other visitors' interactions.

When interviewees were asked about the ideal age to target when aiming at avoiding the average adult's misconceptions about the physical world and encouraging interest for natural science, answers pointed out periods prior to the theoretical acquirement of abstraction capacities. Ohlson (2008, personal communication) proposes the use of experimentation from very young ages, in agreement with Gant (2008, personal communication). The efforts put by schools, universities and other science centres in attracting teenagers to science seems to her like a fight over the pool of students that would have anyway contributed, in any other area, to further knowledge for the community. Furthermore, she continues, there is a gender bias in the average adult's technological culture, what makes her suggest that it might be worth trying to get girls interested into natural science before they set into puberty. The gender aspect has been investigated in Finland as part of the ROSE ('The relevance of science education') project by Juuti *et al*. (2004), who concluded that girls where less interested than boys in all physics topics, except for those related to the human being, in which the results for both sexes are similar. As part of the same project, a similar study was carried out in Sweden by Jidesjö & Oscarsson (2004), showing the same tendency of girls towards those areas of science and technology that focused on the 'body and health', while boys' main fields of interest were 'weapons and space'. The ROSE project has produced a number of reports that give an overview of the student's perceptions on science in more than 20 countries (Sjøberg, 2004). In all cases, boys agreed in a higher proportion with sentences like 'science and technology are important for society', 'I like school science better than most other subjects', 'I would like to become a scientist', or 'I would like to get a job in technology'. Girls rate over boys in the question 'I would like to work with people rather than things'. Aware of this situation, Sten Ljungström (2008, personal communication) explains that Universeum targets a 12 year old girl when they project a new exhibition.

Within the outreach program of Universeum, some new activities are being planned to provide experimental learning in physics and biology to school groups in the spatial frame of their classrooms. In the context of these activities, children will measure the electric and magnetic fields of objects of common use such as toys, radio receivers, mobile phones, car keys, etc. The activities are aimed to children from 10 years old on, not only because the centre believes it is strategic, but because secondary school teachers seem to have a lack of self-confidence when it comes to their abilities to promote natural science learning. As Gant (2008, personal communication) many school teachers have made a conscious choice to remove science contents from their curricula, perpetuating the norm of a deficient science literacy in contemporary societies.

4.8. A brief comment on the design of informal learning environments

Several researchers have noted the relevance of the spatial configuration of museums in for the visitor's experience (Choi, 1997; Ciolfi,& Bannon, 2002b; Iguchi, 2007). Botelho & Morais (2006) suggest the placement of displays with high attracting and holding power in discrete places while those with lesser attraction power are located in strategic places., while Iguchi (2007), points out the importance of both topographical and conceptual orientation when designing exhibitions within museums. Accordingly, physics education research has revealed the importance of the design of the spatial environment, as well as the physical disposition of the learners (Henderson, 2007; Nilsson, 2008, personal communication). Ideally, students should be tested to determine how they could be best stimulated to acquire knowledge in order to customize the learning experience. In the time frame of the museum visit this option becomes impossible, but the museum can provide different environmental features to try to suit its heterogeneous audience.

As it has been discussed in this research piece, the use of the senses is key to the understanding of the physical world. The link between bodily experiences and the spatial environment in which they take place opens a whole debate that could be examined as a self-standing topic, although it is, unfortunately, out of the scope of this thesis.

5. Conclusion

This thesis has attempted to discuss the role of the senses and interactivity in the understanding of physics, within the context of non-formal learning environments. The main conclusions than can be drawn from this research are summarized in the following lines.

Although the understanding of physics includes aspects that are common to those of other subjects, sensory experiences are key to intuitive learning in this field. Museums, much more free from constraints than formal learning environments, can simulate the natural learning processes that children undergo, by displaying objects and phenomena to enhance the understanding of the physical world. The relationship between intuitive understanding and learning should gain prestige and become more central to the museum practice.

Physically interacting through the sense of touch seemed to be what visitors to the science centres studied engaged longer with. The possibility of using more than one sense when interacting with museum exhibits increases the probability of triggering curiosity and interest in the visitor, and increases the quality of the engagement. Moreover, multiple sensory experiences facilitate catering for heterogeneous audiences.

A model that could be derived from this study would place the sensory relationship between visitor and object/phenomenon (a piece of reality) as central to the construction of understanding about the natural world. Peripheral to this core would be the visitor's previous experiences and references (including knowledge acquired in formal settings), the interaction with other visitors (the social environment), facilitation (guides), and other aids provided by the museum (labels, additional materials, spatial features, ambience, etc). The essence of the central relationship above described allows for a coherent conceptualization of nature, far from unfortunate misconnections between models and everyday experiences.

Although most museums evaluate their exhibitions by using indicators such as visitor numbers, assessing the effectiveness of physics displays requires other indicators of performance. Measuring revisiting and evaluating engagement should give a better understanding of the success of an exhibition in achieving its goals. Moreover, identifying who is missing among the audience can help improving the scientific literacy of society.

