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Towards Living Exhibitions

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ABSTRACT

This thesis introduces the concept of *living exhibitions*: continuously evolving museum exhibitions that are cooperatively developed and evaluated by teams of museum professionals and visitor representatives. The author argues that the living exhibition design process should draw its inspiration from multiple resources, including current research on museum learning, interaction principles and technology. As a case-in-point, the thesis provides a description of how such results have inspired the design of *The Well of Inventions*, a public installation at the Museum of Science and Technology in Stockholm. Furthermore, the thesis describes how an evaluation methodology from cooperative design was adopted and successfully applied within the museum domain. The ultimate aim of the work is to increase the opportunities for communication between museum professionals and their audiences.

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This work would not have been possible without the help from a number of people. I am very fortunate to have Yngve Sundblad as my main supervisor. Yngve is one of the key personalities in the Scandinavian cooperative design movement and his continuing efforts to advocate the participation of computer users in design is the main inspiration for this work.

I would also like to extend a special thank you to Mariana Back at the Museum of Science and Technology, and to my colleagues Sten-Olof Hellström, Helena Tobiasson and John Bowers at the Centre for User Oriented IT Design (CID) at the Royal Institute of Technology (KTH). Mariana introduced me to the world of museum exhibition production and graciously offered to host the installation presented later in this monograph, *The Well of Inventions*. She provided invaluable feedback on its design and an unwavering enthusiasm, even in times of difficulty. Sten-Olof and Helena are the co-creators of *The Well of Inventions* – without Sten-Olof's fantastic sound design and Helena's competent resource management – and the wonderful ideas of both – the exhibition would have been quite impossible to complete and evaluate. John, whom I am very fortunate to have as assistant supervisor, has taught me more about the history and practices of science and research than any other person. His remarkable creativity has been a constant inspiration for me and provided focus and guidance for my work. John was also instrumental in developing interaction concepts that the design of *The Well of Inventions* builds upon.

I would also like to thank the rest of my colleagues at CID for their support, feedback and encouragement. In particular, Sören Lenman and

Björn Thuresson helped me focus and structure my research, and Pär Bäckström and Olle Sundblad helped me in my efforts to develop *Wasa*, a technical infrastructure for developing graphics applications that is described towards the end of this text. Many thanks also to Ambjörn Naeve for providing many fruitful opportunities for discussing learning, pedagogy and education politics.

In chapter three, I briefly describe an exhibit developed by CID for the *Space Adventure* exhibition at the Swedish Museum of Natural History. Its virtual environment was designed and constructed by Pär Bäckström, and Olle Sundblad implemented parts of the physical exhibit, and provided important maintenance work.

I would also like to extend a special thank you to Allison Druin and Benjamin Bederson, who kindly invited me to work with them at the Human Computer Interaction Laboratory at the University of Maryland, USA. Thank you also to the patient participants of the KidStory and SHAPE projects.

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CONTENTS

CHAPTER 1

INTRODUCTION

This monograph is about cooperative design methodologies, technology and pedagogy, and how they can come together in museum settings to produce *living exhibitions*.

Today, many museums are experiencing increasingly fierce competition from theme parks and similar amusement facilitators. For such museums, it is essential to produce exhibitions that meet the expectations of their visitors as closely as possible. To this end, many museums are adopting audience-focused design methodologies where visitors are asked to, for example, provide ideas for new exhibitions, give feedback on exhibition mock-ups and answer questionnaires about existing exhibitions.

However, while these methods often produce excellent results, research in human-computer interaction indicates that under certain circumstances, even better outcomes can be expected if users are invited to become full collaboration partners in the design process. Thus, my work ultimately aims at *determining if it is feasible to adopt such cooperative design methods for museum exhibition production*.

A central activity in many cooperative design methods is the construction of prototypes. Such prototypes are typically created through collaboration between persons with a wide range of expertise, including designers, developers and the users who will ultimately work with the target system. Advocates of cooperative design also often argue that evaluation of such prototypes should take place in the appropriate work context, and should be done in collaboration with the target user group.

In the museum domain, an important design target is naturally the exhibition itself and the target user group is normally museum visitors. Thus, the notion of evaluation in the appropriate work context transfers into the notion of visitor evaluation of an evolving prototype exhibition. I shall argue that an appropriate way to accomplish such evaluation may be to evaluate the evolving prototype exhibition while on display.

In this monograph, therefore, the term 'living exhibition' denotes an exhibition that is being developed through design partnerships between people with a wide range of expertise, including visitor representatives. Furthermore, living exhibitions are evaluated and evolve while on display.

The issue of user participation in design necessarily brings up the question of expertise and its role in the relationship between end-users, designers and developers. My view is that cooperative design requires that designers and developers learn from users, *and vice versa*. In a design partnership, everyone's opinion should ideally be equally important. But this also implies that expertise be recognized as such. Thus, I see designs produced by cooperative methods as the outcome of negotiations between the different partners involved. The designs thus represent and combine aspects of the partners' individual expertise in various domains.

In the case of living exhibitions, I believe that current research on museum learning and exhibition design can at least provide useful input to such negotiations. Much of this research is inspired by a philosophy called *constructivism*. Thus, as a background, *chapter two* of this monograph presents an overview of constructivism and how it has been applied in educational practice. The chapter also presents some examples of constructivist-inspired computer-based learning tools.

Chapter three deals with museum exhibition production, and reviews some existing guidelines for how exhibitions should be designed with respect to personal motivation, socio-cultural mechanisms and the physical environment. In addition, the chapter provides a number of examples of how different technologies have been used to support such designs. It also includes a short overview of the cockpit exhibit in the *Space Adventure* exhibition at the Swedish Museum of Natural History, which I partly designed.

In *chapter four*, I describe design methodology work I have been involved in: I assisted in the development of a cooperative design method that was used within the EU-funded KidStory project. The method was designed specifically for school environments and builds upon different selections of cooperative design methodologies. The chapter reviews the history of cooperative design and describes the KidStory project.

In the spring of 2002, I was invited to manage the design and production of a small exhibition for long-term display at the Museum of Science and Technology in Stockholm. This provided me with an opportunity to begin experimenting with some of the aspects of the living exhibition concept in practice. The design process and the resulting installation, *The Well of Inventions*, are described in *chapter five*.

The issue of how to develop appropriate cooperative design methods for the museum domain is complex and is beyond the scope of a licentiate thesis to answer. Thus, the work presented in this monograph represents some initial steps towards addressing it. In particular, I have chosen to focus on three research issues:

1. As the first stage of the development of a cooperative design method for the museum domain, I chose to attempt to adopt an evaluation methodology from cooperative design. How was this done and was the attempt successful?
2. The educational goal of *The Well of Inventions*, as we shall see, is to encourage discussions between visitors on a certain subject, and to encourage the construction of individual pedagogies. How was this done and was the attempt successful?
3. Cooperative design often involves the development of prototypes. For exhibitions like *The Well of Inventions*, what are the features the underlying technology must incorporate if prototyping is to be made possible?

Chapter six describes these questions in detail and the methodology I used in my attempt to answer them. The results of the study indicate that the adoption of the evaluation methodology was indeed successful, and that *The Well of Inventions* does encourage communication between visitors (although not quite of the nature I expected).

However, the technology used to generate the interactive graphics in the exhibition is not flexible enough to warrant the easy modifications required for prototyping. *Chapter seven* describes the fundamental requirements of such a framework and presents relevant previous work. Since I have not been able to find any system that has the appropriate combination of features, I have had to resort to developing a new framework of my own, *Wasa*. Thus, the chapter also describes the evolution of *Wasa* and presents some ideas for its future development.

Finally, *chapter eight* re-examines the living exhibition concept and discusses some implications for future work.

In summary, I see my work mainly as a part of the cooperative design movement. However, it also contains elements of interaction design and technology development, with a particular focus on the application of advanced rendering methods and interactive simulations. Thus, it draws upon results from human computer interaction, computer science, and numerical analysis.

It should be noted that my work is, to a large extent, part of the EU-funded SHAPE project (http://www.shape-dc.org/), and *The Well of Inventions* is an important component of the SHAPE second year deliverables. SHAPE is devoted to understanding, developing and evaluating room-sized assemblies of hybrid, mixed reality artefacts in public spaces, with a particular focus on museum environments. An important vehicle for the dissemination of this research is public exhibitions of ongoing project research activities. The idea is that through working and presenting in public, the SHAPE research and its outcomes become more generally accessible than through standard methods of dissemination. In the SHAPE project annex, these exhibitions are also denoted "living exhibitions". Although there is significant overlap, there are distinct differences between the SHAPE definition of living exhibition and the definition I have adopted in this monograph. In SHAPE, such exhibitions are seen as a public demonstration of research activities, whereas in my work, a living exhibition denotes an evolving exhibition co-designed by visitor representatives.

CHAPTER 2

CONSTRUCTIVISM

The philosophy of *constructivism* has become increasingly advocated in the educational sector over the last couple of decades. Its proponents typically use it to challenge traditional didactical practices in schools (e.g., Ernest, 1991, Twomey Fosnot, 1996, Rogoff et al., 2001, von Glasersfeld, 2001) and a similar process is taking place within the museum domain (e.g., Hein, 1998, Hooper-Greenhill, 1994, Falk and Dierking, 2000). Also, the epistemological characteristics of constructivism are also often described as fundamental in cooperative design (e.g., Ehn and Kyng, 1991, Tudhope et al., 2000). Thus, many authors consider constructivism as the underlying philosophical foundation for many of the changes currently being proposed in school education, museum exhibition design practices, and computer software design practices.

Because the constructivism is mentioned in so many contemporary texts on museum exhibition design, I judged that it was important to learn more about it. Thus, I included a number of frequently cited constructivist texts in my literature survey. I am in no position to judge whether constructivism is "correct" or "efficient" from an educational point of view and, as we shall see, constructivism is definitely not without its critics. However, *I do claim that it can inspire interesting and novel museum exhibition designs.* As I shall describe in the chapter three, the pedagogical design of many museum exhibitions are based on a communication theory perspective. Over the last five decades or so, this perspective has led to a rather stable form of exhibition that is typically based on a spatially distributed hierarchical narrative (frequently mediated through text panels and labels). The constructivist models of learning, however, are quite different from communication theory, and thus they often lead to a different kind of pedagogy. Therefore, when constructivist educational practices are carried over to the museum domain, they can lead to exhibition designs that are substantially different from the traditional hierarchical narrative (I shall present an in-depth example in chapter five). The rest of the present chapter describes some important aspects of the constructivist philosophy and presents an overview of some available guidelines for applying it in teaching.

Few people would argue against the notion that we construct many aspects of our lives. Languages, legal systems, economic systems, social institutions and governments are typically seen as the results of actions, beliefs and intentions of human beings. Also, many people would probably say that at least some of our concepts are constructed – for example, the notion of colour is "optional" in the sense that we might, in the course of history, have "chosen" a different name for, say "red" – or indeed, have "chosen" an entirely different way of describing appearance.

But what about scientific concepts such as "gravity", "photons" or "quarks"? Typically, scientific work is seen as a form of hypothesis testing: the scientist examines a certain aspect of the world, formulates some theory about its nature and then, through experimentation or observation (following one of the agreed-upon scientific methodologies), determines whether the theory is true or not. These kinds of descriptions of science are often said to belong to the school of *empiricism*. Empiricism, in turn, can be said to build upon the philosophy of *realism*, i.e., the notion that objects of perception or thought exist independently of the mind.

However, in his book *The Structure of Scientific Revolutions*, the historian T. S. Kuhn presents a description of scientific work that to a certain extent challenges the empiricist ideal (Kuhn, 1996). Kuhn argues that science stems from *paradigms*, i.e., sets of theories or beliefs adhered to by groups of scientists. These beliefs, in turn, determine what is considered valid research: persons who do not adhere to the currently dominant paradigm are simply not accepted into the scientific profession. Thus, according to Kuhn, scientific work is more about forcing the world to fit the conceptions provided by paradigms than it is about hypothesis testing. But paradigms are not infallible: Kuhn argues that historically, there has always come a time when the world does not seem to fit the reigning paradigm and anomalies appear. It is only when such anomalies bring about a crisis that scientists can begin to construct new theories about the constitution of the world. These candidate theories compete for domination until one remains, which becomes the foundation of a new paradigm. Kuhn calls this mechanism a *scientific revolution*.

Typically, facts produced by science are seen as objective, true knowledge. But according to Kuhn, every such fact stems from a paradigm, and because paradigms are fallible and, to a certain extent, also influenced by social phenomena, he argues that no scientific statement should be seen as final, objective or absolutely correct.

The mathematician and philosopher Paul Ernest argues that even mathematics is no exception: he claims that mathematics has several incompatible theories and standards for proofs (Ernest, 1998). Instead, Ernest suggests that objective knowledge should be thought of as

> that which is accepted as legitimately warranted by [a scientific] community. Thus it is the mutually agreed upon, shared knowledge of that community, knowledge that satisfies its knowledge acceptance procedures and criteria, not something superhuman or absolute (p. 147).

Both Kuhn and Ernest claim that their views of scientific knowledge are different from those of *relativism*, i.e., the belief that scientific theories can be adopted at will, and that the members of the scientific community have the ability to turn to alternative paradigms whenever they choose to. Instead, Kuhn and Ernest argue, once a paradigm has been established it becomes more or less impossible for a scientist to see the world differently and still remain a member of the scientific community. Conversely, becoming a member of such a community involves a long period of study, where the views of the current paradigm are assimilated through education (e.g., textbooks, lectures and key literature). Thus, rejecting the paradigm also implies rejecting potential community membership. So according to Kuhn and Ernest, once the basic (implicit and explicit) rules of a paradigm have been established scientific method and logic follows, and these can only be challenged by anomaly and crisis.

Philosophers that subscribe to these and similar views of knowledge are often called *constructivists* or *social constructivists*. Not surprisingly, many philosophical variations of constructivism can be identified. André Kukla notes that constructivism can be associated with three different categories: *the metaphysical*, *the epistemic* or *the semantic* (Kukla, 2000).

The metaphysical category concerns the ontology of the world (i.e., its nature). Metaphysical constructivism implies that the world itself is socially constructed: for example, elementary particles like electrons and neutrinos would simply not exist if they had not received the attention of human beings.

The epistemological category relates to the nature of human knowledge (epistemology is the study of, or a theory of, the nature and grounds of knowledge). Epistemic constructivism implies that rationality is only relative to culture, individuals, or scientific paradigms; and that knowledge depends on and is shaped by human activity.

Semantic constructivism implies that that sentences and utterances have no determinate empirical content – instead, the meaning of an utterance is always relative to context and the persons involved in the exchange.

Kukla points out that it is quite possible to favour constructivism in one or two of these categories while adhering to a realist view in the others. For example, it is possible to argue that facts (in the metaphysical sense) are socially constructed, but that it is possible to have absolutely correct knowledge of them. The reverse view is also possible: this is the belief that there is a world independent of human beings but that our knowledge of it is socially constructed. Also, semantic constructivism can be combined with a realist epistemological view: while sentences and utterances have no determinate content we can still have tacit knowledge of the world that is absolutely correct. Or conversely, while our beliefs may be socially constructed, we can still produce absolutely correct utterances (we just do not know which of them that are correct).

From what I gather, most educationally oriented constructivists combine a realist metaphysical view with a constructivist epistemology and semantics. That is, they claim that although there is a world "out there", we can never know exactly what it is like. The reason is that social relations and individual perception necessarily influence the development of knowledge and semantics.

This philosophical position can be further divided into two main categories: *cognitive constructivism*, which focuses on the mental mechanisms of individual persons, and *socio-cultural constructivism*, which focuses on the internalisation of socio-cultural activities. The main difference between these categories is that cognitive constructivists normally argue that mental mechanisms give rise to social interaction, whereas socio-cultural constructivists claim that social interaction gives rise to mental mechanisms. I shall return to this difference in a later section, but first I will describe the two categories in some detail.

Cognitive constructivism

Cognitive constructivists typically see organizations of experience as a fundamental unit of epistemology. According to their view, cognitive structures develop in response to experiences of the world, so that if the current set of structures does not accommodate a specific experience they can be updated to again support a conceptual equilibrium.

One of the most well known cognitive constructivists is Ernst von Glasersfeld. His *radical constructivist* model of learning (von Glasersfeld, 1995) is largely based on Jean Piaget's notions of *assimilation*, *accommodation* and *schemes*.

Piaget's description of assimilation, von Glasersfeld argues, has been widely misinterpreted as a mechanism through which the organism incorporates elements from the environment. Instead, he proposes that in the context of learning, assimilation should be viewed as a mechanism where a new perceptual stimulus is treated as an instance of something already known. In other words, von Glasersfeld's interpretation of assimilation is that it fits an experience into a conceptual structure the assimilating person already has. Since no two experiences are exactly alike, assimilation is prone to – unconsciously – disregard elements of perception that do not fit the structure.

However, the assimilation mechanism alone would not be enough to account for learning: if our conceptual structures were never refashioned through our experiences, then it would be impossible for us to learn anything new. Von Glasersfeld argues that for this to take place, another mechanism is required, that of *action schemes*. In his model, an action scheme consists of three parts:

1. The recognition of a situation.
2. The carrying out of an activity associated with the scheme.
3. An expectation that the activity produces a certain previously experienced result.

The scheme begins by the assimilation of an experiential situation. If the experience fits the conditions associated with the scheme, the activity is triggered. This, in turn, produces an outcome that again is assimilated to the expected result. If this assimilation is not possible, the result is a *perturbation*, i.e., disappointment or surprise.

At this point, von Glasersfeld claims, the initial situation that triggered the scheme may be viewed (if it remains available) as a collection of sensory elements rather than as a compound unit. If the outcome was disappointing, the new characteristics may be incorporated into the recognition pattern so that the conditions for triggering the scheme change. Alternatively, if the outcome was pleasant or surprising, a new scheme may be formed. These two alternatives are together referred to as accommodation, and thus in the radical constructivist model, accommodation is equivalent to learning.

Von Glasersfeld argues that when a perturbation is eliminated through accommodation, the new scheme may turn out to be incompatible with respect to other schemes or operations that were established earlier. This may again lead to perturbation, but on a higher conceptual level, that of reflection (or metacognition). The resolution of such higher-level perturbations may require modification of lower-level schemes.

According to Von Glasersfeld, the action scheme mechanism is carried out unconsciously. For example, when walking up a staircase, a person would not have to be conceptually aware of the individual stairs: his or her perceptual system would recognize the situation and trigger the associated motor action automatically. However, human beings also have the ability to form purely mental concepts. Von Glasersfeld's model of such concepts is based on the notion of *re-presentation*, i.e., that action patterns can be called up spontaneously or through words even though the sensory input that characterize them are absent, and without triggering the associated activity. He also claims that one or several such schemes may merge to form concepts.

In the context of speech, the mechanism of re-presentation is central. Here, von Glasersfeld extends the work of Ferdinand de Saussure. De Saussure defines a *linguistic sign* as the association between a mental concept and a sound-image, i.e., an abstraction generalized from acoustic phenomena (von Glasersfeld, 1995, p. 130). In the radical constructivist model, concepts are collections of re-presentable action schemes, and sound images are examples of such concepts. Thus, listening involves the assimilation of an acoustic perception to a sound-image. Through re-presentation, a corresponding concept can be recalled. For utterances, the situation is reversed: a given concept can indicate, through re-presentation, a sound-image. Then, the action scheme associated with the sound-image can be activated to produce an utterance.

Advocates of the radical constructivist model, like other constructivist models of learning, often see realist views of objective knowledge as problematic. Von Glasersfeld instead proposes that *intersubjective* knowledge – personal knowledge corroborated by other thinking subjects – should be viewed as the highest, most reliable level of experiential reality. According to Von Glasersfeld, young children, through contact with others, gradually construct the notion of other beings that, like themselves, have goal-directed behaviour, deliberate planning and feelings. Eventually, these others come to be seen as individuals much like oneself. Since others can be expected to having assimilated more or less the same knowledge as oneself, predictions about their behaviour can be made, i.e., if others behave like I expect them to, then I am likely to conclude that the knowledge I assume they have is viable not only to me, but to them as well. In radical constructivism, this second order viability constitutes intersubjective knowledge. Von Glasersfeld argues that since predictions of this kind often turn out to be false, other people are the main source of perturbations.

Socio-cultural constructivism

For socio-culturally oriented constructivists, participation in social interaction and cultural activities influences psychological development, i.e., learning comes about through co-participation in cultural practices.

One example of a socio-cultural learning model is that provided by Paul Ernest (Ernest, 1998). He sees conversation as a fundamental unit of knowledge, i.e., he equates the mechanism of inner speech with thought. This notion is largely based on the work Lev Vygotsky, who claimed that every function of a child's cultural development – including voluntary attention, logical memory and the formation of concepts – is *internalised*, i.e., transformed from being a social, public action to an internal, psychological activity (Vygotsky, 1978).

Vygotsky distinguished between the spontaneous, primitive concepts first acquired by young children and higher-level concepts acquired through language. He argued that the internalisation of higher-level concepts and eventually language leads to the ability to think, which is radically different from previous mental functions. Thus, Vygotsky concluded that socio-cultural participation both creates and shapes the mind. By interacting with other people, children gradually learn to participate in a growing range of different social contexts. A fundamental outcome of such participation, according to Vygotsky, is that children learn to understand and use language and multiple other forms of communication (facial gestures, body movements, etc.) and develop a sense of self.

Another cornerstone of many social constructivist perspectives is the later writings of Ludwig Wittgenstein on the subject of language semantics. Ernest summarizes his interpretation of these writings as follows (Ernest, 1998, pp. 70-71, my emphasis):

> 1. Terms and sentences do not in general have distinct individual references or meanings.
> 2. Instead, their meaning(s) are identical with their roles and uses in *language games.*
> 3. Language games are the patterns of linguistic behaviour embodied in types of social activity: "*forms of life*".

4. Language games are based on rules. These may be implicit, but are the invariants or norms underpinning patterns of linguistic behaviour anchored in forms of life.
5. Forms of life have priority; they are the socially given. They are the identifiable clusters of social behaviour, social practices, which can only be given extensionally, because their existence alone is what legitimates them.
6. There are many forms of life and many language games, and any particular word or expression may be involved in several of them.
7. Forms of life may develop and change. Similarly language games have an open texture and may grow, change, and lead in unanticipated directions.
8. Language games are largely learned by participating in them. Nevertheless, explanation is undeniably a part of many language games.
9. Just as games do not share a set of essential properties but a "family resemblance," so too language games are of varying and different types.

Further detail on the notion of language game is provided in (Svensson, 1978). According to Svensson, Wittgenstein argued that a language consists of utterances, which include single or multiple expressions, questions, statements, requests, etc. These utterances are always used in concrete situations, and in order to understand an utterance, its context has to be taken into consideration. Thus, Wittgenstein claimed that the meaning of language resides in the context of which an utterance is expressed rather than in the semantics of the language itself. This context includes the linguistic or syntactic context alone, but also the physical and social situation in which the utterance is spoken.

