
CeTI

# 04

## Design of Out-of-the-Lab Science Exhibits for Enabling Learning Experiences – A Research Proposal

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The importance of a general public being informed about science and technology has never been greater. Research institutions add to informal science communication with face-to-face events, during which the public interacts with scientific prototypes, functioning as science exhibits, in order to learn about science. The relevance of these out-of-the-lab science exhibits, for enabling the visitor to actively learn through experiences, has neither been explored nor recognised. This article illuminates this relevance, context and background, concluding with a research procedure. Based on empirical findings from various disciplines examining science centre exhibits, a comprehensive overview of design principles for science exhibits will be developed. Transferring and evaluating these design principles to exhibit design practice in technology development at research institutions will follow. Providing scientists with informed design knowledge to efficiently develop good science exhibits has the potential to greatly improve visitor learning experiences and to facilitate dialogues between current science and the public.

## Introduction from Three Perspectives

This article will present the relevance, background and outlook of a research project in the discipline of design research. The research object is the scientific prototype, or demonstrator, – coming directly out-of-the-lab and developed by scientists at research institutes – aiming to facilitate learning experiences about science and technology for the general public. The overall aim is to build up a knowledge base in science exhibit design and improve its practice in technology development at research institutions. Communicating science to the public is embedded in the broad field of research and practice of *science communication,* which is more than just "giving facts". Today's modern information age lead to the need to carefully design science communication inventions. The importance of a general public being informed about science and technology has never been greater. From understanding the COVID-19 pandemic policies or global climate change issues, to personal lifestyle choices we make in our everyday lives, understanding the science of the situation is essential for making informed and evidence-based decisions. Although the relevance of the subject is unquestionable, little is known about how to design effective science exhibits for science communication. Within this research project, special attention is given to science exhibits communicating technology, as a subcategory of broadly defined science.

The following sections introduce the subject matter from three perspectives: the research institute (here the university), the science exhibit (here the scientific prototype), and the design practice.

### *The University's Responsibility for Science Communication*

The traditional role of the university has changed. Its first mission *teaching students* and second mission *research* have been extended with a so-called third *mission dialogue between science and society* (Predazzi, 2012). This third mission functions as an umbrella term for several dimensions, such as technology transfer, lifelong learning and social engagement – all of which are supposed to strengthen the impact of science on society. Examples for social engagement measures are popular scientific publications, laboratories for children or science nights (Berghäuser & Hölscher 2020) – activities for communicating science to the public. The university's responsibility for communicating science outside of the academic community becomes clear and further manifests itself in public engagement requirements by funding bodies (Palmer & Schibeci, 2014).

Why is Science Communication so important? Science and technology are embedded in nearly every aspect of our society. The public faces an increasing need to integrate information from science with their personal values and other considerations as they make everyday life decisions. Moreover, science and technology are important drivers for enhancing innovation which affects everyone in society. Aiming to incorporate science into our culture, communication of science in different formats with different strategies and aiming at different target groups, is an essential activity in our knowledge society.

The most common approaches in science communication can be divided into two groups: *Formal science communication* (e. g. science education at schools, colleges and universities or academic conferences) and *informal science communication* (e. g. popular science books, science communication YouTube channels and museums) (Burns et al., 2003). One part of informal science communication is likewise the various activities of universities, like science nights or children's laboratories, as previously mentioned.

The focus of this research lies on a university's face-to-face events, where the public interacts with scientific prototypes (demonstrators) – serving as science exhibits. So far, relevance for these out-of-the-lab exhibits for science communication has neither been recognised nor investigated.

***The Demonstrator as a Science Exhibit***

Where do out-of-the-lab science exhibits at research institutions come from, who designs them and why? In technology research and development, a prototype emerging at different stages of research is called a demonstrator (or demo). In literature, there is little research about demonstrators, but it can be seen that these demonstrators play a complex role and serve multiple purposes. As their name suggests, they demonstrate scientific principles, but they also show technical or market feasibility. They are used to communicate research within the scientific community, to the general public or other target groups, such as investors (Moultrie, 2015). In Figure 1 and 2, examples of out-of-the-lab science exhibits communicating technology to the public are shown.