Finally, more research could be done to discuss all other aspects relevant to the understanding of physics in non-formal environments, such as the role of spatial configuration of exhibitions, or the analysis of aesthetic elements that could be significant to the perception of the natural world.

Museums are privileged institutions where curiosity and creativity can be celebrated. Science museums practitioners should take advantage of this position to facilitate understanding through discovery experiences that are enjoyed and remembered.

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Appendix

Visitor’s behaviour observations

Form for data collection of visitor’s behaviour at Fysikaliska Leksaker.

GROUP #	DATE	TIME	N (M/F)	AGE / GRADE	SCHOOL	LOCATION	COMMENTS

INDIVIDUAL OBSERVATIONS

				HOLDING TIME (seconds)			
REG #	SEX	AGE GROUP	WITH…	BAROMETER	RUBBER	NEWSPAPER	COMMENTS

Form for data collection of interaction among visitors at Fysikaliska Leksaker.

DATE	TIME	GROUP #	N	NUMBER OF PEOPLE INTERACTING WITH DISPLAYS ON THEIR OWN	♂	♀	COMMENTS

Form for data collection of visitor’s behaviour at Universeum.

INDIVIDUAL OBSERVATIONS							
				HOLDING TIME (seconds)			
REG #	SEX	AGE GROUP	WITH…	READING	LISTENING	PLAYING	COMMENTS

Form for data collection of number of visitors (interacting and not interacting with the studied display) at Universeum.

VISITORS INTERACTING WITH THE DISPLAY

♂	AGE GROUP		
	1		
	2		
	3		
	4		

♀	AGE GROUP		
	1		
	2		
	3		
	4		

VISITORS NOT INTERACTING WITH THE DISPLAY

♂	AGE GROUP		REPEATED "VISIT" WITHOUT INTERACTION
	1		
	2		
	3		
	4		

♀	AGE GROUP		
	1		
	2		
	3		
	4		

Questionnaires

The following questionnaire was answered by teachers and students that had visited Fysikaliska Leksaker during the period 2003-2004. The questions, originally in Swedish, have been translated into English by the author.

Name, telephone number and e-mail address of the teacher:
Name and address of the school:
Grade (orientation):
Number of students in the class:
Number of students participating in the visit:
Number of students participating in the present questionnaire:
Date of the questionnaire:
Where did the suggestion of the visit come from? (i.e., colleagues, acquaintances, parents, students, etc.)

Ask the following questions orally in the class, approximately one week after the visit. Let the students answer YES and NO by raising their hands. Write down the number of "YES" after each of the following questions. For very young kids it might be difficult to fully understand the questions. Therefore, it would be useful if the teacher explains them (although it is important not to change the content).

Question 1.
Do you think now, after the visit, that it was a good idea to go to Fysikaliska Leksaker?

Question 2.
Did you think before the visit that it was a good proposal?

Question 3.
Do you think it was a fun visit?

Question 4.
Do you think the visit should have been longer?

Question 5.
Did you learn something during the visit?

Question 6.
Would you like to make another visit for example in one year (when there will be new experiments)?

Question 7.
Do you like now Physics and Technology more than you did before the visit?

Question 8.
Would you also like to do other visits to Chalmers (for example, to research laboratories)?

Question 9.
Did the visit make you think of going to Chalmers to study engineering (in case you hadn't considered it before)?

Question 10. Not all students need to answer this question.

Let some students shortly explain what they think about the gadgets. What do they think about the demonstrations and help? Something that was especially good during the visit? Something that was bad? Any ideas about new (kinds of) experiments? Other opinions?

For the teacher: summarize opinions that arise from question 10. Use page 3 for that purpose. You can, of course, add your own opinions as well.

Interviews

In this section, the basic set of questions asked to the interviewees is presented. Each of the interviews was customized by adding specific questions related to the activities of the person interviewed and questions that naturally arose during the interview.

Questions:

1. In your experience, what are the main differences between formal school or university learning/teaching and informal learning/teaching?

2. How do you think understanding and learning processes about Physics are different from other disciplines?

3. In your opinion, which is the role of the senses in learning Physics, and how do you think it could be used in teaching / presenting Physics to the public?

4. Physics education research has shown that when someone is trained in Physics for years, new patterns of thinking appear. The difficulty in going back to the state in which you didn't know about Physics and the lack of memory about how did you discover and understand might be preventing Physics teachers /facilitators from successfully delivering the information to the public, frustrating the learning process. Have you experienced this phenomenon? If you agree with this statement, what tools do you think could be used to bridge this gap?

5. What is your practical definition of interactivity and how do you use it in your daily work? how would you use it to deliver Physics contents in the museum context?

6. How do you deal with time constraints when teaching/delivering Physics contents?

7. What age do you think is ideal to aim for when trying to challenge misconceptions about the physical world?

8. Any other comments/experiences in the use of senses in exhibitions, learning/teaching experiences, etc.