In Wittgenstein's model of communication, if a listener understands an utterance spoken by someone, communication can continue. If not, the utterance constitutes a problem that must be solved before the dialogue can be resumed. In such a situation, the meaning of the utterance becomes an issue. Wittgenstein claimed that its resolution can vary depending on the context, but that any such resolution necessarily has to clarify constituents of the context that have previously not been observed: the utterance in itself carries no meaning.

According to Wittgenstein, the way people indicate understanding is by following the (often implicit) rules of language games. If, in a conversation, the recipient of an utterance does not act according to the rules of the game, the speaking person becomes puzzled. Conversely, if the speaker does not act according to the rules, the recipient becomes puzzled. Thus, in Wittgenstein's model, following the rules of the game is *equivalent* to understanding, not an indication of, or criteria for, understanding. In this sense, the only mechanisms required for the construction of meaning is the ability to follow the rules of language games and the experience of puzzlement when others do not.

Wittgenstein argued that the rules of the language game do need to be made explicit: their complexity and context-dependence makes them virtually impossible to represent explicitly. Instead, he was of the opinion that the rules are learned implicitly through the use of the language: it is the reaction from the recipients of an utterance that determine whether it has been used correctly or not in a specific context. Initially, utterances and actions are learnt through their use in concrete situations (e.g., a parent presents a ball to a young child, points to it and utters the expression "Ball!"). Later, these same utterances and actions can be tried in different contexts and situations, and the response of the recipient determines whether the use is warranted or not. According to Wittgenstein, this process never ends: because no two situations are exactly alike, we are constantly experimenting with the use of language and reapplying its rules in different contexts. Thus, in his view, language and meaning generation is *intersubjective* in the sense that nothing can be learnt in isolation: a language can only be learnt from people who are already speakers of that language.

The notion of language games is largely compatible with Vygotsky's model of learning (Vygotsky, 1986). In this model, young children first learn to use utterances through their relationship with parents and other people. Gradually, they become capable of *egocentric speech*, i.e., to talk aloud to themselves. In such speech, children simultaneously assume the roles of both speaker and recipient. Eventually, egocentric speech is internalised and develops into what we describe as thinking.

The role of play is central to Vygotsky's theory. In play, he claims, children create imaginary, rule-governed situations that, in a sense, loosen some of the constraints of perception. By imposing meaning on objects and actions rather than vice versa (e.g., allowing a toy car to "stand in" for the concept of a real car), they can manipulate and experiment with concepts in relation to imagined situations. In the long run, such activities both facilitate the acquiring of language games (e.g., through role-play) and the decoupling of meaning and objects, which leads to the ability of abstract reasoning (Ernest, 1998, pp. 216-218).

Furthermore, Vygotsky's research suggested that children are able to solve problems too difficult for them to tackle on their own if they receive assistance from an adult or more capable peers. He argued that in such situations, it is necessary to distinguish between different levels of mental development. Vygotsky used the term *actual developmental level* to refer to the level of development that has already been established from completed developmental cycles. If the child encounters a problem alone, the possibilities for solving it depend on this level of development. However, through assistance, children can solve problems that require a higher level of mental development. Vygotsky used the term *zone of proximal development* to indicate the difference between these two levels (Vygotsky, 1978, pp. 84-91). He argued that the zone of proximal development is created through learning, in that it enables processes that can only exist in collaboration between a child and the assistant. Once these processes have been internalised, the child has reached a new level of development.

By extension, some socio-cultural constructivists see the acquiring of knowledge as *successively inclusive participation in different formal or informal communities of practice* (e.g., Lave and Wenger, 1991, Rogoff, 1990). In such models, the learner receives the status of apprentice when he/she acquires (formal or informal) membership in a community, and his/her studies are governed and guided by masters of the particular knowledge domain. After successfully convincing the community – or an acceptably large part of it – that a sufficient level of knowledge has been reached, the learner acquires the level of master and may in turn take on apprentices. When a master's apprentice himself/herself has reached the level of master, the master attains the level of grand master. Grand masters are responsible for the large-scale development and well being of the community.

Coordination of constructivist perspectives

Although the philosophical perspectives outlined in the last two sections both share the notion that the construction of knowledge is an active process carried out by individuals, the cognitive variant emphasizes conceptual reorganization while the socio-cultural variant emphasizes enculturation in different social communities and groupings. This has led to a continuing series of debates among educational constructivists concerning which of the two that should be viewed as primary, and whether cognitive processes or participation in communities of practice should be prioritised in teaching. However, Paul Cobb has argued that the two strands of constructivism should be seen as complementary rather than opposing (Cobb, 1996). The reason is, he claims, that a cognitive perspective implicitly assumes a socio-cultural foundation and vice versa.

For example, although many socio-cultural constructivists see learning as the internalisation of a social practice, Vygotsky offered no account of how such a social practice external to the learner can become internal to his/her mind. This problem can be circumvented by taking the perspective that observation and participation is a social activity in itself, which would imply that interpersonal aspects of the learner's functioning is fundamentally connected to his/her individual aspects (Rogoff, 1990, p.

195). But according to Cobb, this implies that the learner can make use of some form of previous understanding related to the activity, and this previous understanding is an appropriation of the shared understanding of the group. Thus, Cobb claims, this treatment is essentially equivalent to the cognitive constructivists' notion of internal organization of understanding acquired through interaction with others.

Conversely, from a cognitive constructivist perspective, learning may be seen as an accommodation that follows from a perturbation. Such perturbations, it is assumed, are caused by novel physical (or conceptual) features that emerge when the learner carries out an action scheme. However, Cobb argues, action schemes are normally appropriated from cultural practices, and schemes are also typically carried out as the learner participates in different forms of cultural practice.

Thus, Cobb reaches the conclusion that the two constructivist perspectives are complementary, and proposes that learning should be viewed as a *process of active individual construction that occurs when the learner is engaged in a social practice, frequently while interacting with others*. This coordinated description of learning is similar to a number of proposed models of learning in museums, as we shall see in the next chapter. Before turning to that subject, however, I shall provide a short overview of some existing guidelines for applying constructivist epistemology in educational practice.

Constructivist pedagogies

Cobb's coordinated constructivist perspective describes learning as an active process situated in different forms of cultural practices. This does not immediately implicate any specific teaching methodology. However, some authors claim that it does put the traditional didactic methodology of lecturing into question (e.g., Ben-Ari, 2001).

According to these authors, a lecture necessarily follows the lecturer's line of thought (since the lecturer designed the lecture) – but this does not necessarily mean that the narrative matches the listeners' conceptual explanatory framework, i.e., one cannot assume that listeners will learn exactly what the lecturer is presenting, let alone acquire some version of the lecturer's knowledge of the subject. However, this does not necessarily imply that lectures have no place in modern education: lectures can be quite suitable for raising an interest and presenting demonstrations (ibid; Rogers, 1989, p. 120). Lectures can also provide learners with a framework of a subject, to which knowledge they acquire through other methods can be related.

Von Glasersfeld distinguishes between *training* and *conceptual learning* in pedagogy (von Glasersfeld, 2001). Training, he claims, is appropriate when social conventions must be learned verbatim (e.g., dates in history, days of the week and the names of colours). However, from his radical constructivist point of view, training methods are insufficient for acquiring knowledge that requires active thinking and conceiving. For such situations, von Glasersfeld offers the following guidelines:

- The teacher should aim to manoeuvre the learners into situations where their network of explanatory concepts turns out to be unsatisfactory, while remaining as neutral as possible. The learners' current knowledge should not be seen as "wrong", nor should the teacher's view be seen as "correct"; the learners are simply interpreting the world according to their current epistemological equilibrium.
- In addition to being familiar with the subject in question, the teacher needs a repertoire of didactic situations in which the corresponding concepts can be applied, situations that ideally evoke the learners' spontaneous interest.
- When learners solve problems, their work and effort should be acknowledged, regardless of whether the solutions are viable or not. Otherwise, their interest in future work may disappear.
- In order to be able to appropriately challenge the learners' current mental concepts, the teacher must have some model of these concepts, i.e., the teacher must know something about the learners' current knowledge.
- The easiest way to encourage reflection is by having the learners talk about what they are thinking. Thus, problem solving should ideally also initiate conversations.

In (Twomey Fosnot, 1996), the following additional guidelines are proposed:

- According to the constructivist epistemologies, learning is equivalent to the development of individual learners' understanding. Therefore, learners should be allowed to raise questions, generate hypotheses and test them for viability.
- The learners should be given time to reflect so that they can mentally organize and generalize what they have learned. Examples of techniques to support this process include journal writing and the creation of representations in multiple forms of media.

- The learners should be responsible for defending, proving, justifying and communicating their ideas to the rest of the classroom community. An idea should only accepted as viable when the community has reached consensus.

Socio-culturally oriented constructivists often place a large emphasis on *scaffolding*, i.e., methods where the teacher makes use of the zone of proximal development to guide the learner towards a solution to a problem, or where the learner solves a problem in collaboration with peers. In (Stoll Dalton and Sharp, 2002), the following teaching principles are proposed:

- Joint productive activity: teacher and learners produce together.
- Developing language and literacy across the entire curriculum.
- Connecting school activities to the learners' lives.
- Teaching through instructional conversation.

For some socio-culturally oriented constructivists the concept of classroom teaching itself is problematic, because it implies that knowledge can (at least in part) be socially *decontextualised*, i.e., that knowledge acquired in one context can be reapplied in a different context. However, according to these authors, such decontextualisation may not always be possible, especially not for advanced topics (Lave and Wenger, 1991, pp. 91-105). Thus, they instead propose that teachers focus on the relationships between the school and the communities of practice where the knowledge is to be applied, and how the learners come in contact with those communities.

Technology-based learning tools

The constructivist pedagogy movement has inspired the development of a large number of computer-based learning tools, and a number of researchers have developed learning tool development guidelines (e.g., Osberg, 1997, Murphy, 1997, Leron and Hazzan, 1998, Jonassen and Rohrer-Murphy, 1999). These tools are typically conceived of as environments where the learners can experiment with the parameters of a mechanism or simulation of some sort. As we shall see in the next chapter, this underlying principle is also common in many existing museum exhibition technologies.

Two of the most well known examples of constructivist learning tools are the *LOGO* programming language (introduced in 1967) and the more recent *LEGO MINDSTORMS* robotics kit, both developed by Seymour Papert's research group. A fundamental goal of Papert's work is to develop methodologies for helping children learn how to acquire new knowledge through experimentation and critical thinking (Papert, 1993). According to Papert, the ability to construct knowledge is critical for the ability to function in society, and the current situation in institutional education (that he views as problematic) would improve if knowledge construction was treated as a subject in its own right.

Papert argues that a useful method for introducing learners to experimentation and problem solving is through what he calls *constructionism*, i.e., learning through the construction of artefacts*. While creating artefacts, he claims, learners typically encounter many problems that must be solved in order for the work to continue. If the artefact is felt to be personally meaningful and has a strong connection to the learner's everyday life, the motivation for attacking such problems is strong. If not, the learner might give up and turn his/her attention elsewhere (ibid, pp. 137-156).

Papert claims that computers are particularly suited for providing "microworlds" in which such experimentation and construction can take place. The *LOGO* programming language, for example, was developed to allow children to construct their own graphical images and animations. Central to the language is the notion of a *turtle*, i.e., a graphical representa tion of an oriented entity that can be moved through commands. When the turtle moves across the screen it can, optionally, leave a trace in the form of a line. Thus, entering the command

```
REPEAT 36 [FORWARD 10 RIGHT 10]
```

will move the turtle forward 10 units, then turn it to the right 10 degrees and repeat the process 36 times. The result is a circle, as shown in figure 1.

* Papert's notion of constructionism should not be confused with the social constructionist philosophical movement advocated by, e.g., Kenneth Gergen (Gergen, 1999).

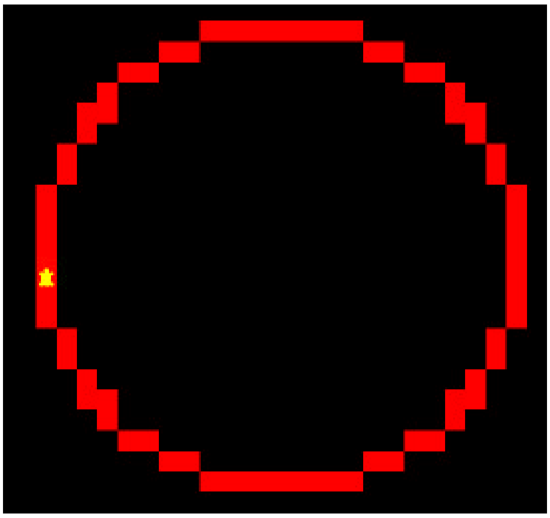

Figure 1. Drawing a circle using LOGO. Note the turtle on the left.

Implementations of *LOGO* include the *Microworlds* line of products (http://www.microworlds.com/) and the freely available *StarLogo* (http://education.mit.edu/starlogo/) produced by the MIT Media Lab. Alan Kay's group at the Viewpoints Research Institute has developed a similar system based on the SmallTalk programming language called *Squeak*. It is freely available from http://www.squeakland.org/.

Papert's group has also extended the constructionist methodology into the domain of cybernetics (a scientific field that studies automatic control systems) through the *LEGO Mindstorms* commercial product line. *Mindstorms* consists of a number of motors, sensors and lights, designed as *LEGO* bricks. These components are programmable through a special dialect of *LOGO*. Papert argues that cybernetics should be a fundamental subject in school education because its rich connections to other sciences like mathematics and biology. Through the creation of personally meaningful "cybernetic creatures", connections to additional domains like art and design are made (Papert, 1993, pp.179-185).

Other examples of constructivism-inspired learning tools include CD-ROM-based multimedia products (e.g., *Mulle Meck*, http://www.barnlandet.se/mulle), WWW-based on-line museums (e.g., *Virtually the Ice Age*, http://www.creswell-crags.org.uk) and simulation toolkits (e.g., *Stella*, http://www.cognitus.co.uk/academic-solutions.html). In addition, a number of shared virtual environments have been developed by different researchers to support active knowledge construction in various subjects (e.g., Dede et al. 1996, Spalter et al., 2000, Taxén and Naeve, 2002, Kaufmann and Schmalstieg, 2002).

There also exist a number of tools intended to support socio-culturally oriented constructivist teaching methodologies. One example is the *Talk Tracks* system developed by Klas Karlgren et al. at the University of Stockholm (Karlgren, 2001). The aim of this work is to give students access to the concepts, problem solutions and jargon used by experienced computer systems designers, with a particular focus on object oriented modelling. A Talk Track is an indexed video recording of a session where experienced designers complete a particular modelling task. A written transcript of the dialogue runs together with the video, and a representation of the designers' solution is continuously updated to reflect the developing design model. An alternative view where the problems the designers encountered are presented is also available. Karlgren's initial evaluation of the system indicates that learners did adopt some jargon and concepts from the solutions of the experienced designers, although the character of the knowledge the students acquired remains unclear.

Another example of a socio-culturally oriented tool is the *Straight Shooter!* game developed for the Bankers Trust New York Corporation. The aim of this tool is to guide employees in acquiring the policies and practices of the corporation (Prensky, 2001, p. 248). The tool is designed as a simulation game where the learner encounters virtual clients and is presented with a number of problems. The response to these problems determines the outcome of the game.

While computer-based technologies are often described as holding great potential for education, their introduction in schools has sparked an intense debate. Critics are arguing that careless use of computers in schools may have a negative influence on the intellectual and social development of young children, as well as their health (Oppenheimer, 1997, Cordes and Miller, 2000). Prolonged computer use may distract from important interaction and play with peers and adults. Also, if children are hurried to attain a recognizable competence in a subject (e.g., counting or knowing the alphabet), as is sometimes done through the use of computers and computer-based assessment, may attain superficial skills that does not help (or may even hinder) the development of a deeper understanding of the subject (Rogoff, 1990, p. 153). Such superficial skills may promote a "cut-and-paste" approach to learning and presenting where incoherent pieces information is simply brought together in, say, a word processor or a drawing program, rather than being thought through and reflected upon (Healy, 1999). Software that uses special effects or game-like methods to encourage learning may have unintended outcomes: instead of thinking about what the information represents and how it is connected, children may focus excessively on how to get the software to advance to something fun. Thus, the children learn about the built-in rules of the game rather than the subject the game is attempting to portray. Furthermore, the introduction of expensive computer technology in schools may cause funding to be withdrawn from other activities that are sometimes considered low-priority, like music, wood / metal workshops, art and book reading (Oppenheimer, 1997).

Critique of Constructivism

The constructivist movement is not without its critics. Kuhn's work, for example, has been attacked both for being imprecise (e.g., Masterman, 1970) and for being an oversimplified and untrue description of scientific work (e.g., Weinberg, 1998). Weinberg, who is a Nobel laureate in physics, also argues that Kuhn is wrong in claiming that paradigms are always fallible: according to Weinberg, there are "hard" (i.e., durable) and "soft" aspects of modern scientific theories: the soft aspects change much like Kuhn describes, whereas the hard aspects remain unchanged over time (i.e., scientists have failed to prove them wrong). Other authors (e.g., Slezak, 2000) argue that Kuhn and his followers have failed to show why social processes should be a significant factor in determining scientists' choice of explanatory theory. According to these critics, other criteria such as simplicity, fecundity and coherence – that arguably are independent of social circumstances – are much more important.

The constructivist pedagogies described above have also been criticized (e.g., Anderson et al, 1998). The critics' main concern is that constructivism is founded on writings that are of questionable quality compared to today's standard of psychological research. Furthermore, the critics challenge the advocates of constructivism to show that their proposed way of approaching education leads to more knowledgeable students: recent studies within cognitive psychology suggest that students that were exposed to a constructivist-oriented pedagogy in their early school years do not have significantly different knowledge after college graduation than peers taught using traditional didactics. The critics are also concerned that constructivism may encourage teachers to refrain from making use of explicit instruction and practice in lieu of inefficient *discovery learning*, i.e., a pedagogy where the learners are given full control over their studying activities. Furthermore, the kind of collaborative learning often advocated by socioculturally oriented constructivists may be difficult to facilitate in practice: there is a risk that students divide the work between themselves instead of solving the problem together. Finally, constructivists are typically uncomfortable with traditional methods for evaluating learning outcomes and thus often advocate methods of a more qualitative character. However, the critics point out that such qualitative methods may cause social, cultural and intellectual bias that, in turn, might lead to an unfair assessment of the learners' achievements.

Constructivism and Living Exhibitions

Given the above summary of constructivism, what is its relation to the living exhibition concept and to what extent is a philosophy like constructivism a prerequisite for exhibition design?

I believe that for the purposes of evaluating educational outcome, a certain epistemology is always assumed, either implicitly or explicitly. I also think that epistemological preference is, to a large extent, a matter of which underlying philosophical view of the world one believes is correct. Because my field of research is human-computer interaction rather than education, psychology or philosophy, I have attempted to avoid making an explicit epistemological "choice".

However, I do think that the constructivists' focus on exploratory and social learning may be fruitful for inspiring museum exhibition design, mainly because current research suggests that the activities of museum visitors are, to a large extent, exploratory and social in nature. Also, constructivist ideas are often embodied in contemporary museum exhibitions, most notably in science centres like the San Francisco Exploratorium, the *Launch Pad* gallery in the London Science Museum, or Tom Tits Experiment in Södertälje, Sweden (Caulton, 1996, pp. 36-38), and the number of museums that are adopting constructivism as an explicit educational strategy is increasing (Hein, 1994a).

This, however, does not at all imply that the design of a living exhibition necessarily must follow constructivist pedagogy or make use of constructivist-inspired technology tools. Indeed, how the constructivist philosophy and the classroom teaching guidelines presented above are to be applied in the museum domain (and whether they should be applied at all) is still being debated (e.g., Caulton, 1996, p. 21-22). In light of the critique against the introduction of computers to young children, I also believe one should carefully consider of how technology is designed and used in museum exhibitions. Thus, my view is that constructivism can certainly provide an exhibition production team with useful and novel design ideas (as it did for the design of *The Well of Inventions*, as we shall see in chapter five). But living exhibitions might just as well draw upon other educational resources (and probably should).

The next chapter reviews some current research literature on museum learning. It also contains an overview of a common approach to exhibition production and some guidelines for how to effectively combine different exhibit elements.

CHAPTER 3

MUSEUM EXHIBITIONS

The word *museum* originates from the Greek word *mouseion*, which translates into "house of the muses", i.e., the temple of the nine Greek goddesses who gave artists their inspiration. The first *mouseion* was built in Alexandria around 300 B. C., and was primarily used as a research institution and knowledge centre where researchers of various disciplines would live, meet, study and work (Ashmawy, 2001). In the Greek and Roman societies, pieces of art and other items were often put on display in public environments such as baths, theatres and forums. However, during the middle ages, artefacts were increasingly collected and kept by religious institutions.

In the mid-15th century, Italian nobles begun to collect artworks from ancient Greece and Rome and put them on display in order to rise in social position. As a result, a new interest in these cultures was raised (Hooper-Greenhill, 1992). One of the most well known banker families, the Medicis, built a famous palace in Florence that is now often considered to be the first museum in Europe. The Medici palace housed not only a treasure in precious metals and stones, but also commissioned artworks and Greek and Roman items that they had collected. The family also commissioned artwork from architects, painters and decorators to furnish the building itself. The palace was not open to the public – rather, the merchant prince personally invited visitors (ibid.).

In the 17th century, collections of items from around the world were rather abundant in Europe. The way of displaying them became different, however: the function of the displays changed from being tools for forwarding the owner's social position to exhibitions with an encyclopaedic goal. Some collections were kept for teaching purposes by individual researchers at universities, but many were put together to represent a picture of the world as a whole (ibid.). A classic example of these kinds of displays is the *Wunderkammer*, or the "cabinets of curiosities". Such cabinets typically had numerous compartments (of which a large part typically were secret or required a special procedure to open) that held items of varying types. For political reasons, such cabinets were developed into *Kunstkammers*, i.e., large indoor spaces to hold art and curious artefacts, sometimes built specifically for the purpose of hosting ambassadors and other important visitors. The development of palace gardens is, in turn, an extension of the *Kunstkammer* concept (ibid.).

During the mid-17th century, the Royal Society was formed in England. One of its aims was to standardize language among tradesmen, scientists and the church. To support this process, the Society assembled a collection of items, known as its Repository, to represent this standardized language. By arranging for an institution to own the collection rather than a private individual, it was hoped that it would stand a better chance of surviving and growing than private collections, which tended to disperse at the death of the owner. Because the Repository was assembled with the intention of providing opportunities for study, the motivation for obtaining complete collections was high. The Royal Society also appointed a *curator* to manage the laboratory that was made available in connection with the collection (ibid.). Not surprisingly, perhaps, the cataloguing attempt failed. At this time, there was no standardized way of classifying specimens and the Society lacked the funds necessary for pursuing its goals. Also, the collection was only available to the members of the Society, of which a too small part were scholars. Today, the Repository is a part of the British Museum.

After the French revolution, the collections of the aristocracy were appropriated in the name of the new Republic, gathered together, reorganized and transformed. The aim was to make the collections available to all citizens of the Republic. Another reason for organizing this new type of museum was to display the decadence and forms of control of the old regime and to present the democratic values of the new. A similar perspective was gradually adopted throughout the rest of Europe. Thus, the nature of the content changed from the notion of a three-dimensional encyclopaedia to that of information undergoing constant change (ibid.).