Demonstrators usually emerge during research as a means of scientific exploration or at the end of research projects as a tangible translation of research results (Linke et al., 2012; Moultrie, 2015). Researchers developing demonstrators to function as science exhibits for the general public typically lack information about how to design effective exhibits, so they end up with ad-hoc or intuition-driven approaches.

Fig. 1: Example of out-of-the-lab science exhibits.

The visitor wears a data glove in order to control a robotic hand while playing a game of rock, paper, scissors.

Fig. 2: Example of out-of-the-lab science exhibits.

Visitors can apply different scenarios to the autonomous swarming module for agriculture, and it reacts accordingly.

***Design Practice***

When designing and evaluating exhibits with the aim to communicate science to lay people, established design approaches for cyber-physical systems in professional or consumer contexts apparently reach their limits. The following three aspects demonstrate challenges for exhibit design:

(1) Visitors interact with an exhibit because they *want* to, not because they *need* to, with the purpose of enjoyment and/or obtaining information.
(2) There is only a short time of interaction, which can be ended by the visitor at any moment.
(3) Interaction with one exhibit mostly happens just once.

From the perspective of the exhibit designer, the major goal of visitor-exhibit-interaction is learning, while visitors might have different main drivers of interaction, such as enjoyment (Perry, 2012). Moreover, science exhibits are at best highly interactive, should respond to a large target group, and need to be extremely robust (Wideström, 2020). These circumstances leave the designer with intuition-based approaches, uninformed design decisions and without established evaluation tools at hand. When looking at best practice examples for good science exhibit design, much can be learned from science center exhibits. Literature shows that science centers, with their educative and visitor-centred approach, are rich learning environments due to their highly interactive, hands-on exhibits.

***Conclusions***

The relevance of this research is clear. It can be assumed that there is great opportunity for engaging the public at face-to-face events with interactive science exhibits deriving directly from current research, systematically, thoroughly and consciously designed for science communication. Interdisciplinary research teams lack information about how to design and develop effective science exhibits in an efficient way, to avoid unattractive, confusing or frustrating visitor-exhibit-interaction.

In order to proceed, theoretical background in the areas of science communication, demonstrators, informal learning in museums and exhibit design needs to be thoroughly understood. This will be the aim of the following section.

## Overview of Relevant Research

Science communication can be defined as:

**"... the many ways in which the process, outcomes, and implications of the sciences – broadly defined – can be shared or discussed with audiences. Science communication involves interaction, with the goal of interpreting scientific or technical developments or discussing issues with a scientific or technical dimension."** P. 3 (van Dam et al., 2020)

The aim of science communication is to achieve a high *scientific literacy* in society, also described *as scientific culture or public understanding of science* in society (Burns et al., 2003). Scientific literacy in society helps to form interest in and understand the world around oneself. It should engage discourses of and about science. People should be skeptical about certain claims made about scientific matters and be able to identify questions, investigate and draw their own evidence-based conclusions for the environment and their own everyday life (Hackling et al., 2001).
Over the last three decades, there has been a shift in perspective in science studies *from public understanding of science to public engagement in science*. In the 1980s and early 90s, the quite narrow model of public understanding of science (PUS) focused only on what the public knows and consequently what the public does not know. A large scale shift has taken place over the last few years from this 'deficit model' of communication to a 'dialogue model' towards public engagement in science and technology (PES), agreeing that PUS was an outdated approach that implied a one-way communication from the science community to society (House of Lords, 2000; Rennie & Stocklmayer, 2003).

What does the word *science* in science communication comprise? In literature, there has been much discussion about the exact definition of science. Very generally, science can be described as "a systematically organized body of knowledge on a particular subject" or even "knowledge of any kind" (Oxford University Press, 2020). More specifically speaking, there are broad and narrow definitions of science. A narrow definition would *exclude* social and applied sciences and only refer to basic science like biological, life and physical sciences. Broad definitions of science include technology (as applied sciences) (Weigold, 2001). In the context of science communication and within my research, I use the definition of Burns et al. (2003), who refer to science as basic sciences, mathematics, statistics, engineering, technology, medicine and related fields.