The evolution of the modernist philosophy in the nineteenth century influenced the transformation of museum collections into representations of chronology so that the exhibitions evolved into a physical record of the past (ibid.). The chronological display of artefacts, and groupings of collections of artefacts belonging to similar periods in history is a practice that remains today, but many other presentation techniques are also used in contemporary museums.

Types of Museum Exhibitions

There exists no standard terminology for classifying museum exhibitions. However, many authors follow David Dean in using the term *display* to denote a presentation of objects for public view without significant interpretation added, *exhibit* to denote a localized collection of objects and interpretative material that forms a coherent unit, and *exhibition* to denote a collection of such displays and exhibits (Dean, 1994).

The content of exhibitions vary greatly from simulations or recreations of different environments of interest, to presentations of controversial issues that are intended to provoke debate. The Swedish museologist Per-Uno Ågren proposes the following taxonomy of exhibitions (Ågren, 1995):

Contextual exhibitions present objects in their appropriate (possibly reconstructed) environments to make their interpretation easy. Examples of such exhibitions include dioramas and "period rooms".

Exhibitions with an *isolating* mode of presentation aims to focus the visitors' attention towards the aesthetic properties of isolated objects. This type of exhibition is common in art galleries.

In a *systematic* exhibition, objects are subordinated to a scientific ordering of the world. Such orderings are often chronological, but can also be based on species classification or other features the curator wants to draw attention to. This is one of the most frequently occurring exhibition types.

Exhibitions with an *analytic* content present objects as integrated into ecological, economic and social cultures. They often focus on the everyday life of human beings and frequently use graphic material and multimedia to provide a visualization of the subject. This kind of exhibition is common in ethnographically oriented museums.

Storytelling exhibitions focus not on the objects and artefacts themselves, but rather on the history of the humans associated with them. The aim is to provide visitors with perspectives on cultural history through hermeneutic interpretations of human life stories. Such exhibitions are common in historically oriented museums.

Finally, *metarealistic* exhibitions use novel and unexpected combinations of objects, artefacts and quotes to stimulate visitors' thoughts and convey abstract ideas and concepts. The aim is often to provoke intellectual curiosity and reflection, but sometimes also to encourage debates on controversial issues. This type of exhibition is gradually becoming more common, but is most frequently found in art galleries.

Ågren points out that most exhibitions consist of combinations of these categories. In addition, I think it may be warranted to extend his taxonomy with a *hands-on/science centre* exhibition category. Although such exhibitions frequently present scientific content, they do not always provide a specific ordering like systematic exhibitions do. Instead, they are often organized as a collection of loosely connected interactive experiments whose aim is to allow visitors to discover the details of certain physical mechanisms (Caulton, 1996, pp. 2-6).

Learning in Museums

The educational design of museum exhibitions is often inspired by *communication theory* and is typically based on derivations of Claude Shannon's work. In 1948, Shannon presented a mathematical model of transmission of written messages. His model was first adopted for the museum domain in the 1960s, and such adoptions have substantially influenced exhibition design ever since (Hooper-Greenhill, 1994, p. 32). The goal of Shannon's original paper was to contribute to the development of a general theory of communication that could assist in the analysis of different forms of communication media (Shannon, 1948). His model consists of five parts:

1. An *information source* (or sender) that produces a message.
2. A *transmitter* that transform the message in some way in order to make it suitable for transmission.
3. A *channel* through which the modified message is transmitted. This channel may be subject to *noise* that distorts the message in some way.
4. A *receiver* that performs the inverse operation of the transmitter.
5. A *destination*, i.e., the person for whom the message is intended.

Because noise may perturb a message, the amount of actual information contained within the message as compared to the amount of redundancy becomes important. Through a statistical analysis of written English, Shannon was able to deduce a mathematical quantity that measures the amount of information that is produced by the information source, the *entropy*. For a noisy channel, it is possible to increase the probability of success in decoding the message by increasing the amount of redundancy in the message.

In the museum domain, the information source is thought of as an exhibition production team who wants to convey knowledge to the museum visitors (Dean, 1994, pp. 103-105). The team's messages are encoded and embodied into an exhibition design. The communication channel corresponds to the physical embodiment of the exhibition, i.e., texts, images and audiovisual cues, together with its associated events and activities (e.g., guided tours and lectures). Visitors are modelled as receivers that decode the content of the exhibition and transform the resulting information into knowledge. The concept of noise translates into factors that draw attention away from the exhibits or degrades the quality of the transmission, e.g., fatigue, crowding, poor graphic design and broken exhibits. Increasing the likelihood of knowledge acquisition involves either decreasing the noise (e.g., provide couches on which visitors can rest, resolve crowding problems, etc.), or increasing the redundancy of the message (i.e., present the same information in several different ways).

Models such as this have been criticized by contemporary museum researchers (e.g., Hein, 1994a, Hooper-Greenhill, 1994). Shannon's original model assumes that the receiver performs the inverse operation of the transmitter, and it follows that in order to apply the model in a museum context, all visitors must be assumed to perform the interpretation process in the same way. However, from the point of view of the critics, learning is subjective: the knowledge acquired from an exhibit is mainly a function of what the individual visitor already knows and his/her current interests. Furthermore, the appropriations of Shannon's model for the museum domain typically only consider the exhibition itself and thus disregard other sources of information, and they seldom provide for visitor feedback.

This critique has resulted in the development of a number of alternative models of communication and learning in the museum domain. One example is the *holistic approach to museum communication* proposed by Eilean Hooper-Greenhill. She argues that the exhibition itself should not be seen as the ultimate source of information. Instead, her model attempts to portray the museum with its exhibitions as an institution situated in society and culture in general (Hooper-Greenhill, 1994, pp. 40-42). The public image of the museum depends on the experience people have of it. This image is shaped by numerous factors, including not only the exhibitions and the buildings in which they are situated, but also outreach events, orientation facilities, publications and practical issues like the availability and quality of shops, cafés and toilets. The public image of a museum in turn influences the number of visitors, the number of recurring visits and, by extension, ultimately also the learning outcome.

Another alternative is the *contextual model of learning* developed by John Falk and Lynn Dierking (Falk and Dierking, 2000). From their perspective, learning in museums is the result of interaction between three different contexts: the *personal context*, the *socio-cultural context* and the *physical context.* The individual visitor shapes his or her knowledge through the experience of events within the physical world, all of which are mediated through social mechanisms and activities. If any of the three contexts is neglected in an exhibition design, the result is a negative influence on the opportunities for learning provided by the exhibition.

The personal context consists of the prior motivation and expectations a person has upon a pending museum visit, together with the person's current knowledge, beliefs and interests. According to Falk and Dierking, human beings are highly motivated to learn when they when they are freed from anxiety and other negative mental states, and can become engaged in meaningful activities where they have a choice and control over their learning (ibid, pp. 18-19). Furthermore, they claim that the outcomes of learning differ significantly depending upon whether the motivation to learn is *extrinsic* (i.e., anticipated benefits are external to the activity) or *intrinsic* (i.e., an action is done for its own sake). For example, the work of psychologist Mihaly Csikszentmihalyi suggests that most people exhibit a common set of behaviours and outcomes when they are engaged in free-choice tasks. They typically state that what keeps them involved is an inherent quality of the experience that Csikszentmihalyi calls *flow*. It is characterized by clear goals and immediate unambiguous feedback, and tends to occur when the opportunities for action in a situation are in balance with the person's abilities (Csikszentmihalyi, 1990, Csikszentmihalyi and Hermanson, 1994).

The socio-cultural context is related to facilitated mediation by others and within-group social and cultural mediation. According to Falk and Dierking, most activities in museums are fundamentally social: what a visitor learns is inextricably bound to the cultural and historical context in which the learning activities occur. Human perception, descriptions and understanding of the world are all culturally and historically bound (ibid, p. 41). Falk and Dierking argue that Vygotsky's theory of learning can be successfully applied to museums and mention scaffolding as an important group activity (ibid, p. 45). In addition, they cite several studies that suggest that *modelling*, i.e., learning through observation and imitation, frequently occurs in museums, especially in connection with interactive exhibits.

The physical context involves the design and architecture of the museum space. Falk and Dierking quote a number of studies that suggest that learning is bound to and influenced by the physical environment in which it occurs (ibid, p. 59). Thus, according to these studies, knowledge can be generalized to new situations only when elements of the context in which the knowledge was originally acquired can be recognized in the new context. When conceptual information is generalized to a new situation, it is as much the physical context that is being generalized as it is the information or some generalized problem-solving algorithm or strategy. In addition, Falk and Dierking claim that the nature of the physical environment affects the personal and socio-cultural contexts. Barriers or social regulations that restrict movement in a museum can make learning considerably more difficult, especially for young children (ibid, p. 62). For example, if a single-person interactive exhibit is designed in such a way that other visitors cannot see the interaction, modelling is inhibited. Or, if an exhibit is mounted too far from the floor, young children might not be able to reach or view it, which may cause them to turn their attention elsewhere.

Science centre exhibitions typically consist of a number of loosely connected interactive exhibits that are designed to challenge visitor's current knowledge (Caulton, 1996). Similar to cognitive oriented constructivist pedagogies, they attempt to manoeuvre visitors into a position where their current knowledge is insufficient to explain the observed workings of the exhibit. Often, some sort of written question or challenge is provided to encourage visitors to interact with the exhibit, and typically, the answer to the riddle posed by the exhibit (and an explanation for its behaviour) is also provided in writing.

Practical Exhibition Design

Research in psychology and human factors has resulted in a number of different guidelines for museum exhibition design, some of which have been summarized by David Dean (Dean, 1994). According to Dean, most people feel at ease in spaces that allow freedom of movement without giving the impression of either confinement or exposure. The scale of such spaces are related to the human scale: ceilings in most homes are high enough to allow us to raise our arms, while being low enough to feel comfortable. High ceiling heights are often awe-inspiring, but can give an impression of lack of control. Conversely, smaller spaces provide a feeling of intimacy, but may also feel crowded and smothering (ibid, pp. 41-42).

According to Dean, most human beings have a predisposition towards touching, which means that if a museum object or artefact is within reach, it is likely to be touched. Because such artefacts are often fragile, they may have to be protected by barriers, which may be physical (e.g., vitrines or ropes surrounding an exhibit) or implied (e.g., raised platforms). Implied barriers are useful because they do not interfere with the ability to see the exhibit, but because they are enforced through social conventions, children who have not yet learned such conventions may not adhere to them.

Furthermore, people will often lean or sit on any surface that is at a comfortable height and will also prop feet on raised platforms. Such actions are typically carried out in response to fatigue and are often unconscious and automatic (ibid, pp. 43-46).

Behavioural research carried out in North American museums suggests that their visitors share a number of behavioural patterns (ibid, p. 51). These patterns include:

- If all other factors are equal, visitors favour turning to the right.
- After having turned right, visitors are likely to continue to follow the exhibits along the right wall.
- The first exhibit area on the right typically receives most attention.
- Visitors are more likely to stop at the first exhibit in a gallery than the last.
- Exhibits along the shortest route to the exit receive more attention than other exhibits.

Many exhibitions make use of text and graphics in different ways. According to Dean, printed material should be positioned so that the centre of the material is at eye-level. The human field of vision is a cone of about 40 degrees, extending above and below the horizontal axis. Placing objects or materials are outside the field of view leads to difficulty in viewing and fatigue (ibid, p. 43). Dean also claims that most people find vivid colours, large typefaces and bright illumination visually engaging.

For systematic exhibitions or exhibitions where the order of appearance of objects are important, the physical layout of an exhibition must be carefully considered (ibid, p. 53-55). Such layouts can be *unstructured*, *suggested* or *directed*. An unstructured layout allows visitors to choose their own path through the exhibition. This enables visitors to determine their own priorities, but requires that each exhibit is independent of the others. Suggested layouts use colours, lighting, headlines and landmark exhibits to encourage visitors to move along the preferred path without physically constricting movement. Such a layout allows for structured information while making it possible to "skip ahead". However, its success relies on the ability of the exhibition design elements to draw visitors' attention. Directed layouts provide a physically enforced one-way path through the exhibition. This allows for heavily structured content but may lead to crowding, bottlenecks and a sense of entrapment.

One of the main means for conveying information in exhibitions is through text. The way text is typically presented in museum exhibitions can be said to have developed from communication theory and human factors research in the sense that the messages that the exhibition design team want to convey are transformed into manageable pieces of text. The design of the texts aims at, in combination with the artefacts on display, both increase redundancy overall and decrease the risk of noise.

The main storyline of the exhibition is typically divided up into hierarchical sections, which are given appropriate headings (ibid, pp. 106-109). These sections are normally also reflected in the physical layout of the exhibition, where the same headings are used to identify each area. Within each section, a number of exhibits may exist and labels of different sorts commonly accompany them. Since the labels traditionally are the main form of text in exhibitions, there exists a large amount of guidelines for how to compose label texts (e.g., Lord and Lord, 2002, pp. 393-404, Falk and Dierking, 2000, pp. 121-122, Ekarv, 1994, Gilmore and Sabine, 1994, Carter, 1994, Coxall, 1994). A common trait among all these guidelines is the emphasis on factors that increase the *readability* of the text, i.e., how easy the text is to read. Recommendations include:

- Within a single text panel, avoid using redundant words and phrases (i.e., such that do not contribute to the overall meaning of the text or statement).
- Avoid syllable divisions.
- Present one main idea per line of text.
- Avoid lines longer than 45 letters and keep paragraphs shorter than 4-5 lines.
- Avoid texts longer than 200 words.
- Use a large and easy-to-read font.

Tim Caulton has developed a number of guidelines for the design of interactive exhibits (Caulton ,1996). These include:

- Exhibits should have direct, obvious actions and feedback and should be intuitive and easy to use.
- The goals of an exhibit should be clear and encouraging, and it should have variable, open-ended outcomes.
- Exhibits should work at multiple intellectual levels in order to reach visitors of different ages.
- Different forms of sensory material should be provided to allow a range of interpretative styles.
- The exhibits should be enjoyable, well-designed, robust and easily maintained.

The background material used to develop the contextual model of learning also provides a number of guidelines for exhibition design (Falk and Dierking, 2000). These include:

- When exhibit puzzles or wall mazes are partially completed, children are more likely to approach the exhibit and complete the task than if the exhibit is either totally disassembled or completed.
- People seem to recall most vividly exhibitions that build upon prior knowledge, rather than those that present totally novel objects and ideas.
- People can mentally organize information effectively if it is recounted to them in a story.
- Visitors are more likely to utilize museums to confirm pre-existing understanding than to build new knowledge structures.
- Curiosity is a major factor in determining whether environments are appealing. Complex environments that are felt to be mysterious, provide a moderate sense of the unknown and invite exploration are far more desirable than those without these qualities.
- People are more likely to read three 50-word labels than a single 150-word label containing the same text.
- Reds, oranges and yellows give a sensation of warmth, while blues, greens and violets evoke coldness. Warm colours stimulate, while cool colours relax. Sounds appear louder in a white room than in a dark-coloured room. Dark colours make objects appear heavier.
- Exhibitions for children are more successful when everything in them is built to match their physical dimensions.
- Parents are most likely to choose which gallery to explore, but children are more likely to select individual exhibits.
- Most families do not read labels before interacting with hands-on exhibits. Children are more likely to interact than adults, and adults are more likely to read labels. Adults in family groups are more likely to have a positive frame of mind if the exhibition is perceived to be designed for children.
- Physical abuse of an exhibit is far more likely to occur if visitors cannot immediately understand what they are supposed to do.

Technologies in Museums

Because of competition from the entertainment industry, many museums are finding it increasingly difficulty to attract visitors (Caulton, 1996, p. 1). As a result, many museums are attempting to increase the accessibility of their collections through interactive or hands-on exhibits, live interpretations by docents (i.e., educational staff) and visible storage. In addition, using new and potentially awe-inspiring technology is becoming increasingly important.

Technology has been used in a large number of ways in museums, ranging from devices for presenting video clips to massively interactive IMAX cinema presentations. Furthermore, technologies are also used to augment exhibitions in order to increase the number of opportunities for learning. Examples of common technologies include:

- Mechanical devices and models
- Audio / video / multimedia stations (often based on VCR or CDi technologies)
- Multimedia theatres
- Simulation and experiment stations
- Interactive catalogues or documentation
- Audio tour guides (tape or CD based)
- Information kiosks
- Internet access stations

Recently, a number of technologies have been introduced to enhance, augment or replace traditional audio tour guides (e.g., Broadbent and Marti, 1997a, Burgard et al., 1999, Aoki et al., 2002) or labels (e.g., Oberlander, 1997).

Computer-based imagery has been used for a number of years to provide access to parts of museum collections that are in storage or are too fragile for public display (e.g., the *Micro Gallery* at the London National Gallery, http://www.nationalgallery.org.uk/). In addition, digital images of very high resolution have the potential to provide scientists with enough data to conduct research without necessitating access to the real artefact. Laser-based scanning hardware that allows the construction of three-dimensional virtual models is also available. Such equipment has recently been used to construct extremely high-resolution virtual 3D models of a number of Michelangelo's sculptures (Levoy et al., 2000).

The possibility of reconstructing objects and artefacts in digital form has led to the notion of the *virtual museum*, i.e., a museum with digital content, often publicly accessible through the Internet (Cutler, 2000, Rayward and Twidale, 1999). Many museum institutions design virtual museums as extensions of their website (e.g., the National Museum of Korea, http://www.museum.go.kr/eng/), whereas some virtual museums have no institutional counterpart (e.g., the Virtual Museum of Canada, http://www.virtualmuseum.ca/).

Some exhibitions combine virtual and physical components. One such exhibition that I assisted in designing is the permanent *Space Adventure* gallery at the Swedish Museum of Natural History, which opened in December 2000. The museum's production team had decided to design the gallery as a spacecraft with a cockpit towards the back (figure 2).

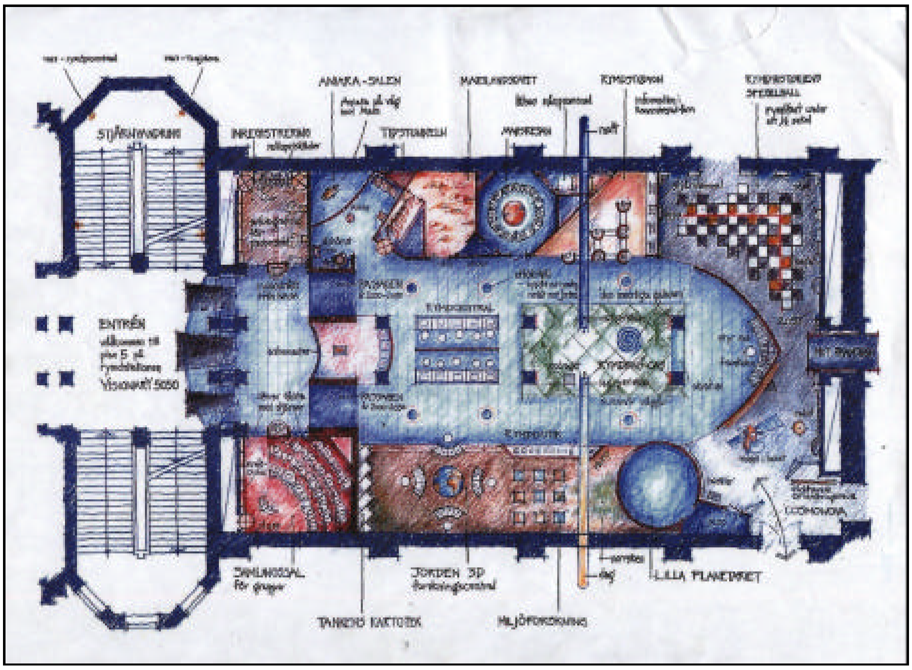

Figure 2. Layout of *Space Adventure*. The cockpit is at the far right.

The Museum's proposed design for the cockpit exhibit combined a blue-screen camera with a back-screen video projection to give the visitors an impression of flying over a remote planet landscape. But the museum research team at the Centre for User Oriented IT Design (CID) instead suggested that an exhibit where visitors could interactively fly over a virtual 3D planet might be more suitable. More specifically, I provided the idea of *positioning objects on the virtual planet surface in such a way that they represented concepts present in the physical exhibition*. For example, the physical exhibition contains a section on the history of space exploration, which is represented in the virtual environment by a Voyager monument (figure 3). When visitors in the virtual environment move close to the Voyager monument, a text panel appears. The panel provides an introduction to the subject and specifies where the corresponding physical exhibit is in the *Space Adventure* gallery. The other virtual exhibits are treated similarly.

By allowing visitors to access a virtual representation of the exhibition before they visit the physical counterpart, they are given an opportunity to prepare for their visit, which may help facilitate learning (Falk and Dierking, 2000, pp. 116-117). Also, the implementation platform we chose (*ActiveWorlds*, http://www.activeworlds.com/) allows for communication between visitors to the physical exhibition and visitors to the virtual exhibition through text chat, which I believe provides further opportunities for interaction and learning.

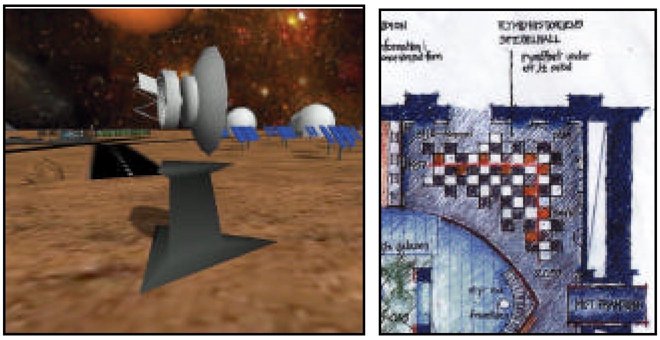

Figure 3. Virtual representation of the spacecraft exhibit.

People visiting the virtual exhibition remotely are represented as astronauts (figure 4), while the cockpit exhibit in the physical exhibition is represented as a spacecraft.

Figure 4. *Space Adventure* avatars.

Since *Space Adventure* opened, another access terminal has been built at the Museum of Science and Technology in Stockholm. This ties together two physically remote museums and potentially also provides a conceptual link between them.

Recently, a number of museums are also making use of *mixed reality* technologies, e.g., technologies that provide a blend between a physical and virtual environment. Often, these technologies are projection-based, like the *Virtual FishTank* at the Boston Museum of Science (http://www.mos.org/exhibits/current_exhibits/virtualfishtank/), the *Mimetic Dynamics* art installation (presented in the Oslo Konserthus Foyer in October 1999, http://kunst.no/mimdyn/), the table projections in the *In Future* gallery of the London Science Museum's *Wellcome Wing* (http://www.sciencemuseum.org.uk/wellcome-wing/), or the wall projections used in the visitor centre at the Sellafield power plant to present quotes on nuclear power provided by visitors (http://www.sparkingreaction.info/). As we shall see in chapter five, *The Well of Inventions* also makes use of projection-based mixed reality technology.

Another example is the EQUATOR project's mixed reality installation at the Lighthouse (Scotland's Centre for Design, Architecture and the City) in Glasgow (Brown et al., 2003). In this case, the physical exhibition is also represented as a virtual reality model and as a collection of web pages. The aim is to allow visitors to each of the three representations to share their visit. A voice link provides communication opportunities. In addition, the position and orientation of each visitor is tracked and shown on a two-dimensional map, which is accessible in the physical exhibition and from the web (orientation and position is indicated by avatars in the virtual reality representation). The evaluation of the installation indicates that while visitors had some difficulty in communicating, it did generate a sense of a shared experience.

I believe modern technology usage in museums has a large potential. It can help attract new visitors to museums and may motivate them to explore exhibits they otherwise would ignore. It can easily provide multiple perspectives on museum artefacts and present their background in exciting ways, and it provides new forms of interactivity. Internet technologies can also be used to access museum information from school and home and also creates new opportunities for collaboration and communication between people. I also believe that careful use of technology can provide new and exciting forms of learning.

But there are also drawbacks. Novel technologies are often expensive, typically require special training to be designed and maintained and quickly become obsolete. They may also draw attention away from the real-life artefacts and collections in the museums' possession. I believe that such artefacts are the main distinguishing feature of many museums and that there are powerful learning opportunities associated with the encounter of real, physical objects.

I also think many museum technologies are susceptible to the same critique as that of multimedia-based technologies for young children, as described in the previous chapter. In my opinion, computer-based exhibits are far too often designed to reduce visitors' interaction to the mere playing of simplistic action games. The argument for using games is typically that because today's children have grown up with television and interactive computer games, they turn away from anything that is not technically awe-inspiring and game-like in its appearance (Prensky, 2001, pp. 35-65). However, I think the focus on gaming and "fast" information acquisition may lead to a situation where children find themselves unable to think and reflect. A quick exposure to a game may certainly lead to an interest in learning more about a subject, but it is not at all clear to me that it necessarily leads to new conceptual knowledge. Thus, as we shall see in chapter five, an important goal for the design of *The Well of Inventions* was to provide an environment that is both technically sophisticated and at the same time encourages reflection and discussion of a certain set of museum artefacts and what they represent.

Museum Exhibition Production and Evaluation

The details of how individual museums produce their exhibitions vary, but there seems to be a number of common features (Dean, 1994, pp. 8-18, Lord and Lord, 2002, pp. 1-8). From a production perspective, there are three main types of exhibitions:

- Exhibitions conceived, designed and constructed in-house.
- Exhibitions conceived in-house, but designed and constructed by contractors.
- Exhibitions produced entirely by contractors.

Many museums have in-house workshops for developing exhibits, but contracting different aspects of the production is common. Contracting can be beneficial in that difficult parts of the production can be handled and built by people with the appropriate expertise, but it can also be problematic. For example, when an artist or professional designer is hired to produce the implementation design for the exhibition, it is vital that the production team communicates its goals clearly. Otherwise, the finished design may turn out to be unsatisfactory and require additional development (Persson, 1995). I shall return to the issue of communication between members of a multidisciplinary design team in the next chapter.

Many museums have an organizational structure with the following roles (Lord and Lord, 2002, pp. 5-7):

- *Museum director*: appoints the core exhibition planning team and the exhibition team coordinator. Provides the team with a large-scale policy, schedule and financial guidelines.
- *Core exhibition team*: consists of people with expertise in finance, collections management, security, design, development, marketing, curatorial issues, education and evaluation. This team ensures that the museum fulfils its exhibition policy by producing an *exhibition brief* and monitors that the brief is implemented properly.
- *Design team*: consists of people with expertise in graphic design, writing, acoustics and multimedia. This team is responsible for providing a design that fulfils the exhibition brief. It often consists of a combination of museum staff and outside contractors.
- *Construction team*: responsible for building the exhibition according to the design provided by the design team. Consists of people with skills in fabrics, graphics, woodwork, multimedia, etc. The construction team is often appointed through contracting.
- *Implementation team*: responsible for providing support for the design and construction teams. It consists of developers, researchers, educators, marketing, conservation, etc. It develops exhibits, provides support materials, operate the exhibition, etc.
- *Project manager*: responsible for implementing the exhibition on time, on budget. Coordinates the members of the design, implementation and construction teams.

New exhibition projects typically begin with a *conceptual phase* in which a subject and a visitor target group are selected. Traditionally, this choice has often been the result of the interest and opinions of curators, whereas today it is also common to make use of a *front-end analysis* to generate subject candidates (Caulton, 1996, p.46). In such an analysis, previous projects are assessed and demographic data of the visitor population is acquired. It is also common to assess the kinds of knowledge the target group have of the chosen subject, their interests and priorities, or to attempt to find ways to attract visitors from community groups that seldom visit museums (e.g., Dodd, 1994, Falk and Dierking, 2000 pp. 179-181). After the production team has generated a number of ideas, available resources for completing the project are assessed, together with the appropriation of a suitable time-slot in the exhibition schedule.

A *development phase* follows in which funding is acquired and the physical and educational design of the exhibition is completed. After a project budget and an exhibition plan have been completed, production can commence. Activities include the building, preparing, mounting and installing of the exhibits, and also involve training of docents (i.e., educational staff) and marketing. Since it is costly to redesign exhibits after they have been put on display, many museums have adopted a prototype-oriented design process where mock-ups or early exhibit versions are tested by selected groups of visitors (Caulton, 1996, pp. 39-43). Such evaluations of prototypes are often referred to as *formative evaluation*, and can be directed at both physical and educational aspects of the exhibits.

The time period when the exhibition is on display is often referred to as the *functional phase*. In this phase, educational programmes are implemented and the exhibition is typically also presented to the public through regular guided tours. It also includes personnel administration and maintenance work, and ends with the dismantling of the exhibition and the balancing of accounts. In this phase, *summative evaluation* is used to determine if the exhibition meets its goals. Such evaluation is normally relatively easy to conduct, but may lead to expensive re-design of entire exhibits (ibid, p. 47).

The production cycle ends with an *assessment phase* where the exhibition development process is evaluated. The intended outcome is a number of suggested improvements to the production process and ideas for future exhibitions.

A large number of evaluation methodologies exist, including *questionnaire surveys*, *in-depth interviews*, *structured and semi-structured interviews* and *behavioural observation* (Binks and Uzzell, 1994). Often, several of these evaluation methodologies are combined to triangulate the findings and strengthen the conclusions of the data analysis (Hein, 1994b).

Questionnaires are typically cost-effective and are easy to distribute and analyse but can be difficult to design and require a large number of responses in order to be reliable.

In-depth interviews can give useful detailed information on visitors' thoughts, feelings and motivations, but are time-consuming and may require a skilled interviewer. They are often used to inform the design of questionnaires.

Structured or semi-structured interviews are easier for inexperienced interviewers to carry out and allow respondents to provide additional information that would be missing from a questionnaire. They can also be used to test the design of a questionnaire. However, they are also time-consuming and require a large sample if they are to be seen as representative of a larger population.

Behavioural observation involves following groups of visitors around the exhibition (or exhibitions) and in some way record what they say and do. Typically, this is done through note taking on paper, but video cameras can also be used (if the appropriate rules and guidelines are followed). Observation provides information that the other forms of evaluation do not (namely what the visitors *do* rather than what they say they did), but can be time-consuming. There are also ethical issues involved, i.e., is it acceptable to record the actions of visitors without them knowing that they are observed? Conversely, if visitors are told that they are being watched, they may not act the same way as they would if they were alone.

For *The Well of Inventions*, the evaluation consisted of triangulation of semi-structured interviews, behavioural observation and workshop evaluations. The process is described in chapter six.

Sometimes, representatives of a community that is to be portrayed in an analytic or storytelling exhibition are invited to participate in the production process. For example, in the *HuupuKwanum • Tupaat: Out of the Mist, Treasures of the Nuu-chah-nulth Chiefs* exhibition at the Royal British Columbia Museum, representatives of the Nuu-chah-nulth community were directly involved in orchestrating protocols for the inclusion of the community, sponsorship, marketing, exhibit content and design, loans, exhibit interpretation and educational programmes (Lord and Lord, 2002, pp. 35-38). Another example is the *Warm and Rich and Fearless* exhibition at the Walsall Museum and Art Gallery where the local Sikh community were consulted to inform the exhibition content and design (Hooper-Greenhill, 1994, pp. 257-258).

While exhibitions like these are excellent examples of how community representatives can be involved in exhibition production, visitors in general are rarely given a chance to participate fully in the exhibition design process. The most frequent way of involving visitors is through feedback acquired from front-end, formative and summative evaluation as described above. Sometimes, feedback and ideas for exhibitions are acquired through "suggestion-boxes" (Lord and Lord, 2002, p. 28) and some exhibitions also give visitors an opportunity to provide their own content to put on display (e.g., through the text-entry terminals in the London Science Museum's *Wellcome Wing*).

An example of a closer collaboration between visitors and museum staff is the technology workshops initiated by the HIPS project (Broadbent and Marti, 1997b). The HIPS project aims to allow people to navigate both a physical space (e. g., a museum) and a related information space at the same time (e.g., information about the items in the museum), with a minimal gap between the two (http://www.cs.ucd.ie/prism/HIPS/). The focus of the workshops was the design of a portable appliance that allowed visitors to acquire information about a museum object or artwork, and the design team consisted of a museum director, an art expert, a museum custodian, a fine arts superintendent, the administrator of a museum bookstore and two tourists. While these workshops provided ideas for technology design and implementation, it did not focus explicitly on a particular exhibition.

Given that many museums are finding it increasingly difficult to attract new audiences, I would argue that it is vital for such museums to establish as many ways of communicating with the public as possible. I believe one appropriate such way is to directly involve museum visitor representatives throughout the exhibition production process, and therefore the notion of visitor involvement in exhibition design is the most fundamental aspect of the living exhibition concept. However, within the museum domain there does not appear to exist a standard methodology for achieving such involvement. Thus, my work instead borrows from methodologies from the domain of computer software design, which is topic of the next chapter.

CHAPTER 4

COOPERATIVE DESIGN

If visitor involvement in exhibition design is a desirable goal, then how is it to be achieved? As we saw in the previous chapter, apart from their participation in summative evaluation, visitors are commonly asked to provide feedback on exhibit mock-ups or provide ideas for future exhibitions. In such situations, one can view the visitor as having the role of *user, tester* or *informant* (cf. Druin and Fast, 200, Boltman et al., 1999, pp. 14-15).

When visitors are in the user role, researchers or members of the museum staff observe their interaction with an existing exhibit or exhibition. The rationale is that such observations provide data that, when analysed, can lead to improved future designs.

In formative evaluation, visitors are frequently assuming a tester role, i.e., they are being observed by researchers or museum staff while they interact with an exhibit (or exhibition) prototype. They may also be asked to comment on the exhibit design and provide feedback of various sorts.

As informants, visitors play a part in the exhibition design at various stages, based on when the production team believes that they can inform the development process. For example, if a specific design problem is found difficult to tackle, visitors may be asked to answer, say, a questionnaire in order to provide further information that can be used to settle the issue.

However, to achieve the best possible match between an exhibition design and its visitor population, it may be necessary to involve visitors further in the design process, in ways similar to those used in the HIPS project, as mentioned in the previous chapter. Within the domain of human-computer interaction, such involvement has been attempted in a number of research projects since the 1970s. The first of these projects were initiated in Scandinavia, and thus they are often collectively referred to as the *Scandinavian tradition in computer systems design* (Greenbaum and Kyng, 1991, Schuler and Namioka, 1993). Design methodologies within this tradition typically share the following features (Iivari and Lyytinen, 1998):

- Design is conceptualised as evolutionary (i.e., the design process is characterized by continuous change rather than consisting of a fixed life cycle).
- Users are invited to participate in different ways.
- They employ non-traditional process models.
- They seek varying and innovative theoretical foundations for systems design.
- They frequently apply action oriented research programmes.

In the 1970s and 1980s, the Scandinavian countries had some distinctive features: they had high living standards, one of the highest educational levels in the world with full literacy, shared political traditions, similar socio-economic institutions, a history of fairly intense and casual cooperation at all levels of society and they were open societies with an advanced technical infrastructure (ibid). This led to a lucrative environment for the exploitation of information technology. In addition, the level of unionisation was high and the national trade union federations were in a strong position, in part because of their close connections to the large social democratic political parties, but also because the relations between trade unions and employers were regulated by laws and central agreements.

For example, the Swedish Joint Regulation Act of 1977 stipulates that employers have to negotiate with the local trade union before making major changes in production (Ehn, 1993). Since the introduction of new computer technologies intended to support the planning of work and make it more efficient often also resulted in substantial modifications of the production process, the unions became interested in management issues. However, the activities of the unions had previously mainly involved distribution issues (e.g., wages and working hours) and therefore they lacked the necessary competence to initiate discussions. Thus, the support of activity-oriented researchers was requested (ibid).

When Kristen Nygaard's *SIMULA* simulation programming language became available in 1965, it was immediately used in a number of companies in Norway and Sweden as a tool for the analysis of workplace processes. Nygaard, who held the view that his language was used to promote an unfair Tayloristic view of management, initiated a collaboration with the Norwegian Trade Union with the aim of assisting it in developing an information technology policy (Nygaard, 1992).

This led to a research project, initiated in 1972, involving the Norwegian Computing Center, where Nygaard worked, and the Norwegian Iron and Metal Workers' Union (NJMF). The aims of the project initially included the studying of existing computer-based planning and control systems, assessing the goals of the union in areas such as working condition and organization control, the formulation of a set of demands for computer-based systems and to evaluate the need for knowledge within the Union in areas of planning, control and data processing (Ehn, 1993).

However, the realization that the outcome of the project, as originally conceived, would not directly benefit the Union necessitated a reformulation of the project goals towards a more action-oriented approach. In the new formulation, the project results were seen as actions carried out by the trade unions, at local or national levels (Nygaard, 1992). Consequently, a small number of workplaces were selected, and an investigation group consisting of union members was formed at each of them. The goals of the groups included the accumulation of knowledge about process control, investigate problems of special importance to the local unions and to take actions directed at management in order to change the usage of newly introduced technology. The outcome of the NJMF project was a number of "data agreements" – both local and national – that regulated the design and introduction of computer based systems and the availability of related information (Ehn, 1993).

The success of the NJMF project inspired a number of similar projects across Scandinavia. For example, the four-year Swedish DEMOS project (Trade Unions, Industrial Democracy, and Computers) was initiated in 1975 with the intention of identifying possibilities for the unions to influence the design and use of computer-based systems at local company levels (ibid). It was carried out by a multidisciplinary research team with competence within computer science, sociology, economics and engineering, in cooperation with workers and their trade unions at a locomotive repair shop, a newspaper, a metal factory and a department store. At the repair shop, the project involvement led to the participation of workers in the redesign of a computer-based planning system, but also to a reorganization of the workplace organization in general and to improved opportunities for dialogue between management and workers (ibid).

However, projects like DEMOS and NJMF could only influence the introduction of technology to a certain degree, and workers' opportunities to develop skills and have an impact on work organization was lacking. In particular, limitations of existing technologies made desirable alternative local solutions difficult to achieve. Thus, a new set of projects was initiated to support union-based efforts to design new technology (ibid).

One of the most well known of these projects was the UTOPIA project (Training, Technology, and Products from a Quality of Work Perspective) that begun in 1981. The project was a collaboration between the Nordic Graphics Workers' Union, the Swedish National Institute for Working Life and the Computer Science departments at Aarhus University and the Royal Institute of Technology in Stockholm. The primary goal of the project was to develop opportunities for workers to influence the design of computer-based workplace technologies, the rationale being that such an influence would have a positive outcome on the design. Thus, the project attempted to investigate how the then recently developed graphical workstation could support common tasks in the newspaper cutting room work process. The project members consisted of six graphics workers and about fifteen researchers (Bødker et al., 2000).

One of the main contributions of UTOPIA was its development of a "tools perspective" on computer systems design. From this perspective, new technology should be developed as an extension of the current practical understanding of tools and materials at a given workplace. The future users have knowledge of their work process (often tacit), but remain unaware of the new possibilities offered by the introduction of technology (Bødker et al., 1991). At the same time, the systems designers, who do know the technology, lack important knowledge about the workplace (Ehn, 1993).

As a result, the project initiated a process of mutual learning between designers and workers. This process involved demonstrating existing state-of-the-art technologies to the workers and visiting existing workplaces where different generations of technology were available. However, communication issues became increasingly problematic when the project moved on to design new systems. The reason was that the workers did not share the developers' concepts and language (e.g., data and information flow diagrams). As a result, a more concrete "design-by-doing" approach was adopted where the workers carried through hypothetical work scenarios using low-tech prototypes (e.g., paper, cardboard boxes and slide projectors) (Ehn and Kyng, 1991).

The designs produced by the project members were implemented in a prototype system that was used for a time at *Aftonbladet* (a Swedish newspaper), but for different reasons the prototype was never developed into a marketable product (Bødker et al., 2000, Ehn 1993). However, from a methodology perspective, the UTOPIA project was a success and it has spawned a number of other similar projects (one recent example is KidStory, which I describe below).

An alternative way of developing new workplace organizations is through *future workshops* (Kensing and Halskov Madsen, 1991, Bødker et al., 1993). These workshops were developed as a way of creating visions about future work situations that explicitly support and derive from interplay between the competence of users and designers.

A future workshop is divided into three phases. In the *critique phase*, specific statements about problems with the current work practice are documented in the form of Post-It notes. As a way of supporting the process, the workshop facilitators can offer metaphors from other domains. The workshop participants then develop a number of general headings together by analysing the notes. The headings are positioned on the wall of the room and each note is placed under the appropriate heading. After this, the participants are divided into smaller groups, and each group formulates a number of concise critiques based on the notes and headings.

In the *fantasy phase*, the critiques from the previous phase are inverted into positive statements, and the participants are asked to sketch pictures of their workplace illustrating the way they want to see it in five years. After this, new statements are written and placed on the wall, and each participant votes on their favoured statement (or statements). A selection of statements with the highest score then constitutes a "utopian outline". Again, the participants are divided into smaller groups, this time to discuss and develop the outline (it is important that possible drawbacks are ignored at this stage). As in the critique phase, the facilitators can suggest using different metaphors to support these discussions.

The purpose of the final *implementation phase* is to discuss the outcomes of the two previous phases in plenary form. The discussion focuses on whether it is possible to implement the utopian vision using current available resources. If not, then what is needed? The outcome of the implementation phase is a plan for how the first steps towards implementing the vision should be taken.

The Scandinavian tradition has also been the inspiration of new theoretical perspectives on human-computer interaction, including the *activity-oriented approach* to computer systems design developed by Susanne Bødker (Bødker, 1991). Bødker views human activity as conducted through *actions* with specific intentions, which take place in a finite length of time and space. An action is conducted through one or more *operations*, which are bound to specific material conditions in the sense that the correct operation to be used in a specific situation is triggered by such material conditions.

Through learning, people obtain a repertoire of operations to be used in a specific activity.

Activities are always mediated through tools of different sorts and frequently, the tool is used to transform some object. Thus, the activity is not consciously directed at the tool as such, but rather at the object *through* the tool. For example, the target of operations in a word processor is typically not the keys of the computer keyboard or the word processing software, but the document being written.

However, unforeseen changes in the material conditions that correspond to a specific activity may cause *conceptualisation*, i.e., it may lead to reflection upon former operations and to attempts to use former operations as actions, thus shifting the focus from object to tool. Bødker refer to such situations as *breakdowns*. For example, if a particular key press causes the word processing tool to produces an unexpected result, the focus shifts from the document being processed to the computer keyboard or the software.

A novice who is attempting to learn how to use a new piece of software is more likely to target his / her actions at the tool rather than the object the tool is to transform. With increased understanding, the actions gradually turn into an unconscious collection of operations. Bødker argues that computer systems design should ideally target such operations, i.e., that computer systems should be designed for experienced users rather than novices. As a result, it is also necessary to co-develop educational strategies that assist novices in the process of operationalisation (Bødker, 1991, p. 33).

Bødker's activity-oriented perspective can be seen as part of a larger trend within human-computer interaction research. Traditionally, such research has been targeted almost exclusively at *human factors* (i.e., physical and psychological capabilities of human beings). The focus on human factors grew out of an increasing frustration with the lack of validity, generality and precision of early human-machine interaction research, and its rationale is that psychological experiments can lead to an increased understanding of the underlying principles of the interaction between machines and humans (Schneiderman, 1998, pp. 28-29). The outcome of human factors research is often guidelines for computer interface design or models of human performance (e.g., Card, Moran and Newell, 1980).

However, researchers within the Scandinavian tradition often oppose this focus, claiming that it has a limited scope that may lead to a view that de-emphasises peoples' individual motivation, their membership in different communities of practice and the importance of their work context. For example, Liam Bannon argues that human-computer interaction research should deal with *usability*, which requires that attention should be directed at the design process as much as at the specifics of a particular user interface (Bannon, 1991). In addition, Bannon advocates the following shifts in research focus:

- From individuals using the computer in isolation to workplace group dynamics.
- From conducting research within laboratories to the understanding of workplace organization.
- From novices to expert users.
- From the analysis of existing systems to the design of new systems through prototyping.
- From designing *for* the users to designing *with* the users.
- From the development of user requirements specifications to iterative prototyping.

The interest in the Scandinavian projects has led to several attempts at implementing their methodologies under the name *participatory design* in the United States (Schuler and Namioka, 1993, Muller et al., 1993). However, because of differences in socio-economic structures (e.g., the lower level of unionisation in the United States), the political aspects that were central to the original Scandinavian projects have been downplayed in their North American counterparts. Indeed, it is questionable whether the Scandinavian tradition has remained true to its original intentions of democratising the workplace (see, for example, Bansler and Kraft, 1994, Iivari and Lyytinen, 1998, Bødker et al., 2000). Furthermore, it seems that most of the projects have failed to achieve sustainability: when the researchers' involvement ended, most of the workplaces associated with the projects reverted to previous activities (Clement and Van den Besselaar, 1993). These authors argue that the most important contribution of the cooperative design movement is rather the introduction of a rich set of methodologies for involving users in design.

Thus, the "second generation" North American projects tend to focus on the development of efficient prototyping or work analysis techniques rather than on workplace reorganization (e.g., Crane, 1993, Floyd, 1993, Bennett and Karat, 1994, Muller, 2001).

One example is the *PICTIVE* (Plastic Interface for Collaborative Technology Initiatives through Video Exploration) method developed by Michael Muller (Muller, 1993). The method can be seen as a development of the low-tech mock-up techniques used in the UTOPIA project and involves using combinations of low-tech paper-based elements to construct and evaluate prototype software user interfaces. The low-tech interface elements belong to two categories: the first contain elements constructed by the session participants themselves from Post-It notes and coloured pieces of paper. The second contain common user interface elements in the form of plastic cards that the session facilitator has prepared in advance, e.g., windows, scrollbars, buttons and icons. Scissors and permanent markers are provided to allow modification.

Before the session, each participant is given a piece of "homework" that is related to the target system. Users are asked to think about different relevant work and task scenarios, and designers are asked to think about useful system components. The session begins with a review of the assignments and a discussion on how the technology can be applied to the users' work analysis is initiated. Different suggestions for user interfaces are then created and evaluated at a shared work area. Throughout the session, a video camera records the interaction at the work area. A microphone is positioned in such a way that that the conversation is recorded as well.