### *The Demonstrator*

To date, there has not been sufficient research that examines the role of demonstrators in technology research. Moultrie (2015) presents one of the few studies. He proposed a model which classifies demonstrators by referring to their purpose, and proposed to differentiate *application* *into potential application and specific application* in the established 'STAM' model (Science, Technology, Application, Market). His research focused on *design demonstrators,* as industrial designers were part of the research team. Moultrie presented the following list of demonstrators purposes: "Demonstrating scientific principles, technical feasibility of potential future applications, technical feasibility of specific applications, commercial feasibility of a specific application, potential to scale-up physical size of science, potential to scale-up and reproduce in volume, visualising potential future applications, demonstrators to convince potential funders or investors, beta-prototypes demonstrating market feasibility, demonstrators to support communication within the community and demonstrators to support communication outside the scientific community." (Moultrie, 2015)

Regarding cross-disciplinary collaboration, *boundary objects* are typically discussed to help mediate the boundary between actors with different perspectives, knowledge or skills (Nicolini et al., 2012; Star & Griesemer, 1989). Nicolini et al. (2012) present one of the few studies about boundary objects in scientific research, concluding that interdisciplinary research forms around, and is mediated by, these objects.

When looking at these objects from an instructional design perspective, they become *knowledge objects* which can be defined as external representations of knowledge to facilitate learning (Merrill, 2000). Accordingly, the internal representation and use of knowledge by learners can be described as mental models.

### *Informal Learning in Museums*

As already mentioned, informal learning institutions, such as museums, science centers and universities, contribute to the societies science literacy while providing opportunities for people to engage in science and scientific issues. In exhibitions or on public face-to-face events, interactions with exhibits make up the most significant part of the visitor experience (Barriault, 2016). A commonly identified characteristic of informal learning is so-called *free-choice learning* (Falk & Dierking, 2002), where each individual visitor can choose the exhibit to engage with and for how long. Often, but not restricted to informal learning environments, the educational approach of *inquiry-based learning* is applied. Here, the visitor follows methods and practices similar to those of science in order to construct knowledge. It is organized into inquiry phases such as formulating hypotheses, designing experiments to test them, collecting information and drawing conclusions (Keselman, 2003).

Early research into learning in informal science settings was based on behaviorist definitions of learning. The primary focus was on assessing cognitive gains made by visitors as a result of their visit, which led to disappointing findings with little evidence of learning (Miles & Tout, 1992). In the 1990's, researchers started to gain a broader understanding of learning, admitting that learning in informal environments is more complex. Constructivist and socio-cultural theories about learning emerged and are now well accepted in this context because free-choice learning experiences are highly personalized, socially constructed and appeal to visitors' motivations, interests, previous experiences and prior knowledge (Falk et al., 2007). It is now understood that people are not the passive recipients of knowledge, but are in fact active learners who make meaning from their interactions with their environment by building on their past experiences and prior knowledge (Dierking et al., 2003; Hein, 1991; Rennie & Johnston, 2004). Falk and Dierking's widely adopted *Contextual Model of Learning* (2000) provides a theoretical construct for these informal learning environments regarding three contexts which affect learning (personal, socio-cultural and physical context).

*Informal Science Learning in Science Centres*
Science centres are characterised by their highly interactive, hands-on exhibits in contrast to traditional, more passive museums with their primary goal to conserve artefacts. The first two science centres opened in 1969 (Exploratorium in San Francisco, USA and Ontario Science Centre, Canada) out of the social and political need to increase the public's science literacy (Friedman, 2010). Since then, the amount of science centres worldwide grew exponentially due to the popularity of engaging experiences they offer, but also because of the valuable role they play for the informal learning infrastructure. Although collecting, preserving or researching are still important activities, the primarily role of science museums has gradually shifted towards a more educative visitor-centred approach (Weil, 1999). Science centers are rich learning environments that "nurture curiosity, improve motivation and attitudes toward science, engage the visitors through participation and social interaction and generate excitement and enthusiasm, all of which are conducive to science learning and understanding" (Barriault & Pearson, 2010, p. 91).