The PICTIVE method has been further developed into a methodology called *CARD* where the design team uses a special set of coloured cardboard cards to collaboratively develop system designs (Muller, 2001).

In North American computer system design, it is common to involve users as informants, the rationale being that the success of a system is proportional to the degree in which users are involved in its design. This has resulted in a number of methodologies, several of which originate from the computer industry rather than academia. One example is the *Joint Application Design* method developed by IBM in the late 1970s (Carmel et al, 1993). It focuses primarily on design meetings, and includes a number of guidelines of how to structure such meetings. Each meeting stems from four components: a *designated leader* (or leaders) that manages the meeting, an *agenda* (i.e., the plan of action for the meeting), one or more persons that carefully *document* everything that occurs at the meeting and *group dynamics techniques* that are used for inspiring creativity, solving disagreements and handling speaking protocols. The roles the meeting participants play include: *users* (in this case both end users and their managers), *executive sponsor* (defines the overall project purpose and direction), *facilitator* (neutral, leads the meeting, often trained specifically for that purpose), *scribe* (documents the meeting activities) and *information system team* (analysts, project managers, technicians, etc.). A similar approach that involves video recording in a way reminiscent of PICTIVE is described in (Rettig, 1994).

The *contextual inquiry* method described by Karen Holtzblatt and Sandra Jones in (Holtzblatt and Jones, 1993) aims towards helping users articulate their current work practices, system practices and work experiences; information that can then be used as input to other forms of participatory design. It makes use of the three principles of *context*, *partnership* and *focus* to guide and support the design process.

The context principle involves learning about users' current work. Because much of the workers' knowledge can be tacit and difficult to articulate, Holtzblatt and Jones recommend that the designers allow users to describe their work while they are doing it. In addition to producing useful information, this also provides access to a number of important artefacts (e.g., books, meeting documentation, file storage structures and calendars), which can provide further understanding of the work process.

The partnership principle emphasizes that users are the experts within the domain of their own work: the designer's role is to understand the users' work and experience in order to envision technological systems. Thus, the designer must deliberately share control of the dialogue with the users. In practice, this means that the designer asks open-ended questions and invites the users to lead the conversation. Also, the designer should share his / her design ideas with the users as they occur.

Finally, the focus principle is the way the conversation with the users is managed. The designer always begins the inquiry with a number of assumptions (decided upon and documented in advance) that direct information collection and analysis. However, the goal is always to expand (or redirect) the focus in response to the information obtained through the interview. This means that the designer must inform the users of his / her focus, and that contradictions that arise between what the designer sees and what he / she believes are explored together.

During the interview, the designer writes down what the users do and say, how the designer interprets the situation, aspects of the different tools that support the work process and disruptions of the users' work (and the corresponding workarounds). At the end of the interview, these notes are read back to the users for confirmation.

The information is brought back to the design lab where it is further analysed. The notes are transcribed and are read back to the other members of the design team, who record their own understanding of the information on Post-It notes. The content of the notes include work descriptions, workflow structures, problems, design ideas and questions for subsequent interviews. The notes are then distributed among the members of the team and are organized in an *affinity diagram*, a hierarchical collection of note groups that crystallize the team's understanding of the users' work. Finally, the diagram is recorded and summarized in a system vision document.

The contextual inquiry methodology has been further developed into a process called *contextual design* that includes more detailed information on aspects such as user work models, system work model (i.e., the way systems impact users' work), work artefact models and models of the users' physical environment (Beyer and Holtzblatt, 1998).

The aims of the related *ETHICS* method (Effective Technical and Human Implementation of Computer-based Systems) developed by Enid Mumford at Manchester University is to allow users to articulate their information and organization needs (Mumford, 1993). This is done by forming a *decision structure*, i.e., a team that incorporates representatives of all groupings that are affected by the future system, and by initiating a *process* that enables the design task to be carried forward. The process incorporates the following steps: First, the design team assists the users in identifying a mission for their work and descriptions of its key tasks. Then, the team diagnoses the current workplace needs and the fit between the users' expectations of their work and their current experience is assessed by allowing them to complete a questionnaire. Problems and possible future changes in the workplace organizations are documented. This information is then used to develop an information requirements specification, which may or may not include computer technology. Finally, the group considers how the workplace as a whole and individual work activities can be redesigned to assist the implementation of the work mission, while making the best possible use of the suggested information structure.

Cooperative Inquiry and KidStory

All the cooperative design methods I have described so far involves adult users in formal work settings. However, there also exist a number of methods for designing with children (Druin, 1999a). One such method is the *cooperative inquiry* method developed by Allison Druin at the University of Maryland. It combines contextual inquiry, low-tech prototyping and technology immersion (i.e., observing children using large amounts of technology over a concentrated period of time) to allow children to become partners in design (Druin, 1999b). The method involves forming long-term design teams with both adult and child members.

The purpose of using contextual inquiry is both to analyse current technology to provide ideas for new designs, and to provide feedback on prototypes the design team has developed. The sessions are set up in the following way: the user (child or adult) is observed using the system by a pair of adult researchers and a number of children. Both adults and children take notes: the adults record quotes and activities (together with a time stamp so that the notes can be synchronized later) and the children record the interaction in the way they feel most comfortable with. A designated *interactor* initiates discussions and asks questions about the activities (this person does not take notes). Because video cameras tend to distract the children, they are rarely used.

The inquiry data is then analysed by the team. Here, the goal is to examine the notes to extract patterns of activity and different roles the user played during the interaction. At this stage, individual design ideas are also recorded. The resulting analysis is used as input to a brainstorming process where the team use low-tech prototyping materials to construct new system proposals.

In 1998, the cooperative inquiry method had only been used in laboratories with small child-adult design teams. Extending the scope of the method was part of the reasons for initiating the three-year KidStory project, of which I was a participant. It was funded by the European Union's Experimental School Environments initiative and the partner institutions were the Centre for User Oriented IT Design (CID) at The Royal Institute of Technology (KTH), the Swedish Institute of Computer Science (SICS) and the University of Nottingham. One of the project aims was to understand the extent to which the cooperative inquiry method could be used in school settings with larger design teams (Taxén et al., 2001). In Stockholm, the project collaborated with two school classes of a total of 27 children, together with their teachers. KidStory also worked with younger children than Druin's group: the children aged between 5 and 7 years when the project started. A number of research disciplines were represented, including computer science, educational research, user interface design and storytelling. The focus of the project's first year was to refine and evolve existing technologies. During the second year, new tangible storytelling technologies were developed and the work of the third year aimed to integrate the technologies from the first two years into a creative augmented storytelling space. My main project roles were 1) to study Druin's work method at her laboratory in Maryland (c.f. Alborzi et al. 2000) and then assist in adopting it for the Swedish context, and 2) to act as a programmer for *KidPad*, one of the project's main demonstrators (see below).

The KidStory design process consisted of about 60 design sessions where different constellations of adult researchers visited the children in their school. The ultimate goal of these sessions was to generate new or refine existing technology design ideas. It quickly became apparent that in order to achieve the desired project goals within the time given, it was necessary to introduce *off-line elaboration* where adults and children elaborated on ideas away from the sessions. Thus, the role of the adult researchers were, apart from taking an active part in the school sessions, to evaluate the ideas that were generated, see how they related to the larger goals of the project, select a number of them for implementation and possibly elaborate on them.

The process is summarized in figure 5. There were three main types of session activities: *educational* (assisting the children in acquiring knowledge of a particular role or concept related to the project), *evaluation* (generating suggestions for improvement of existing technologies) and *brainstorming* (exploring ideas and possibilities without having to make a commitment to act upon them). Sometimes, more than one set of activities occurred within a single session.

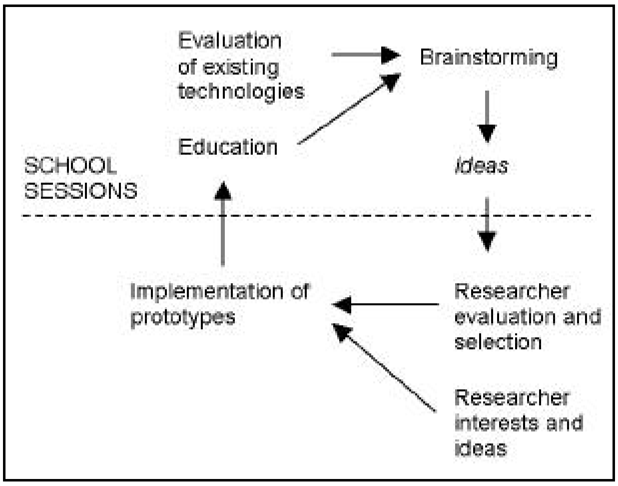

Figure 5. The KidStory design process.

The education and evaluation sessions provided the children with a framework for thinking critically about technology and also helped children and adults to develop a shared vocabulary for design. The outcome was typically a number of design suggestions that were either used to make changes to existing pieces of technology or were fed into brainstorming sessions where ideas for new technology were generated and elaborated upon.

The adults then analysed the subsequent ideas and selected a number of them for implementation. Both researcher interests and constraints on time and technology influenced the selection process. Prototypes that implemented the ideas were then built and brought back to the school for further refinement.

Typically, the sessions lasted about 60 minutes and often begun with a short briefing (5-15 minutes), after which children and adults split up into smaller mixed teams of 2-3 adults and 3-6 children. After the teams had worked for about 30-45 minutes, they gathered for a short debriefing (5-10 minutes). Each child had a personal KidStory project journal in which his/her ideas and design suggestions were recorded. The debriefing typically included writing and drawing in the journals. Often, the adults would ask the children to describe what it was that they had recorded so that no information was lost. The descriptions were then typed and inserted into the journal next to the appropriate drawing.

The educational sessions were held mainly to help the children to become familiar with their co-designer role. Sometimes, they were necessary to carry out before brainstorming or evaluation activities could take place. Our five-year-olds, for example, had trouble grasping the concepts of constructive criticism and brainstorming. Therefore, a number of sessions were held where we talked about being inventors, a role we felt captured the spirit of the work being done within project. We also asked the children about possible problems with existing everyday objects such as milk cartons and computer mice. The following is an account of one of the early educational sessions:

> Children and adults gathered on the floor and talked about what it means to be an inventor and the children were asked to describe what inventors do. The group talked about the KidStory project and why the adults would like the children to help inventing new storytelling tools. The children were then asked to work individually to invent a new kind of sandwich and to build a model of it using low-tech materials (e.g., paper, clay, glue and crayons). Afterwards, the children were asked to describe their sandwiches and the adults helped them to write down the descriptions in their journals. A photograph of each sandwich was later added next to its corresponding description in the journals (figure 6).

Figure 6. A novel sandwich design.

The evaluation sessions were quite similar to Druin's evaluation sessions. We evaluated both prototypes that were produced by KidStory and commercial applications. The aim was to offer opportunities for the children to identify problems with existing technologies and to encourage them to use constructive criticism, a notion that many of the children were unfamiliar with. The following is an account of an evaluation session:

> The children and adults gathered on the floor and the children were asked to work in pairs to figure out good and bad things about the storytelling software that we had brought with us. While the children were working, the adults took contextual inquiry notes and also wrote down general impressions and thoughts. Afterwards, the children were asked to write or draw what they liked and didn't like about their experience in their journals.

Brainstorming sessions were held to produce ideas for new technologies and elaborate on existing ideas. The aim was to create a setting where it was felt that any idea (related to the task at hand) is welcome. We found that our particular group of children were very comfortable with low-tech prototyping, so we chose to build non-functional prototypes with cardboard, crayons, balloons and similar materials. The following is an account of a typical brainstorming session:

> The children and adults gathered on the floor and the session facilitator started by reviewing the inventor's role and also talked a bit about what a storytelling machine could be like. The facilitator also reviewed previous inventing sessions. The children and adults talked about different machines for telling stories and some ideas were written down on a blackboard. After this, the children and adults split up into mixed teams of 2-3 adults and 3-4 children. Each team used low-tech prototyping materials to build models of their machine. The children were then asked to draw interesting details or machine usage examples in their journals. Finally, everybody gathered on the floor and each team described its machine to the others.

We found that the session content changed substantially during the first two years of the project. During the first year, the sessions was mainly directed at establishing a design partnership between children and adults and to refine and develop two existing pieces of desktop computer software, *KidPad* and *Klump*, which researchers had brought to the project. Therefore, the main part of the sessions had education and evaluation activities. The number of brainstorming sessions gradually increased during the second year, in part because the focus of the project shifted towards creating new storytelling technologies, but also, I believe, because the design partnership between adults and children became stronger as time progressed. During the project's first year, a total of 510 design suggestions for the two pieces of software were obtained from the Swedish and UK schools. 288 of the design suggestions were from contextual inquiry notes and 222 from the children's journals. The suggestions were divided into a number of different categories that were then used to improve the prototypes.

KidPad is a freely available collaborative drawing and storytelling tool that can be downloaded from http://www.kidpad.org/. Co-present users can draw together on a zoomable drawing canvas using one computer mouse each, and image elements can be connected by hyperlinks (figure 7). Finished stories can be saved as HTML (or in a special file format) for sharing with other people.

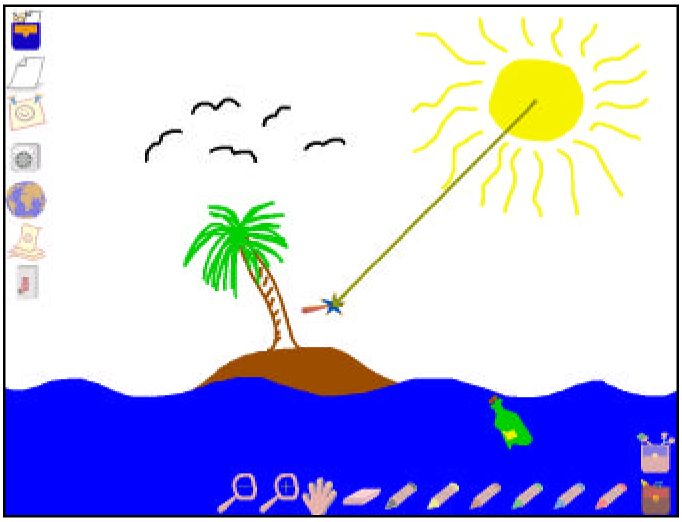

Figure 7. *KidPad*.

When *KidPad* became available for use within KidStory, its basic functionality was similar to when it made its original appearance (cf. Bederson et al., 1996), and so a number of technology evaluation sessions were held to obtain suggestions for improvement. Some issues were identified immediately and some became apparent after the children had made themselves more familiar with the program. For example, some of the original tool images were ambiguous, so the children were asked to provide their own tool images (figure 8). Another example is the addition of a fill tool that was requested repeatedly by the children, since it took a lot of time to fill large areas using crayons alone.

Figure 8. Children's *KidPad* tools: crayons and a crayon box.

In total, 64% of the suggestions from the contextual inquiry notes and 33% of the suggestions from the children's journals were implemented. We also explored different ways of encouraging collaboration between co-present users (Benford et al., 2000).

Klump is an application for conjuring up stories and collaboratively developing creative ideas. As with *KidPad*, the children were able to use multiple mice to interact simultaneously with the application. It is a 3D graphical object with colourful abstract textures and a physically based spring model that gives it organic dynamic properties. It also generates sounds that are directly related to its movements and the user interaction. A number of evaluation sessions were held to improve its user interface. In total, 75% of the design suggestions for *Klump* were implemented.

During KidStory's second year, a number of non-desktop storytelling technology prototypes were developed. These technologies were in part inspired by research on tangible user interfaces (Ishii and Ullmer 1997, Harrison et al. 1998, Fitzmaurice et al. 1995), ubiquitous computing (Weisner 1991) and augmented environments (Wellner et al. 1993), and made heavy use of radio frequency identification (RFID) tagging (Want et al. 1999).

A number of brainstorming sessions were held to generate ideas for such tangible designs. Children and adults were asked to build low-tech prototypes of "storytelling machines" together, machines that could be used as tools for authoring and re-telling of stories. This provided a number of interesting ideas and some of them were chosen for implementation. The resulting prototypes were brought back to the school for further refinement. These included the *Story Die*, the *Story Sofa* and the *Story Feet*.

The original idea for the *Story Die* was to associate a story with each side of a large die. When the die was placed into a special *Story Owl*, the owl would read the story associated with the upper side of the dice (figure 9).

Figure 9. *Story Die* and *Story Owl*.

Each die was implemented as a cardboard box with one hidden RFID tag attached to each side. When the die was placed on a tag reader, different forms of multimedia could be associated with the upwards-facing side. The media included sounds and *KidPad* hyperlink endpoints. Such a die was used at a public KidStory presentation in an improvised performance of a variant of *Little Red Riding Hood*, that the children had written. The children threw the die to randomly select one of a number of pre-written scenes. The *KidPad* image associated with the scene was projected onto a white background screen and adults and children then acted out the scene (figure 10).

Figure 10. The KidStory version of *Little Red Riding Hood*.

The rationale and design of the *Story Sofa* and the *Story Feet* are similar and originated from ideas that appeared independently in two different child groups. The initial concept was that sitting on the sofa or standing on a pair of feet would transport the person to a different location or story world. In practice, this was implemented by placing weight sensors in a sofa and underneath a drawing of a pair of feet (figure 11). When persons sat on the three seats of the sofa in different combinations, different scenes (images and sounds) would be projected onto a screen. The feet worked similarly.

Figure 11. Tangible devices for navigating a narrative space: feet and sofa.

The project's third year involved the combination of designs developed during the two previous years into room-sized storytelling assemblies. One of these was called the *KidStoryRoom* and had a "stage" (positioned next to a wall), and a "backdrop": a computer projector displaying *KidPad* on the wall behind the stage. Through the use of RFID tags, characters and objects drawn in *KidPad* could be associated with physical props. By positioning the prop on the stage, the corresponding *KidPad* object or character would appear in the backdrop image. Recorded sounds could also be associated with props in a similar fashion. The assembly was used by the KidStory children to perform a story for their parents and siblings at a KidStory "fair", a meeting hosted by the school where the outcomes of the project were showcased (figure 12).

Figure 12. Showcasing tools developed during the final year of KidStory.

In my opinion, the KidStory project was extremely successful. It provided a number of different in-depth descriptions of cooperative design work with school children; work that resulted in a large amount of quite sophisticated storytelling technology. The project also carried out a number of studies that suggest that the children's participation in the project strengthened both their storytelling ability and their ability to think critically about technology and design (Fast and Kjellin, 2001, Druin and Fast, 2002).

Furthermore, the *KidPad* application has become very popular. One of the KidStory partner schools introduced it in their standard curriculum as a didactical tool, and hundreds of copies have been downloaded from the official website. It has also been used as a presentation tool (replacing Microsoft *PowerPoint*) and has also been presented to the public in three different exhibitions at the Museum of Science and Technology in Stockholm (*Plexus, FrITt Fram* and *Sm@rt on Tour*). One of these exhibitions (*Sm@rt on Tour*) has also been touring several European capitals and Swedish cities.

However, the project also faced numerous challenges. For example, negotiating a suitable power structure between adults and children was somewhat problematic. I believe this was due to several factors:

- Time was short.
- We sometimes had to work against already established power structures between children and teachers that were present in the school environment.
- The children we worked with were not used to providing critical feedback on designs and some of them were not comfortable with working directly with adults.
- Few of the adult researchers had previous experience with working with children.
- We had to learn how to address the children: tasks had to be presented in a very concrete and precise way, while still avoiding controlling their actions and allowing for flexibility.

As a result, we did not achieve the desired design partnership with the children until about one year into the project. We found that a crucial factor for success was that enough adults were present at each session: less than one adult per three children almost always led to difficulties.

Another project challenge was to negotiate a suitable balance between its promise of delivering innovative augmented reality and ubiquitous computing technologies, and the needs and desires of the children who were unfamiliar with such technological concepts. This issue led discussions about the amount of control the children should have over the nature and design of the technology. If the brainstorming sessions led to designs that were not part of the project's technology focus, then how was the project plan to be fulfilled? Conversely, if concerns about technology were allowed to override specific design ideas provided by different child / adult collaborations, would it still be fair to claim that the project was doing cooperative design?

I suspect that a series of technology immersions might have been helpful in introducing the new technological concepts to the children, but unfortunately the available project resources did not allow such activities. Instead, the notion of off-line elaboration was introduced. This meant that there was a risk that researchers interpreted the ideas from the school sessions incorrectly. As a result, some design concepts changed significantly when they were adapted for implementation, which at occasion would confuse the children.

The Challenges of Cooperative Design

Although I believe cooperative design can be a very useful way of initiating a dialogue between users and designers, I also think there are a number of challenges that need to be dealt with effectively in order for the communication to be truly fruitful.

First, *to what extent are users to be involved in the design process*? There does not seem to be a generally agreed-upon definition of the constituents of cooperative design, but I think Bennett and Karat provide a useful characterization of design partnership when they claim that it is a *strategy to achieve higher performance and/or lower costs through joint, mutually-dependent action of independent individuals*. Such partnerships are characterized by shared goals, predisposition of trust, distinctive competency and resources, shared knowledge and mutual benefits (Bennett and Karat, 1994). Perhaps the most important challenge of any cooperative design project is to negotiate a suitable balance between contributions from different members of the design team. It also appears to be important that the facilitators of the cooperative design process give careful consideration of how to deal with possible discrepancies between users' expressed needs and the technology being introduced.

Second, there is the issue of *user representation*. In many of the original Scandinavian projects, the researchers worked directly with the persons who would use the resulting technologies, whereas in other cases, such as Allison Druin's *SearchKids* project (http://www.cs.umd.edu/hcil/kiddesign/searchkids.shtml), and this licentiate project, the researchers work with user representatives. These representatives are (implicitly or explicitly) assumed to share at least some needs and goals of a larger target user group. However, when working with representatives, there is always a risk that the technologies being developed do not match the desires of the group the design team represents. There is also the question of *when and how user representatives develop into designers*. For example, Druin's intergenerational design team worked together regularly over a period of several years (Druin, 1999b). As the children learn more about technology and design methodology, they in essence become designers. To what extent this role development influences the ability for these children to remain "true" user representatives does not seem to have been investigated.

Third, there are the merits and drawbacks of *action research*. In action-oriented projects, one explicit research goal is usually to achieve a certain change in a process or practice (in the Scandinavian projects this change was frequently related to one or several workplaces). In many forms of science, however, the role of the researcher is passive in nature: the goal is to acquire objective knowledge through observation rather than to actively influence the process being observed (Wallén, 1996). Apart from the philosophical/scientific issues raised by action research methods, there is also the question of *whose goals the researcher really represents*. Do the users actually want and need the proposed changes or is the researcher attempting to implement a personal agenda (cf. Clement and Van den Besselaar, 1993)?

Fourth, there is the issue of *sustainability*: few cooperative design projects aiming at permanent change seem to have been successful in achieving such a change. Thus, if the goal is to establish a continuing user influence over technology design, some thought must be given to how to keep the process alive after the researchers leave the workplace or school.

In KidStory, we did not enter the schools with an agenda of establishing a sustainable cooperative design process (although to a certain extent, we did achieve sustainability with respect to appropriation of the tools we developed). Furthermore, we only worked with children whose parents had given their consent, and the children themselves seemed to appreciate the opportunity to influence the design of technologies provided for their benefit. However, our presence certainly had an influence on the children and their school environment. Had this influence been felt to be negative rather than positive, the project's design and execution might have been put into question.

I shall return to how these issues relate to the living exhibition concept in chapter eight. The next chapter describes the design and implementation of my case study museum installation: *The Well of Inventions.*

CHAPTER 5

THE WELL OF INVENTIONS

This chapter describes *The Well of Inventions*, a temporary installation at the Museum of Science and Technology in Stockholm. Its design represents an attempt at combining a novel interaction technique with a constructivist epistemology and the usage of modern technologies, within the limitations of a tight budget and time schedule.

The Well of Inventions can be seen as an evolution of *ToneTable*, an installation designed and implemented by SHAPE project participants. SHAPE is part of the European Union's IST/Disappearing Computer initiative and is devoted to understanding, developing and evaluating room-sized assemblies of hybrid, mixed reality artefacts in public places. The project defines hybrid artefacts as objects that exhibit physical and digital features and can exist in both physical and digital worlds. Such objects combine interactive visual (computer graphical and video) and sonic (music, recordings and live sound) material with physically present manipulable devices.

ToneTable

At the outset of the SHAPE project, the different partner institutions hosted a number of start-up workshops. The purpose of these workshops was to develop a mutual understanding within the project of the perspectives, backgrounds, and contributions of all project partners, as well as developing technology demonstrations that explored aspects of the hybrid artefact concept. The second workshop, hosted by The Centre for User Oriented IT Design (CID) in February 2001, was devoted to the creation of an artefact, *ToneTable*, which embodied some of the key features the project is interested in. The starting point for the discussions was the idea of an environment with a table in its centre with a surrounding multi-speaker array, where activities at the table would influence both computer graphics projected onto the table surface and the mixing and spatialisation of sound emitted from the loudspeakers (figure 13). Thus, the display surface and the sound environment would be the main ways in which participants would encounter our artefact: the supporting computer technology (workstations, keyboards, monitors) would be hidden. For reasons of simplicity, we decided to use trackball devices for the user/surface interaction rather than to attempt to follow the users' gestures through video-based tracking or through a touch-screen interface. We positioned one trackball at the centre of each side of the table, which allowed up to four users to interact with the application simultaneously.

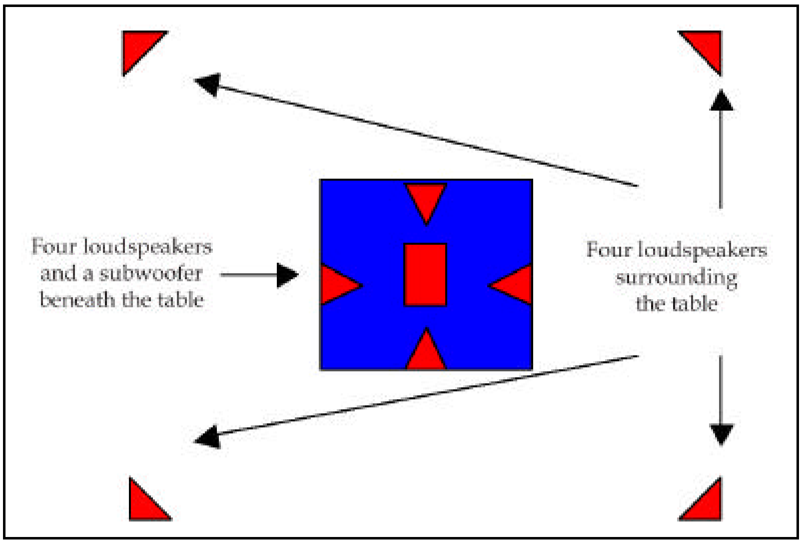

Figure 13. Spatial layout of the *ToneTable* installation.

The workshop took place over five days only. Therefore, we decided to avoid time-consuming development of detailed content by allowing the application to be abstract in nature. As a result, how visitors interacted with the installation became one of our foci. This led to the development of the concept of *collaborative interaction through a shared virtual medium*. That is, we envisioned that the users would interact with a virtual environment rendered on the table's surface by manipulating a virtual medium such as a fluid surface. By carefully designing the dynamics of this medium to respond in various ways, collaborative activity could be supported. This approach avoided switching interaction medium or mode to support collaboration, i.e., the users did not have to do different things or use new technical features in order to collaborate. In contrast, the cooperation encouragement features developed for *KidPad* by the KidStory project change the behaviour of the application's tools when collaboration takes place (Benford et al., 2000). With *ToneTable*, however, the interaction mechanism remains the same whether collaboration takes place or not.

Before the workshop, we had access to a number of different sound and graphics algorithms, including a sound spatialisation algorithm and a watery surface animation I had written. Thus, we decided to develop our virtual medium through a water metaphor. Figure 14 shows a snapshot of the resulting table projection graphics.

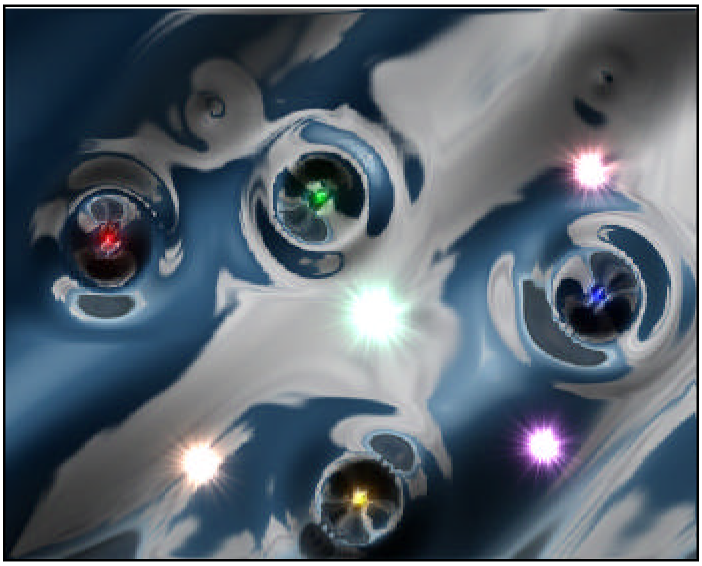

Figure 14. *ToneTable* graphics.

Because we wanted to encourage collaboration between several users interacting simultaneously at the table, we attempted to design the application in such a way that individuals acting alone would gain some benefit from their activity, but that combined collaborative efforts of two or more users would enable features that would otherwise be difficult to obtain. Moving within the virtual medium would produce ripples radiating out from a position given each trackball. The superposition of two trackball positions yielded ripples with a summed magnitude. Following elementary wave mechanics, sometimes these ripples would cancel and sometimes they would reinforce, producing a combined wave of greater magnitude than either participant alone could produce. The behaviours of the floating objects were influenced by the amount of virtual force they experienced: smaller amounts of force would move the objects away from the trackball positions (i.e., the objects "floated" on the surface waves), while a large amount of force (as produced by two or more ripples) would send the objects into a circular orbit. Apart from producing a new visual feature, the orbiting also strengthened the impression of spatial movement of the corresponding object sound.

ToneTable was demonstrated publicly on the final day of the workshop to CID/KTH employees (figure 15) and was also presented at the Connect Computer Expo in Stockholm in April 2001. Although these public displays raised some issues regarding the legibility of the sounds and the effort required to obtain the orbiting behaviour, the response was almost exclusively of a positive nature (Bowers, 2001).

Figure 15. Users interacting with *ToneTable*.

In spite of its simplicity, *ToneTable* provided the SHAPE project with a number of interesting areas for further exploration. It introduced the concept of collaboration through a shared virtual medium and it successfully integrated an interactive graphical display with spatialised sound. The trackballs turned out to be a much more expressive device than we had anticipated: our visitors used at least six different types of gestures to interact with the watery surface, including flicking, circular rubbings and careful positioning using the index finger. It was also a very straightforward application to use: no special instruction or descriptive text was necessary to begin using it. These were features we wanted to retain in our future work.

The Design and Production of The Well of Inventions

The living exhibitions are arguably the most important feature of the SHAPE project. These exhibitions are public displays that are used both as the focus of research and as a way of exhibiting the results of that research. In the original project plan, the Museum of Science and Technology in Stockholm was intended as the host for the first living exhibition. However, for budgetary reasons, the location was changed to Nottingham Castle. In order to compensate the Stockholm museum for the cancellation of the exhibition, the project decided to invest resources in a production of a smaller installation in Stockholm that would inform the design of the larger exhibition in Nottingham. This installation became *The Well of Inventions*. My role was to manage the production and actively drive the design process.

Although the Museum initially wanted *ToneTable* itself to be exhibited, the SHAPE project participants felt that it was important to develop the concepts introduced by *ToneTable* through the addition of more museum-specific content. We also wanted to make use of more advanced technologies to drive the interactive graphics and sound.

We felt that it was important that the installation design was inspired by current research on museum learning. As I describe in chapter three, much of this literature is influenced by different kinds of constructivist models of learning. It emphasizes aspects such as multiple learning modalities, opportunities for visitors to compare and contrast familiar concepts with new information and the presentation of novel perspectives on familiar objects. The research on *flow* suggests that visitors are likely to learn from activities that have clear goals and appropriate rules, provide immediate results and unambiguous feedback, provide a sense of discovery and where opportunities for action in a situation are in balance with the visitors' abilities (Csikszentmihalyi and Hermanson, 1994). This suggested that a *ToneTable*-like environment with a less abstract content might be educationally suitable for the installation.

However, I felt that it was important to attempt to push the envelope a little with regards to the educational aspects of the installation. Instead of evolving *ToneTable* into something more "museum-like" with, say, a hierarchically oriented narrative, *The Well of Inventions* instead represents an attempt at *providing an arena for discussion and communication*. As I describe in chapter two, the basic unit of epistemology in socio-cultural constructivism is the activity of communication. In my interpretation, this means that socio-cultural constructivists view learning as being closely connected to different forms of communication. In other words, dialogue between people may lead to opportunities for learning. This inspired the design of *The Well of Inventions* in the sense that its design aims to *provide an experience that encourages communication (verbal or non-verbal) and collaboration between visitors (or visitors and museum staff)*. Thus, the only explicit epistemological assumption inherent in the design is that communication between people may lead to opportunities for learning. Determining the exact nature of the knowledge thus acquired would require the choice of a more explicit model of museum learning and an in-depth long-term visitor study. Such a study, unfortunately, was judged to be beyond the scope of this licentiate project. Thus, for the purposes of evaluating the educational outcome of *The Well of Inventions*, I settled for determining if the installation encourages communication and, if discussions do take place, what the topics are.

As I mentioned in chapter three, I believe that one of the most important feature of museums like the Museum of Science and Technology is their collections of interesting real-life objects. In addition, new technologies have the ability to present these objects in new and interesting ways, which can facilitate learning (Hooper-Greenhill, 1994, p. 23). Thus, I wanted our installation encourage discussions of items in the museum's collections in some way. Among the most well known objects in the museum's possession is the *Mechanical Alphabet* of Christopher Polhem (1661-1751). Polhem was one of Sweden's greatest inventors and engineer and he made significant contributions to such diverse fields as mining, agriculture, water canals and weapons of war (Nyström, 1985). His Alphabet consists of a large number of wooden models that illustrate how to mechanically convert between different forms of movement (e.g., rotational motion into lateral motion). Unfortunately, it did not seem to integrate very well with the idea of a shared virtual surface. Therefore, in order to gather additional topic suggestions, I composed an email to the museum staff (including educators, guides and curators), asking what they felt were the most interesting aspects of the museum's collections. Many of the replies indicated the Machine Hall as one of the museum's most prominent features. This Hall is a large hangar-like gallery containing steam engines, bicycles, airplanes and cars (figure 16).

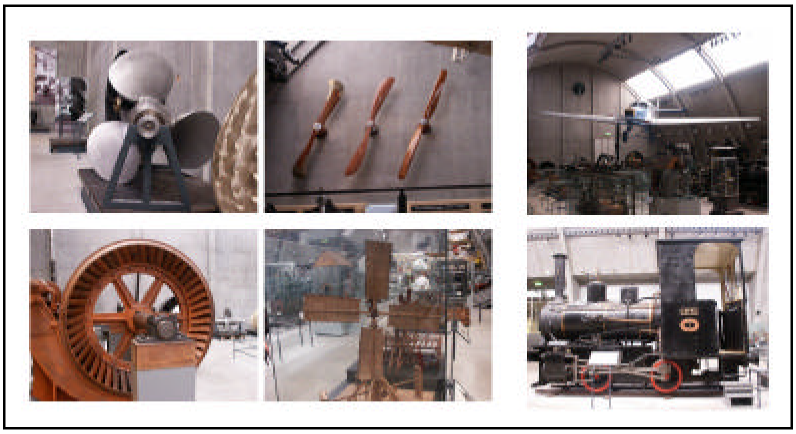

Figure 16. The Machine Hall at the Museum of Science and Technology.

I discovered that many of the objects and machines in the Hall share a common trait: they make use of propellers and/or turbines in different ways. Furthermore, the Hall also contains a number of different such turbines and propellers. This led to my choice of topic for the installation: *the relationship between turbines and propellers and the medium in which they are used*. This topic has the advantage of being communicable to a large range of age groups: with younger children the discussion could be about the usage of turbines and propellers in different forms of machinery, while for adolescents and adults the discussion might be about mechanics or the conversion between different types of energy. It could also readily serve as an introduction into more advanced topics such as that of sustainable energy sources.

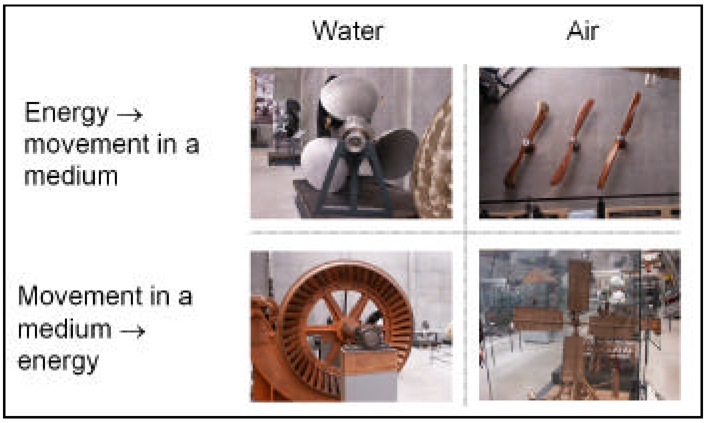

Figure 17. Relationship between propellers and turbines.

At a fundamental conceptual level, a propeller represents a way of converting energy into movement in a certain medium. Conversely, a turbine converts movement in a certain medium into energy. In the Machine Hall, there are representations of such propellers and turbines for both air and water (figure 17 above). Thus, there is a close correspondence between propellers for air and water, and a parallel correspondence exists between water turbines and windmill wings. I wanted these correspondences to be expressed through the installation in an implicit way. Therefore, my collaborators and I settled on the following design:

The installation contains three different simulations: 1) a simulation of a turbulent fluid, 2) a simulation of airflow and 3) a simulation of the boundary between air and water (i.e., a water surface). A number of boat propellers and turbines are floating beneath the water surface, moving with the velocity of the fluid (figure 18). When their velocity increases, so does their buoyancy, so that they move towards the water surface. As an object breaks through, it is visually transformed into its corresponding object for air (i.e., a boat propeller is transformed into an airplane propeller, while a turbine is transformed into a set of windmill wings). Above the water surface, the objects move with the velocity of the airflow. Here, their buoyancy is also connected to velocity, so that when an object slows down, it sinks towards the water surface and may again break through. When this happens, it is again transformed back to its original appearance.

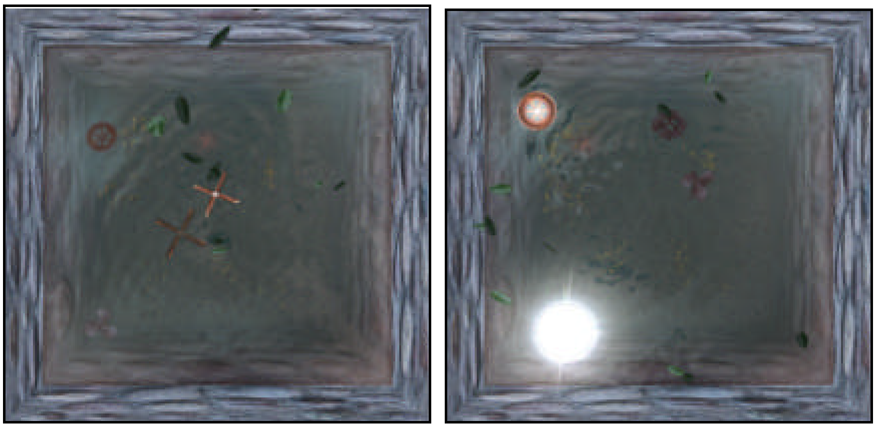

Figure 18. The graphics of *The Well of Inventions*.

As with *ToneTable*, the visitors influence the movement of the objects indirectly through the manipulation of a shared virtual medium (or, to be precise, through two superimposed virtual media). Through collaboration, they can more easily inject force into the simulations and more readily push the objects through the water surface. Similar to *ToneTable*, a graphical representation of the simulations is projected onto a table, into which four trackballs have been fitted. Each trackball has an associated cursor that follows the trackball movement. As the cursors move, they inject force into the simulations. Each object has an associated sound that is spatialised in correspondence to the object's position in the graphical display. The velocity fields of the water and air are indicated indirectly through underwater weeds and leaves, respectively.

In order to implicitly suggest that the installation could serve as a foundation of discussions of higher-level subjects, I also decided to introduce images of machinery where propellers and turbines are used. These images are subtly reflected by the simulated water surface and constitute the inventions referred to in the title of the installation.

Similar to *ToneTable*, the design of *The Well of Inventions* includes features to encourage collaboration:

- If the motion of different trackballs is coordinated, the water velocity field becomes more homogenous. This causes the propeller and turbine objects to move faster, thus making them easier to push through the surface.
- If two trackball cursors are positioned close together for an extended period of time, the viscosity of the water surface is influenced locally around the cursors in such a way that the surface appears to become "sticky".
- The clarity of the invention reflections in the water surface is inversely proportional to the sum of distances between the cursors, so that the reflections become clearer when the cursors are brought together.

The physical environment appointed for *The Well of Inventions* by the Museum (figure 19) presented both challenges and opportunities. It is part of the Museum's science centre gallery and is situated directly to the left of the entrance. It consists of a smaller rectangular area adjacent to a larger, roughly oval area. This second area contains a semi-circular platform that was built by the museum for another exhibition. Since the platform could not be moved, it had to be incorporated into the installation design. Fortunately, it is somewhat reminiscent of an amphitheatre, which seemed to reinforce the focus on communication and discussion. Thus, the projection table was positioned in front of the platform and the machinery used to operate it was hidden behind the platform, close to the back wall.

The rectangular area that acts as the antechamber to the installation contains four computer monitors that each displays a copy of a slideshow with additional information about the installation. Because the main themes of *The Well of Inventions* is implicit in its sound and graphics design, they might not be (and indeed, should not) be readily apparent to visitors. By perusing the additional information presented in the slideshows, visitors are given an opportunity to scaffold their interaction with the installation, or use the information as a foundation for reflection about their experience with the installation.

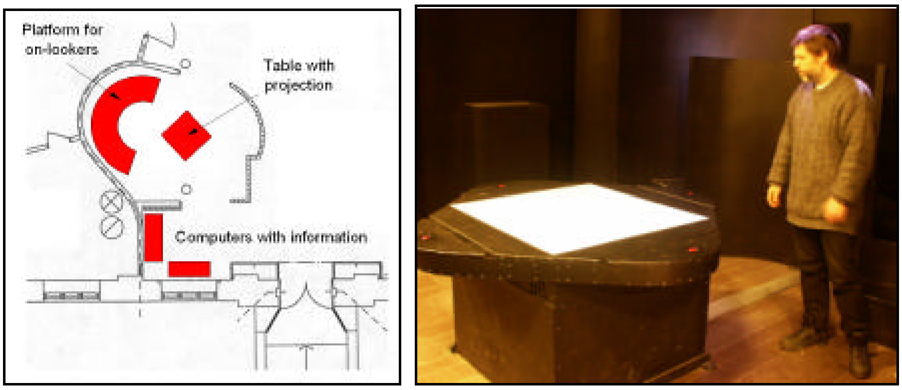

Figure 19. Physical design of *The Well of Inventions*.

The production process of *The Well of Inventions* was somewhat different from the typical approach to museum exhibition production I describe in chapter three. Relative to typical museum exhibition productions, *The Well of Inventions* is a small and rather inexpensive installation. It took about two months to produce and the total cost of the equipment used was roughly 100.000 SEK (approx. £7.500). Four persons were involved continuously throughout the production (of which I was one), and two of the Museum's technicians contributed at various occasions. The construction of the table and the painting of the installation's physical environment were subcontracted to two different companies. The Museum was responsible for the installation's lighting.

Another difference is the anticipation of cooperative design: the main goal was not to produce a finished product at the time of opening. Rather, the aim was to provide something that was finished enough to be presented to the public, but was open to modification in response to visitor feedback (I describe how we obtained such feedback in the next chapter). Because of the time constraints involved, there was not enough time to initiate a design partnership between visitor representatives and museum staff that could provide a design proposal. Instead, the production of *The Well of Inventions* mirrored the approach that was used in KidStory to evolve the *KidPad* and *Klump* applications.

Another difference between *The Well of Inventions* and most museum productions is that its content was developed and modified throughout the production process rather than decided upon before the implementation phase begun. Because the physical manifestation of the installation was determined to a large extent by our appointed area of the Museum gallery, the installation content was represented mainly through computer software. Thus, the manifestation of the content could relatively easily be adapted to ideas and suggestions provided by the project participants. I believe this kind of flexibility is important if cooperative design of exhibitions is to be achieved (this is an issue I will return to in the next chapter and in chapter seven).

The Technology of The Well of Inventions

The Well of Inventions is relatively technology-intensive. Apart from the four trackballs, it contains no mechanical interaction features whatsoever – most of its content is presented through audiovisual renderings. I was not involved in developing the technology that produces the sounds for the installation – further information can be found in (Bowers, 2001) – so in this text I shall focus on the parts I was responsible for: support for multiple interaction devices and the graphics.

Four trackballs (off-the-shelf USB devices) have been fitted into the table (figure 20). They are connected to a PC running *Windows 98* through a standard USB hub. The movement of the trackballs (which are recognized as mice by *Windows*) is differentiated through the use of the *MID* (Multiple Input Devices) package (Hourcade and Bederson, 1999). This package is a tool that can be accessed from the Java programming language, and sends a message each time one of the trackballs moves. Its output is the trackball identity together with a cursor position.

Figure 20. Trackball fitted into a corner of the table.