*Visitor Experience of Science Centres Exhibits*
Emerging from the broader scope of leisure and tourism, in the museum context the *visitor* is the subject of research. Their overall experience is accordingly referred to as *visitor experience*. When looking at visitor experience regarding interactive science exhibits, literature indicates seven interconnected elements that are directly linked to learning taking place: educational purpose, interactive exhibit, interaction, learning, engagement, physical environment and social context (Ocampo-Agudelo & Maya, 2017) (see Fig. 2).

From these seven elements, *visitor engagement* is the major element and primary tool which influences design and evaluation of exhibits (Ocampo-Agudelo & Maya, 2017). Literature suggests that

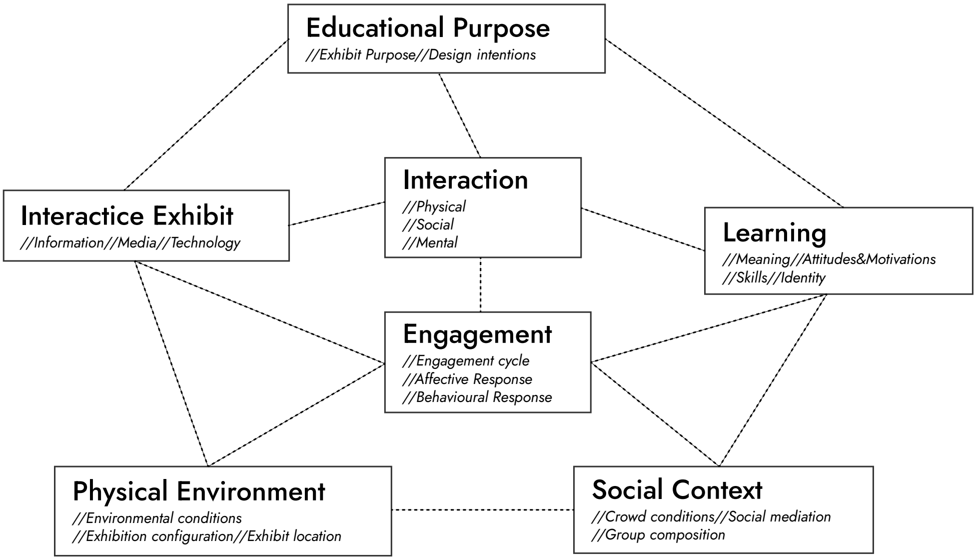


Fig. 2: Visitor experience is influenced by seven interconnected elements (after Ocampo-Agudelo & Maya, 2017)

visitor engagement is a direct indicator of learning taking place (Barriault & Pearson, 2010; National Research Council, 2009; Haywood & Cairns, 2006), which can be assessed either by the amount of time a visitor spends at an exhibit (Serrell, 1997), or by so called *engagement, inquiry or learning behaviours,* such as questioning, observing, reasoning, playing, predicting or manipulating (Barriault & Pearson, 2010; National Research Council, 2009). The engagement cycle describes the visitor's journey at different stages: attraction, initial engagement, deep engagement and disengagement. Therefore, an engaging exhibit must attract and hold the attention of the visitor, have an attractive entry point and encourage prolonged interaction (Hein, 2006; Humphrey & Gutwill, 2017).

When interacting with an exhibit, the visitor makes subjective judgements which result in affective and behavioural responses. For instance, affective responses are feelings of pleasure and enjoyment, involvement, curiosity and interest, confidence and competence, personal meaning and relatedness. These feelings lead to intrinsically motivated visitors (Csikszentmihalyi & Hermanson, 1995). Behavioural responses are observable actions performed by the visitors, indicated above as engagement behaviour. Both affective and behavioural responses strongly depend on the visitor's prior knowledge, interests and motivational needs, and certainly on the exhibit itself – the interaction, the educational purpose, the physical environment and the social context (see Fig. 1).

## Science Centre Exhibit Design

Science centre exhibits – also referred to as interactive or hands-on exhibits – form the heart of science exhibits and have a strong influence on visitor experience. I will further refer to this kind of exhibit as *science exhibit* for emphasizing the intent (communicating science), rather than its location (science center). Science exhibits enable visitors to engage on an intellectual, physical, social or emotional level (Perry, 2012) in order to actively learn through experience (Ansbacher, 1999). The field of science exhibit design is a highly multidisciplinary terrain. Disciplines like museum education, science communication, psychology, instructional design, engineering, industrial design and interactive design add to the discourse. First findings are presented in the following paragraphs.

To make the exhibit relatable to the visitor, to enhance understanding, and to support the process of meaning-making, a science exhibit can make use of reminders, familiarity or analogies. This can be supported by a linear narrative, either through storytelling or a simplified cycle of inquiry (novel phenomenon, exploration, explanation, relevance) (Gilbert & Stocklmayer, 2001; Sue Allen, 2004; Haywood & Cairns, 2006).
Engaging the visitor on an intellectual, physical, social or emotional level (hands-on, complemented by minds-on) is vital for sustaining involvement. Co-presence of other visitors and therefore providing space for observation and reflection can be beneficial. Social interaction can support learning behaviour and could therefore result in multi-user or collaborative exhibits (Dancstep & Sindorf, 2016; Perry, 2012; Haywood & Cairns, 2006).
A diversity of visitors means a diversity of learning styles and levels of knowledge. Applying multisensory learning modes and universal design principles (physical or cognitive) adapts to these variances. Guidance should be given through articulation (label or explainer) and can be supported through physical design. To counteract cognitive overloads, human-centred design approaches should be applied (Perry, 2012; Sue Allen, 2004).

The development of new technology enables new possibilities for visitor-exhibit-interaction, complementing the physical space with virtual or mixed realities. Wideström (2020) proposed a framework of interaction with three dimensions: participation (from static to participatory content), virtuality (from physical to virtual space), and collaboration (from individual to collaborative interaction).

This first insight into literature about exhibit design has several limitations: Only few sources could be found, and a thorough content analysis of sources is missing. In literature, exhibit design is often not directly a subject of study. Instead, it's based on empirical findings where indications for exhibit design are given. Gaining a broader base of literature and synthesising underlying concepts is necessary and will constitute the first step of further work.

## Conclusions

To date, there has not been sufficient research examining the role of the scientific prototype, or demonstrator, for communicating science to the public, nor have these out-of-the-lab exhibits been linked to science center exhibits. However, this field has been thoroughly researched from a diverse field of disciplines. Visitor experience forms the theoretical basis for designing interactive exhibits. When talking about the effectiveness of interactive exhibits, learning and engagement have been recognised as important factors. How are they connected? Following the constructivist approach, visitor engagement is a direct indicator of learning taking place which can be assessed by observing learning behavior, such as questioning, observing, reasoning, playing, predicting or manipulating. There is evidence that indicates the quality of the learning experience is directly related to the qualities of the interactive exhibit (Allen & Gutwill, 2004; Falk et al., 2004; Sue Allen, 2004).

Although theoretical models about visitor experience, visitor learning and engagement have been thoroughly addressed in literature, there is a gap in practical exhibit design that has not been fully understood. As Ocampo-Agudelo and Maya (2017, p. 440) mentioned:

**"[...] the fragmentation across diverse knowledge domains has slowed the consolidation of both theory and practice (Roberts, 2014). In relation to the latter, Macdonald (2006) argued that too often exhibitions are created with little awareness of such contributions leaving the museums to rely only on observations from their own institution. As a result, most of the design decisions are based on intuition or tacit knowledge (Yellis, 2010) and therefore exhibit designers are limited to make informed decisions that might enhance exhibition experiences (Falk et al., 2004)."**

The following section elaborates how I want to contribute to the identified research gaps.

## Research Questions

The literature overview illustrated the need to conduct further research to first of all understand and characterise principles for science exhibit design from a literature analysis. A thorough and systematic overview of these design principles is clearly needed to bridge the gap between visitor experience research and exhibit design practice.
My research question is therefore the following: What are the design principles of science exhibits that facilitate learning experiences for the general public?