The cursor positions obtained by the trackball PC are sent across a network cable to the graphics machine, which is a Silicon Graphics 330 workstation, a PC-based computer running *Linux*. The graphics machine runs a software application that consists of three main components: 1) networking, 2) simulations and 3) rendering.

The trackball data is received by the networking code and is converted to a suitable format. The result is then fed into the simulation code and the rendering code. The simulation component runs three concurrent two-dimensional simulations: 1) water wave dispersion, 2) turbulent fluid flow and 3) linear approximation of airflow.

The wave dispersion algorithm is based on (Kass and Miller, 1990). This algorithm models a body of water as a two-dimensional height field, i.e., it computes the water depth at different points for each simulation time step. I modified the algorithm so that its viscosity parameter can assume different values across the surface. By modifying the viscosity locally, the water surface can be made to appear "sticky" in one part of the display at the same time as having a "flowing" feel in a different part. The output of the wave simulation is a water surface height at each point on a two-dimensional regular grid. The grid contains 900 points (30x30). When a trackball is moved, some water is added to the simulation at the new trackball position. This displacement of the water surface is then diffused as waves.

The turbulent fluid beneath the surface is approximated by an independent two-dimensional simulation (it does not exchange data with the wave dispersion simulation). The simulation is based on Jos Stam's

Navier-Stokes equation solver, which uses the Fast Fourier Transform to force the water velocity field to become mass conserving (Stam, 2001). The output of this simulation is the water velocity at points on a two-dimensional regular grid (figure 21). The grid size used in *The Well of Inventions* is 10x10 points. When a trackball cursor is moved along a certain direction, a force proportional to the speed of the movement and with the same direction is added to the fluid along the cursor's path.

As I mentioned above, the fluid's velocity is not indicated directly as in figure 21. Instead, it is shown implicitly through a number of weeds that are attached to the bottom of the Well. These weeds are modelled as particle / spring systems (Witkin, 1997).

Figure 21. Simulation of turbulent water.

The airflow simulation is also independent of the wave dispersion simulation and is an implementation of the algorithm presented in (Wejchert and Haumann, 1991). This algorithm sums a number of linear flow primitives (e.g., sources, sinks, uniform flows and vortices) to produce a complex velocity field (figure 22). The field velocity at a given point is obtained by evaluating the sum at that point. A combination of a vortex and a sink is positioned above each trackball cursor. Thus, trackball movement reconfigures the airflow. Similar to the fluid beneath the water surface, the airflow is indicated indirectly, in this case through a number of leaves that move with the flow. The algorithm for moving the leaves is also described in (Wejchert and Haumann, 1991).

Figure 22. Airflow simulation.

The motion of the propeller and turbine objects that also appear in the display is governed by rigid body dynamics (Baraff, 1997). The force exerted on the objects is proportional to the underwater velocity field and airflow. In addition, a non-penetration constraint is enforced for the objects. The algorithm I use to detect collisions and respond to them is a modification of the algorithm described in (Dingliana and O'Sullivan, 2000).

The final component of the graphics application is the rendering. This component uses data from the trackballs and the three simulations to produce an image. The image consists of a number of layers. The bottommost layer simulates refraction of the bottom of the well and uses the algorithm described in (Vlachos and Mitchell, 2000). Since this algorithm only handles static imagery (i.e., it can only display the bottom of the well itself, not objects subsumed in the water), I had to develop an extension to the algorithm in order to account for moving objects. Images of such objects are divided into a number of connected sub-images and each corner of these sub-images is passed through the refraction computation. The result is a distorted image that approximates refraction.

A layer representing the reflections in the water is added to the refraction image. The reflections are computed using dual paraboloid mapping (Heidrich and Seidel, 1998). Before the reflection image is used, the leaves and the ghostly images of inventions are copied into it at appropriate positions. Objects above the water surface are rendered as standard textured polygons.

According to the Museum staff, *The Well of Inventions* has required very little maintenance, given its heavy use of technology: between May 2002 and April 2003, two projector lamps have been replaced and three trackballs have been refitted into the table. The weakest part of the installation seems to be the *Windows 98* machine that reads data from the four trackballs. This machine crashes a couple of times each week, necessitating a reboot of the installation. However, members of the Museum staff have informed me that this is infrequent compared to their own *Windows*-based exhibits.

Several design elements present in *The Well of Inventions* have been carried through to SHAPE's first living exhibition at Nottingham Castle (Fraser et al., 2003). This exhibition invites visitors to assemble a sense of a number of periods in the history of the Castle through the use of a number of technologies, including the *Sandpit* (figure 23) where images related to the Castle can be unearthed through "digging" in virtual sand. Here, I used a simulation of eroded terrains (Musgrave et al., 1989) to compute the depth of the sand. To give an impression that the sand moved, I modulated the sand texture with a special filter (Freeman et al. 1991). When the phase of this filter is cycled, the texture appears to move.

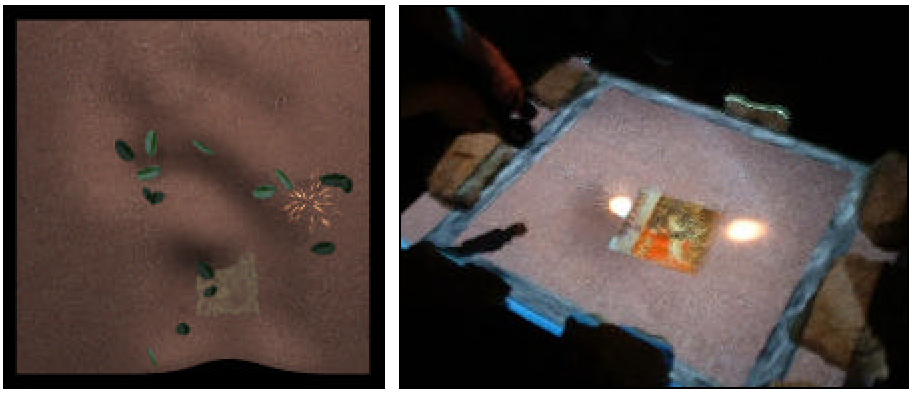

Figure 23. The SHAPE *Sandpit.*

At the time of writing, *The Well of Inventions* has been on display for almost a year. As described above, it has been successful from a technical point of view, but determining whether it met its educational goals required an evaluation study. This study is the topic of the next chapter.

CHAPTER 6

EVALUATION OF THE WELL OF INVENTIONS

In the first chapter of this text, I presented the three research questions I have focused on in this work. To recapitulate:

1. As the first stage of the development of a cooperative design method for the museum domain, I attempted to adopt a technology evaluation methodology from cooperative design. How was this done and was the attempt successful?
2. The design of *The Well of Inventions* represents an attempt providing an arena for discussions of dynamics. Was the attempt successful?
3. Cooperative design often involves the development of prototypes. For exhibitions like *The Well of Inventions*, what features of the technology are necessary to be able to use it as a prototyping framework?

In this chapter, I shall examine these questions in greater detail and give an account of the methodology I have used in my attempt to answer them.

I believe the numerous ways in which the KidStory project collected evaluation data was one of its main strengths. Because the data was so varied (e.g., contextual inquiry, journals, observations and brainstorming) it contained both strong emerging themes (often of a nature that described problems with the technology) and design suggestions (that could be used to remedy such problems and / or to introduce new functionality). Therefore, I wanted to see if it was possible to develop an evaluation method for *The Well of Inventions* that would yield a similar richness.

During my visit in Maryland, we occasionally used a version of the future workshop (see chapter four) to quickly evaluate existing technologies. The design team members were allowed to interact with the technology. Then, they were asked to write down three good aspects and three bad aspects of the technology on Post-It notes and bring them to the facilitator. The facilitator would group notes with similar content on a whiteboard. When all notes had been positioned, the facilitator would summarise the content of each group under a heading. These headings were then used as the basis for small-group discussions of possible modifications of the technology. The discussions were similar in nature to those of the future workshop, but because the children knew very little about software and hardware design (the topics had been discussed but, naturally, the children had no direct experience with such activities), the implementation discussion involved only researchers and was held after the main session had ended.

I wanted to use a similar method to evaluate *The Well of Inventions*, but with the modification that the visitor representatives were to develop groupings and categories for the notes themselves. However, because it was not certain that such an evaluation would provide the richness I sought, I also decided to attempt to triangulate the workshop data with data from observations and interviews. Another reason was that ethnomethodologies and interviews are generally accepted data acquisition methods within the research field of Human-Computer Interaction. Thus, I was interested to see whether the additional data would support or contradict the workshop results. If the results were supported, it would seem reasonable to conclude that such workshops are possible to utilize in the evaluation of museum exhibitions.

As I mentioned in the previous chapter, the evaluation of *The Well of Inventions* intentionally did not focus on the nature of the knowledge visitors acquired while interacting with the installation. The design of *The Well of Inventions* is largely based on the assumption that discussion and collaboration may have a positive influence on learning. An in-depth long-term study of the specific nature of the knowledge acquired was, unfortunately, beyond the available resources of this licentiate project, but it is an issue I intend to return to in my doctoral thesis. Thus, the educational aspects of the evaluation of *The Well of Inventions* deal only with the occurrence and nature of discussions, and collaboration between visitors.

Observations

We* observed visitors on-site for a total of approximately 12 hours, spread across 2 days. During this time, about 130 visitors approached *The Well of Inventions*. The dwell times varied widely from a few seconds to more than 10 minutes (the longest dwell time we observed was about 30 minutes). Typically, visitors would stay for at least a minute if they "got hooked".

A large majority of the visitors that entered the exhibition area also interacted with the exhibition, although a few groups seemed to be unable to spot the trackballs. Of those that interacted with the exhibition, about 20% discovered that it is possible to push the underwater objects through the water surface. It is unclear whether any visitor observed that the objects in the installation are virtual replicas of objects in the Museum's Machine Hall.

Most visitors that interacted with the exhibition went through the following stages (a majority of them left the room before all stages had been completed):

1. A visitor moves a trackball and discovers the association between trackballs and cursors. Alternatively, a visitor moves a trackball and acknowledges the corresponding splashing sound.
2. Visitors discover that they can push the objects through the water surface.
3. Visitors co-operate to push objects through the water surface and keep them in the air.
4. Visitors discover that the water surface becomes "sticky" when two or more cursors are placed close together for an extended period of time.
5. The visitors continue to work (focused) in silence until they leave.

It was common for one visitor to discover a feature and demonstrate to other visitors how to use it. On several occasions, children would run off to fetch peers or parents from other parts of the museum, to whom they would then show the feature they had discovered.

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* The observations were carried out by Sten-Olof Hellström, Helena Tobiasson and myself. Helena and Sten-Olof also assisted me in hosting the evaluation workshops.

Children in the ages 10-13 seemed to be more interested in the exhibition than other age groups. These children typically viewed the exhibition as a game: they often (quite enthusiastically) referred to the transformation of objects moving through the water surface as "a kill". Adults showed the least amount of interest, and would often encourage their children to leave the exhibition while the children were still engaged at the table. Young children were often fascinated by the graphical animation of the water surface and often put their fingers onto the display to "feel" the water.

Many of the visitors that entered the space as a group discussed the purpose of the installation and the nature of the interaction. They also verbally negotiated the meaning and underlying rules of the motion of the objects. However, the discussions rarely focused on dynamics and the relation between propellers and turbines. Furthermore, few visitors read the text on the computer screens in the antechamber. Occasionally, adult visitors would go back to the antechamber to read the texts after having tried interacting with the installation, but this happened very rarely.

Some groups also spent extended amounts of time exploring the physical features of the room, such as climbing the platform or search for the hidden control room.

Interviews

I interviewed two staff members of the Museum of Science and Technology: Rune Svensson and Mariana Back. The interviews were semi-structured. Rune is responsible for the technology of the exhibits at the Museum's science centre gallery. He also works in project management groups for temporary exhibitions and is responsible for the maintenance of the museum's permanent exhibitions. Mariana is the director of the science centre department and has been responsible for a large number of previous productions, ranging from small, temporary, room-sized installations to large, semi-permanent exhibitions.

Rune estimates that *The Well of Inventions* is technically not less stable than any other exhibition, although it is more complex to restart when it does crash. Thus, he would appreciate an easier procedure for starting up and shutting down. The ordinary museum personnel and exhibition docents (i.e., educational staff) have learned how to restart the installation when it crashes and they can do this without assistance. However, during the summer vacations (i.e., June through July 2002), temporary exhibition hosts were employed that do not have this knowledge. As a result, they had to contact ordinary personnel or SHAPE project members for assistance.

When asked whether it is easier or more difficult to work with the SHAPE project than with a regular exhibition production team, Rune replied that working with SHAPE has been more difficult than usual. He thinks that the educational goals and the main points of the exhibition are difficult to comprehend, and that this is directly related to the lack of printed texts and descriptions at the table. Because of this, it is somewhat frustrating to not be able to directly influence decisions regarding such matters, as would be the case for an exhibition produced in-house. He also believes that the trackballs are hard to spot. Many people who may not have previous experience with trackballs will not understand that the exhibition is interactive. Therefore, a sign that clearly describes how the trackballs are used would be useful, although finding a suitable placement and design for it might be difficult.

From a technical perspective, Rune does not think that there has been a major difference between working with SHAPE and other external exhibition producers. As a technician, he constantly has to improvise and try to accommodate the needs of each particular exhibition, and these needs are unique for each project. At the Museum of Science and Technology, there is a blend of people that prefer the traditional exhibition designs and people who likes to work with new technologies. Personally, he feels that it is vital for the Museum to have a healthy mix between the two kinds of exhibition, and that there should be a designated gallery for new and radical projects.

Mariana feels that the SHAPE project initially was unclear about their goals for *The Well of Inventions*. As a result, some logistics issues arose for the museum. However, she thinks that from the time the installation's project plan was finalised, things have been running very smoothly.

Mariana sees herself as co-producer of the exhibition rather than as an advisor to SHAPE, and she feels that her views, suggestions and feedback are reflected in the finished design of the exhibition. The main difference between *The Well of Inventions* project and other museum exhibition projects she has produced, is that the content for *The Well of Inventions* was developed during its production. Typically, exhibition projects are initiated by an educator who wants to convey a specific message or highlight a particular relationship between objects. Then, a form and design is settled upon. With *The Well of Inventions*, design and content were developed simultaneously. She also thinks that another difference is that SHAPE has provided most of the equipment used in the production. In her experience, *The Well of Inventions* makes relatively heavy use of technology for such a small installation, and from a technical perspective it has performed remarkably well.

She believes that the installation has a strong ability to attract people, even children that would otherwise be hard to encourage to stay and concentrate. Most visitors express a curiosity and want to know more. However, because of the lack of written information, many visitors also leave quickly. She believes this is more common among adults than children – it is not uncommon for parents to lose interest first and take their children away with them. Younger children seem to be attracted to the visuals and the sound – they typically look at the images rather than at their peers while interacting – whereas teenagers communicate with each other and try to discover the mechanisms of the exhibition together.

Mariana thinks that *The Well of Inventions* is different from most museum exhibitions. It looks and sounds exciting and is more of an art installation than a traditional exhibition. Its small size and narrow focus is a positive aspect. Typically, exhibitions will try to get across a theme or point out relationships between objects. *The Well of Inventions*, however, is as much an art piece as it is a game: it is not obvious, that is why it is exciting.

She believes that heavy use of technology can be very beneficial for exhibitions, but that careful design and implementation of such technologies is crucial for the educational outcome. She doubts that *The Well of Inventions*, as it is, has such an outcome. Its value is more as an indication of the possibilities of technology than as a way of presenting content. Using image material from the Museum's permanent exhibitions is not without benefit, though. There is a point in depicting old pieces of machinery through modern computer technology: it can raise an interest in the real objects. However, she does not think this connection is strong enough in *The Well of Inventions*; the corresponding objects in the Machine Hall, although physically large, are not typically spotted by visitors. In fact, she herself made the connection "backwards": after having seen a particular object in *The Well of Inventions*, she realised afterwards that it was also present in the Machine Hall, even though she has worked at the museum for a number of years! She feels that on its own, *The Well of Inventions* does not communicate its educational themes well enough. However, with a knowledgeable docent present that can initiate discussions and answer questions, the exhibition has a larger educational potential.

I also conducted two short semi-structured visitor interviews, one with an unaccompanied female adult and one with a two-person group: a boy around 12 years old and his mother.

The unaccompanied female thought the exhibition initially looked like fun and became curious, but then became mildly frustrated with not being able to understand what it was about. She chose to turn to the computer screens displaying the slideshow for more information. There, she learned that the sound is interactive. Still being unable to grasp the point of the exhibition, she turned to one of the museum's docents, who were unable to provide a satisfactory answer. At this time, she lost interest and moved on. When asked what she discovered when visiting the exhibition, she replied that she learned that the sound was generated in the computer before being sent to the loudspeakers (this information is provided by one of the slideshow screens).

When the boy was asked what he thought about when he interacted with the exhibition, he replied that he wondered what the exhibition was about, and how one went about interacting with it. When asked what he saw, he mentioned the waves, leaves, flowers and a wooden wheel. He discovered that interacting with the trackball would move the objects under the water surface, "I tried to chase her [pointing to his mother]". He also discovered the stickiness feature: "the water flew upward". He thought the exhibition looked good, "the water looked real", and he felt that the exhibition gave him a choice, that it was not pre-determined. His mother thought the sounds were exciting, but she did not understand what the exhibition was about. She did not blame the design of the exhibition, but rather herself: "I didn't understand it, perhaps it's because of the heat [it was very hot that day], or perhaps we entered at the wrong end?"

Evaluation Workshops

I hosted three workshops at the Museum of Science and Technology on November 20 and 26, and December 3, 2002. The first of these was organized as an open CID seminar and had about 15 adult participants. I started the workshop by allowing all participants to interact with the installation. Simultaneously, I gave a brief talk outlining its main goals and summarised its implementation. At this point, we discovered that a bug in the trackball code inverted the movement of each cursor (as we shall see, this is an aspect that several of the participants commented in the evaluation). Unfortunately, I was unable to remedy this problem until after the workshop. When every participant had been given a chance to familiarise themselves with the installation, we moved to a quiet conference room (containing tables, chairs and a whiteboard) in an adjoining part of the Museum.

Here, I briefly described the workshop goals and its different stages. Then, the participants were given green and red Post-It notes and were asked to write down at least three positive aspects of the installation on the green notes (one statement per note) and at least three negative aspects on the red notes, and put them on a random location on the whiteboard. This stage took roughly fifteen minutes to complete. When all Post-It notes were positioned on the whiteboard I asked the participants to collectively attempt to group similar notes together and summarise their content in a heading. After about fifteen minutes, all notes had been accounted for.

At this point, we took a fifteen-minute break after which I asked the participants to form groups of about five persons each. I encouraged the groups to examine the whiteboard and try to think of ways in which the negative aspects of the installation could be improved while keeping the positive aspects. Each group was shown to a quiet, private area and were given about thirty minutes to discuss (figure 24). When the groups had reconvened in the conference room, we spent about thirty minutes talking about what the groups had discussed and what design suggestions they had thought of.

Figure 24. Evaluation workshop participants.

The content of the Post-It notes can be found in Appendix A. The headings for the positive aspects were:

- Cooperation
- Graphics / sound
- Realistic
- Aesthetic
- Fascinating
- Other aspects

The headings for the negative aspects were:

- Around
- Pedagogy
- Collaboration / cooperation
- Technology
- Goal?
- Realism

The first group immediately mentioned the inverted cursor movements: the interaction felt unbalanced and stressful. The audiovisual manifestation of the installation gave a mixed impression: it largely indicated a desire for realism but many individual elements were not realistic at all, which gave the installation an unbalanced appearance. The sound gave a similar impression (here, the water was felt to dominate). The group recommended a stronger coordination of the different audiovisual styles. They also felt that the rewards of interaction were too discreetly communicated and recommended introducing some chain reaction events. The collaboration aspects were also felt to be too discreet – it took some time before it became apparent what was going on. Again, the group recommended introducing more interaction elements, including additional rewards for collaboration. The room itself was felt to discourage communication – it was dark and the sound volume was quite loud. It also gave a somewhat claustrophobic impression: the group members felt that they were "channelled through" from the entrance to the exit. Furthermore, they did not think that the installation had a strong pedagogical value – it was impossible to see the implied connections to the real museum objects.

The second group echoed these pedagogical concerns and recommended adding more encouraging elements, perhaps in the form of "highlight" sounds. In particular, they felt that it was important that collaboration should have some concrete result in that it provides the solution to a problem that visitors can focus on together. Concrete suggestions included a labyrinth game, some kind of specific mission or situations where different interaction devices control different aspects of the simulation. The group recommended a science-centre oriented pedagogical approach.

The third group also focused on pedagogical issues. They felt that it was unclear what the pedagogical goal of the installation was and that it was crucial that the underlying educational idea is communicated clearly. The group suggested introducing a "thread" or a narrative to scaffold the experience; perhaps one could be allowed to control the inventions themselves at a certain point? They also encouraged us to attempt to better complement the current possibilities of the Museum. For example, the real objects that were represented in the installation could somehow be indicated or highlighted when their virtual counterparts were manipulated. Another possibility would be to move the physical objects into the installation space itself.

For the second workshop, I invited a high school class with about fifteen students and their two teachers. The session proceeded in the same manner as I have described above. The note statements can be found in appendix A. The headings associated with positive aspects were:

- The idea
- Fun
- Technology
- Insight
- Easy
- Graphics
- Sound
- Graphics and sound

The headings associated with negative aspects were:

- Plot
- Unrealistic
- The environment
- Graphics
- Sound

For the discussion phase, the participants were again divided into three groups.

The first group thought that it was hard to correlate the sounds with the graphics and recommended using a different set of sounds with a more quiet sound volume. The graphics did not really convey a sense of depth: the image felt too "shallow" to be a well, and the image resolution was too low. Another problem was that wells are often thought of as round in shape. The group also recommended using a higher-resolution back-projection device so that hands held over the surface would not cause shadowing. This might also open up the possibility of tracking visitors' hands so that it would be possible to interact directly with the projection. The physical environment was felt to be a bit too empty, which did not help to strengthen the illusion of a well. The group thus recommended adding trees, real water and similar props. They also expressed a concern with the pedagogical aspects of the installation and hypothesized that a narrative or a speaker voice pointing out important features might help.

The second group thought that the installation lacked a purpose and pointed out that more information was needed, e.g., posters with questions, guided tours, some form of introductory text and speaker comments. They also recommended adapting the installation to different target groups, perhaps through some sort of interface where visitors could enter their age. The sounds were thought to be lagging behind the graphics, which made it hard to associate graphics and sound. There was also no wind noise and the sounds were hard to recognize. The graphics cursors were hard to spot: perhaps they could leave some sort of trail? This group also thought the well was too shallow and that it should be circular in shape. Furthermore, the animated leaves moved outside the screen boundaries, which broke the illusion. The number of different kinds of activity opportunities was thought to be too small: perhaps each trackball could control a different aspect of the well?

The last group echoed the concerns of the two previous groups and recommended painting the trackballs in the same colour as their corresponding cursor in the graphics. They also thought the leaves were a too limited indicator of airflow.