Based on this systematic overview of design principles for science exhibits, I want to bridge the gap to out-of-the-lab science exhibit development in technology research. What design principles can or cannot be transferred to technology communication at research institutions? How can interdisciplinary research teams (non-designers) be enabled to efficiently design effective science exhibits? How can designers take informed decisions when designing science exhibits?
My second research question is therefore: How can science exhibit design principles be transferred to science exhibit design practice in technology development at research institutions?

## Research Procedure

This PhD thesis derives from a design research perspective, more precisely, from the industrial design engineering perspective. This research project is going to perform empirical research, applying methods from cognitive or social science, in order to adapt to the scientific question.

### *Classification of Science Exhibit Design Principles*

The first phase of research is going to approach literature in order to find a thorough classification of science exhibit design principles. The proposed data collection method is a qualitative systematic review of the research literature. Unlike traditional literature reviews, which may be no more than a subjective assessment by an expert using a select group of materials to support their conclusion, the qualitative systematic review is designed to be systematic in both the identification and evaluation of materials, objective in its interpretation and reproducible in its conclusions. Comparing the results of a number of small studies in the systematic review process increases the power of the conclusions reached.

More specifically, with the qualitative systematic review, I want to systematically enrich literature already available from section *Science Centre Exhibit Design* with further studies referencing science exhibits design. The final selected literature is further going to be analysed in a qualitative way, which means reducing the volume of data collected by categorising and making connections between the categories resulting in a classification of science exhibit design principles.

### *Transfer to Demonstrator Practice in Technology Research*

The second phase of research will address the transfer of these science exhibit design principles to out-of-the-lab science exhibit practice in technology research at the university. This research will be based on findings from the review of literature in Phase I and will be conducted in an open and exploratory way. This could involve an evaluation of the classification for this specific context with a qualitative approach like expert interviews or focus groups. The focus of evaluation could also shift to the practical application of the classification by means of a case study within the development of a public demonstrator. One more option could involve including the voices of visitors in order to assess science exhibits from a different perspective.

This research phase is going to be situated at the cluster of excellence “Centrum for Tactile Internet with Human-in-the-Loop” (CeTI) at TU Dresden, which started in 2019. New communication technology (5G) allows faster and further reaching data transfer than ever before, enabling new ways for interaction in quasi realtime between humans and cyber-physical systems in real, virtual, and remote environments. CeTI’s aim is to democratize skills and expertise the same way as the current internet has democratized the access to information.
Structurally and contentwise, CeTI is an interesting project to situate this research. First of all, as a cluster of excellence, CeTI is funded with 35.6 million euros over a period of seven years and has a multidisciplinary research team, comprised of five disciplines. These conditions lead to high aims for public engagement and societal impact, which include measures, such as cooperation’s with local secondary schools, a mobile exhibition and further annual and bi-annual open-house events, seeking to engage a general public with CeTI research. These events have led to developing science exhibits across all disciplines. Second, CeTI is interesting contentwise, because it develops applications for 5G technology, a technology which is mistrusted by some parts of society, partially based on fake news and conspiracy theories. Here, facilitating a dialogue between science and society is particularly important.

## Potential

The proposed PhD thesis aims to improve the direct communication of current science to the general public by means of science exhibits. This effort holds great potential for both sides of the conversation. First of all, from science to the public, current possibilities for informal learning in society is going to be enriched. Next for museums and science centres, research institutions invite the public to learn about science and complement other institutions, especially in their content. The high actuality of science – literally out-of-the-lab science – being communicated through science exhibits at research institutions is unique, which is directly linked to the second direction of communication – from the public to science. Shifting from the one-way communication model to the dialogue model, creating a dialogue with the public is substantial. Experiencing out-of-the-lab, on-going research, accompanied by the actual scientist, serving as an explainer, offers the public possibilities to directly respond. Either through discussing further questions or providing valuable feedback, a dialogue between science and the public on an eye-to-eye level can be created, which also has an added value for science itself.

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