The third workshop had about 30 participants, again high-school students and their teachers, and was conducted in the same manner as the previous two workshops. The contents of the Post-It notes can be found in Appendix A. The headings associated with positive aspects were:

- Graphics
- Sound
- Fun
- Cosiness
- Play yourself

The headings associated with negative aspects were:

- Purpose
- Missing
- Darkness
- To do

This time, the participants were divided into five discussion groups.

The first group felt that the installation needed clarification and recommended adding posters with instructions, questions and background information for the visitors. In addition, they thought the trackballs should be made easier to spot, and that their colour should correspond to the colour of the cursors in the display. They also felt that the technology behind the installation should be made more visible. The amphitheatre did not seem suitable for young children: it was thought to be built in such a way that would be difficult for young children to see properly when standing upon it. The group also recommended introducing some form of scoring system, e.g., one would score a point whenever an object broke through the water surface.

The second group questioned the purpose of the installation and wanted to know if we had tested it in other environments or workplaces. They recommended turning the installation into a proper game, perhaps where the goal is to get propellers to turn. Another suggestion was to use several co-situated tables with different purposes. The group recommended adding a speaker voice to explain what the purpose of the installation is while visitors are interacting with it. They also thought that it was unclear which objects were below and which were above the water surface.

The third group echoed the suggestion of adding a speaker voice, but also recommended an introductory text to appear on the projected display before the actual interaction begins. The current texts on the information screens were also thought to be inadequate: they seemed to target people with an interest in computers rather than children. Thus, instead of writing about the computers that drives the installation in the texts, the group recommended making them physically visible instead. They also recommended a "demo mode" that illustrated the interaction to approaching visitors. Another suggestion was to make the content less abstract: perhaps comparing the mechanics of propellers and turbines would make visitors understand the simulation better?

The fourth group felt that it was important to find a way to encourage people to read the information screens in the antechamber. They suggested adding a poster at the entrance of the exhibition. The current information text should be shorter but contain more background information. The group also recommended adding a secondary computer display outside the installation to show the "action" inside to people who happen to walk by.

The fifth group echoed the previous group's concerns about the information screens and recommended using a wall to more clearly separate the antechamber from the main installation area. Furthermore, they suggested colouring the trackballs so their colour corresponds to the cursors in the display. Another suggestion was to allow the visitors to choose a specific object to interact with, possibly augmented by a speaker voice that could provide further information about that object.

Analysis and Discussion

In my interpretation, the data acquired from the observations, interviews and workshops share five common themes. The first theme is that *the educational purpose of the installation is perceived as problematic or non-existing*. During our observations, visitors would frequently express a sense of puzzlement and curiosity (e.g., say things like "What's this?" or "What is it about?"). We also observed visitors discussing the purpose of the installation. Children would also frequently try to discover the "rules" of the interaction.

The purpose of the installation is also mentioned in all interviews: Rune is of the opinion that the educational goals and the main points of the exhibition are difficult to comprehend. Mariana believes that the value of the installation is more as an indication of the possibilities of technology than as a way of presenting content. The visitor interviewees expressed both frustration and puzzlement with respect to the goals of the installation.

In my interpretation, 44% of the workshop Post-It notes on negative aspects mention lack of purpose or difficulty in comprehending the purpose. All brainstorming / discussion groups (in each of the three workshops) raised pedagogical issues.

The second theme is that the *audiovisual design of the installation is largely perceived to be successful*. During the observations, young children are fascinated by the graphics and often attempt to "feel" the water.

In the interviews, Mariana mentioned that she has observed that young children seem to be attracted to the visuals and the sound – they typically look at the images rather than at their peers while interacting. From a personal point of view, she thinks the sound and graphics are exciting. Two of the three visitor interviewees mentioned sound and / or graphics as positive aspects of the installation.

In my interpretation, 51% of the workshop Post-It statements related to positive aspects are concerned with design, graphics and sound. However, some negative impressions of the design were mentioned during the brainstorming discussions. For example, during the second workshop, several of the participants felt that a well should be circular rather than rectangular in shape.

The third theme is that *many visitors perceive the installation as engaging and fun*. During the observations, we saw that pre-teen children were especially enthusiastic about the graphics and sound, and many visitors spent a large amount of time in the installation area.

In the interviews, Mariana told me that she believes that the installation has a strong ability to attract people, including children that would otherwise be hard to encourage to stay and concentrate. The three visitors I interviewed perceived the installation (and / or elements of it) as exciting, although the puzzlement and frustration of not being able to comprehend the purpose of the installation interfered with the feeling of excitement.

In my interpretation, 26% of the workshop Post-It notes on positive aspects were related to fun and excitement. The subject was raised during the brainstorming discussions.

The fourth theme is that the installation *has the ability to encourage collaboration*. We observed that visitors frequently coordinated their trackball gestures in order to increase the velocity of the water simulation, thus pushing objects through the water surface. Some visitors also cooperated to reproduce the "stickiness" effect.

During the mother/boy interview, the boy described how he coordinated his activity with his mother: he chased her cursor around the display.

A small number of workshop statements also mention collaboration (4% as a positive aspect and 3% as a negative aspect, in my interpretation). Collaboration was also mentioned during brainstorming in the first workshop: the participants felt that the collaborative aspects of the installation should be stronger.

The fifth theme is that the *physical design of the installation environment made the interaction devices hard to spot for some visitors*. During the observations, we observed that several visitors left the main installation area without interacting with the installation, quite possibly because they had not seen the trackballs.

The issue is also present in the interviews: Rune told me that he feels the trackballs are hard to spot. Also the unaccompanied female visitor I interviewed learned that the installation was interactive from the computer screens rather than by interacting with a trackball.

7% of the workshop Post-It notes mention darkness, difficulty of spotting the trackballs, or difficulty of relating trackballs to cursors as negative aspects. Darkness and/or difficulty of spotting the trackballs were also brought up as issues during the brainstorming phases in all the workshops.

Recall from the beginning of this chapter that my first research question is concerned with the utility of the workshop evaluation method. I would argue that the emergence of common themes in all three types of evaluation data (observations, interviews and workshops) suggest that *the workshops did provide relevant evaluation information, and that they might be useful to evaluate other forms of exhibitions as well*. Indeed, the Museum of Science and Technology are now independently adopting the methodology for evaluating their science centre exhibits.

An important difference between the workshops and the observations/interviews is the broad range of design suggestions we obtained through the workshops. Some of these suggestions were mentioned in all three workshops (e.g., improving the visibility of the trackballs, presenting the background information in a clearer way). This indicates that many visitors share these concerns, which makes them important to act upon. Obviously, interviews is a good way of obtaining suggestions from visitors, but I would argue that the workshop format can be a *more efficient* way of acquiring a broad range of such suggestions from larger groups of visitor representatives.

In summary, I believe that the answer to the first research question of this monograph is that *the variant of the future workshop described above can indeed successfully be used to evaluate installations like The Well of Inventions*.

My second research question concerns the choice of educational approach for *The Well of Inventions*. In my interpretation, the evaluation data suggests that the installation has the ability to encourage reflection, collaboration and dialogue. For many visitors, it provides a sense of mystery and is perceived to be fun, attractive and aesthetic. Furthermore, it gradually reveals new features as visitors are interacting with it and in many cases the result is long dwell times. On the negative side, the installation fails to communicate its purpose and background and it is perceived to have a questionable (or even non-existent) educational goal. Visitors very rarely make the connection between the contents of the installation and the Museum's Machine Hall.

Recall from the previous chapter that the educational goal of *The Well of Inventions* was to provide an experience that could serve as a foundation for communication (verbal or non-verbal) between visitors (or visitors and museum staff) on the subject of dynamics. I believe the evaluation data indicates that this goal has been partially met. While the installation *does* encourage visitors to interact, think and reflect, *the focus of the reflection process is typically the installation itself rather than the topic its design is intended to represent.*

Thus, it seems to me that some form of modification of the installation's design is necessary to guide discussions towards dynamics and machinery. The evaluation data provides a number of suggestions of how this could be done. For example, replacing the computer screens in the antechamber with properly highlighted posters might encourage visitors to access information about the educational theme of the installation before they begin interacting with it. Another approach might be to attempt to strengthen the connection between the Machine Hall and the contents of the installation, perhaps by placing replicas of the real artefacts in the installation space itself. At the time of writing, I am planning a re-design of the installation and a new set of evaluation workshops.

My third research question concerns technology requirements. The evaluation suggests that compared to most of the Museum's current exhibits, *The Well of Inventions* is technically novel and it is relatively stable. Because CID personnel have been available to remedy the technical problems that occasionally have arisen, the Museum has spent very little time on maintenance.

However, as described above, several of the design suggestions from visitors involve modification of the audiovisual content of the installation. If cooperative design of museum installations such as *The Well of Inventions* is to become a reality, then the supporting technology has to be readily adoptable to suggestions from the design team. In this case, the technology is stable enough, but in the case of the graphics and trackball interaction, it is implemented as monolithic non-extendable applications. Thus, any modification requires rewriting and recompilation of C++ code, and the addition or removal of specific features must be carefully coordinated with the existing code. Also, modifications must be made at the actual computers where the code is running, which causes a number of logistical problems, mainly because the physical space in which the computers are situated is very small.

Therefore, I have been developing a rapid-prototyping framework for graphics applications called *Wasa*. The next chapter describes its design and implementation.

CHAPTER 7

WASA

The evaluation of *The Well of Inventions* described in the previous chapter indicated that its current supporting technology does not adequately meet the requirements of a cooperative design process. First, since cooperative design typically involves different kinds of prototyping, such technologies have to be easily adaptable and modifiable. Second, the living exhibition concept calls for exhibitions that evolve while on display, which implies that the supporting technology must be capable of producing high-quality content that can match other museum exhibits. Clearly, the software used to drive *The Well of Inventions* meets the second requirement, but unfortunately, it does not easily accommodate updated or new content.

During the last two years, parallel to my museum and methodology work, I have been developing a system platform, *Wasa*, that aims to support rapid development of applications capable of using state-of-the-art rendering algorithms. This chapter outlines the history of the platform and describes its current design and provides a number of possible future enhancements.

Background

Since 1995, the Centre for User Oriented IT Design (CID) at the Royal Institute of Technology (KTH) has been involved in a number of projects that make use of Internet-distributed 3D graphics. This work can be seen as a continuation of work that was initiated by the Interaction and Presentation Laboratory (also at KTH) in 1992. Most of the CID projects were based on the *DIVE* platform (Carlsson and Hagsand, 1993), which is a multi-user virtual reality system that allows participants to navigate a computer-generated three-dimensional space, and presents opportunities for meeting and interacting with other users. Although *DIVE* is certainly a system capable of supporting interesting applications, it remains a research prototype and thus lacks the stability and ease-of-use of commercial platforms. In addition, its graphics engine is based on mid-nineties technology, which made its visuals appear somewhat outdated in 2001. As a result, I initiated a search for alternative platforms.

The *ActiveWorlds* platform (http://www.activeworlds.com/) is attractive because of its robustness, security and ease of use, both in terms of system management and of producing new content. Also, CID had used it for previous prototypes (e.g., Walldius, 2001) and therefore, it was chosen as the supporting platform for the *Space Adventure* exhibit we developed for the Swedish Museum of Natural History in late 2001 (see chapter three). However, it is somewhat limited in its ability to produce interactive components, which make it difficult to use to develop applications other than avatar-based virtual environment walkthroughs. In addition, continuous access to the completed virtual environments requires the payment of a monthly fee.

The *ALICE* system (Conway et al., 2000) is similar to *ActiveWorlds* in the sense that it allows straightforward construction of new three-dimensional virtual environments with quite sophisticated interactivity. However, multiple Internet users cannot easily simultaneously share the resulting environments, and the quality of the graphics is somewhat limited.

The *MASSIVE* system developed at the University of Nottingham has been proven robust enough to be used in public settings (e.g., Benford et al., 1999). It has also been used successfully within the SHAPE project (e.g., Fraser et al., 2003). However, it produces graphics of comparatively low quality.

I also evaluated a number of *scenegraph*-based lower-level software architectures. A scenegraph is a hierarchical data structure often used in graphics-related work to describe the geometrical relationships and appearance of sets of graphical entities (cf. Strauss and Carey, 1992).

Open Inventor (Wernecke, 1994) is a well-known extendable scenegraph architecture. Unfortunately, modern rendering algorithms are somewhat awkward to implement in *Open Inventor*. The reason is that its design mirrors a certain form of underlying graphics hardware (the fixed-function pipeline) that is gradually being replaced by more modern architectures.

The *OpenGL Performer* system (http://www.sgi.com/software/performer/) is somewhat less extendable than *Open Inventor* and also has a tight conceptual coupling with older graphics hardware.

OpenSG (http://www.opensg.org/) is an Open Source alternative to *Open Inventor*. Unfortunately, it is still undergoing substantial architectural redesign and was not extendable by application writers at the time I compiled the review.

Java3D (http://java.sun.com/products/java-media/3D/) is similar to *OpenGL Performer* and runs on java platforms (http://www.javasoft.com). However, java applications are typically rather inefficient and the rendering capabilities of *Java3D* are limited.

Thus, none of the systems I evaluated seemed to provide the desired combination of stability, technical sophistication and ease-of-use. As a result, CID initiated the design of a new platform, which eventually turned into *Wasa*.

At the outset, *Wasa* implemented a variant of the scenegraph conceptual framework. However, I found that this design forced me to spend most of my development time writing specialized scengraph components, which resulted in few opportunities for re-use of previously written code. The main reason was that the applications I developed required access to the configuration of the graphics hardware to a greater extent than I had anticipated. As a result, I began thinking about ways to develop *Wasa* into a framework that allowed easy access to the graphics hardware, while still incorporating higher-level data structures like scenegraphs. This development led to the system's current design.

An Overview of Wasa

Wasa can be used both as a programming library and a rapid prototyping environment. Figure 25 illustrates its conceptual design.

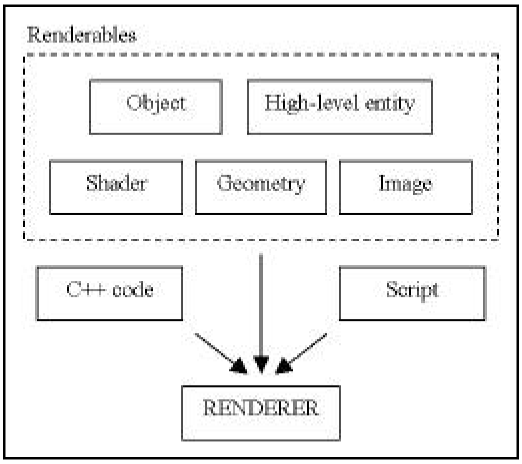

Figure 25. Conceptual design of *Wasa.*

The central *Wasa* component is the *renderer*. It is responsible for producing graphical output in a window and it largely mirrors the functionality of modern computer graphics hardware. Drawable entities (e.g., polygons, surfaces and models) are called *renderables* and can be created from computer code or loaded from files. *Wasa* is capable of reading files stored on a local hard drive or from URLs (i.e., from WWW pages or from FTP servers).

In order to be drawn in a window, all renderables must ultimately be reduced to a finite number of *streams*, i.e., sets of graphical primitives such as points, lines, triangles and quadrilaterals. Any such primitive consists of a number of *vertices* (a triangle has three vertices, for example) together with an optional set of associated data for each vertex (examples include normals and texture coordinates). Streams or sets of streams can be created in applications like *3D Studio Max* (http://www.discreet.com/) or *Maya* (http://www.aliaswavefront.com/), and *Wasa* can import streams stored in a number of common 3D file formats. *Wasa* can also work with two-dimensional image data, e.g. for defining surface textures. Images can be loaded from a large number of common file formats.

The *Wasa* renderer is configured through the management of *state variables*, whose values together determine the appearance of any succeeding graphical entity drawn. Standard graphics programming libraries like *OpenGL* developed by Silicon Graphics (http://www.opengl.org/) or *Direct3D* developed by Microsoft (http://www.microsoft.com/windows/directx/) typically require these variables to be set directly from C/C++ program code. However, in *Wasa* the management of state variables is organized around *shaders*. A shader is defined as a collection of state variable settings and/or pieces of program code that will configure the renderer to produce a certain appearance. Sometimes, a single shader is insufficient to produce the desired visuals. In such cases, it is possible to make use of *multi-pass rendering algorithms* that incrementally build an image by combining multiple redraws of the geometry (applying different renderer settings each time). Thus, similar to ATI's *RenderMonkey* system (http://www.ati.com/developer/), a *Wasa* shader consists of at least one *pass*, where each pass contains a set of associated renderer state variable settings. Thus, when drawing graphics a typical *Wasa* application would begin by sending the renderer a message indicating which shader and pass to configure. Then, any geometry drawn will receive the corresponding appearance. *Wasa* shaders are typically stored in text files adhering to the XML format (cf. http://www.xml.com/). As a result, they can be updated easily in any text editor without having to restart or recompile the application. Furthermore, the renderer state variables are given reasonable values by default (which can be changed if necessary). As a result, only state variables whose values differ from the defaults need to be specified in shader files, which make them quite compact and easy to read.

To combine a certain appearance (i.e., a shader) with a particular geometry description *renderable objects* are used. These are defined as associations between one or more renderable entities and a shader. The associations are also specified in XML text files, making them easy to change or modify, even while the application is running. *Wasa* also provides a number of more abstract entities. These can be divided into two main groups: 1) entities that generate geometry/streams, e.g., height fields (i.e., mathematical functions on the form $z = f(x,y)$) and polygonal surface patches, and 2) entities that organize graphical objects, e.g., scenegraphs and particle systems (cf. Reeves, 1983). I am not aware of any other system that combines the ability to configure the graphics hardware pipeline through text files with the ability to organize graphical entities as such higher-level objects.

The *Wasa* renderer can be also be configured from program code, written either in the C++ programming language or in a number of common scripting languages. *Wasa* uses the *SWIG* system (http://www.swig.org/) to provide support for multiple such scripting languages, including Tcl/Tk and Python. This allows rapid prototyping of applications that, when they have stabilized, can be converted into equivalent (and more efficient) C++ code. Figure 26 shows the focal surface exhibit from *Cybermath* (Taxén & Naeve, 2002) as a *Wasa* prototype, with a graphical user interface generated from a Tcl/Tk script.

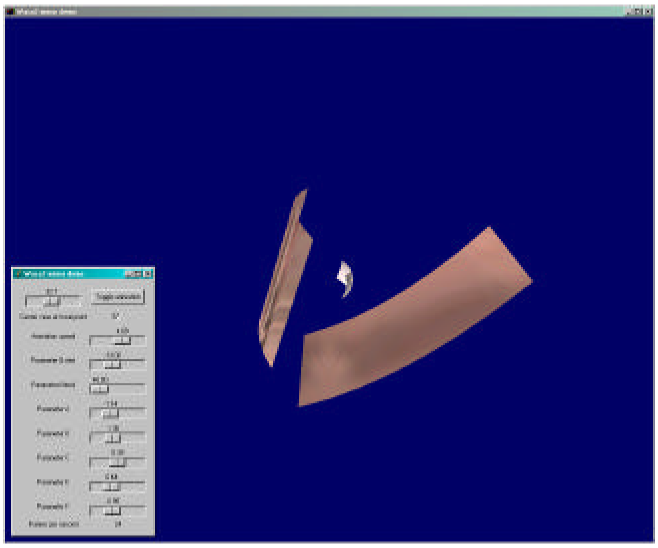

Figure 26. A *Wasa* application with a Tcl/Tk user interface.

The following figures showcase other *Wasa* features such as the ability to import imagery from web cameras and incorporate simulations of visual effects such as refraction (c.f. Vlachos and Mitchell, 2000).

Figure 27. Water refraction in *Wasa*.

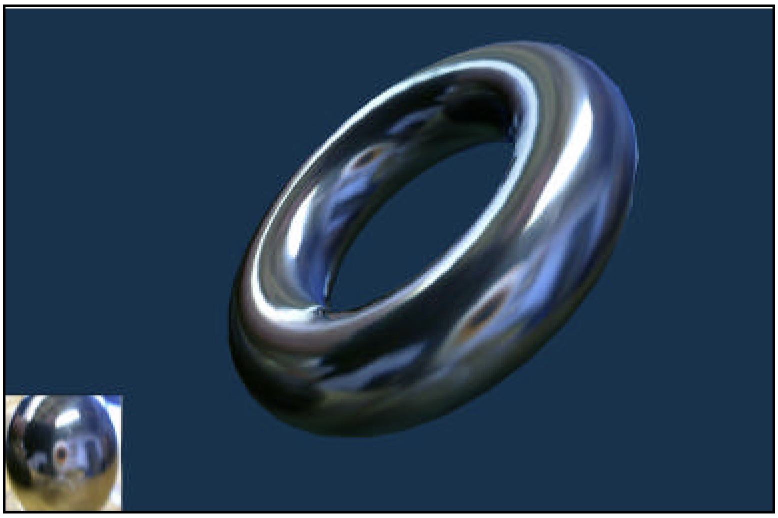

Figure 28. Using live video as a reflection map in *Wasa*.

Implementation Details

At the time of writing, *Wasa* consists of about 50 C++ classes. The renderer implementation is illustrated in figure 29.

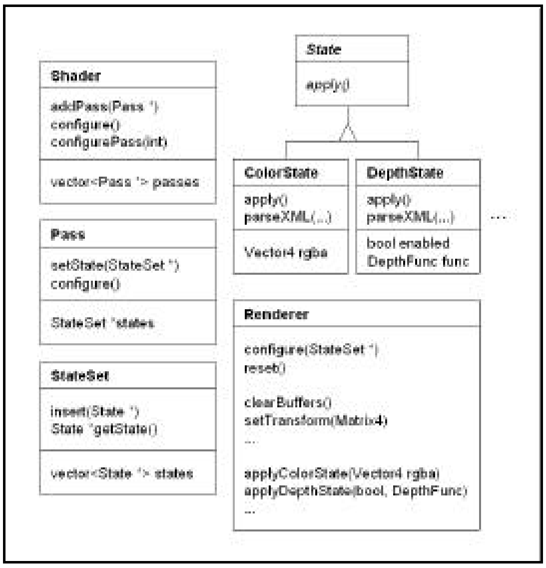

Figure 29. The *Wasa* renderer.

A typical renderer configuration process proceeds as follows. First, a shader is created by instantiating the Shader class. Then, one or more passes are created by instantiating the Pass class. Each pass contains a pointer to a StateSet, i.e., a collection of state variables. At the time of writing, 11 state variable types have been implemented: alpha test, depth test, stencil test, colour, colour blend, lighting, material, texture, fog, mask and scissor. Each state variable type is implemented as a separate class (e.g., ColorState, DepthState). Each implementation must know how to communicate its value to the renderer (done by the apply() method). Also, the State subclasses have functionality that acquires the state variable value from an XML file. To configure the renderer according to a particular shader pass, the user calls Shader::configure(), which in turn will call the appropriate Pass::configure(). Pass::configure() then invokes the apply() method for each state in its ShaderSet.

Instead of distributing the functionality that forwards the renderer state variables to the graphics hardware into the different state implementations, I chose to implement the renderer as a singleton class. The reason is that this design makes it easier to replace the underlying graphics library that is used to generate the graphics (which is currently *OpenGL*). The Renderer class contains a number of methods for applying renderer state to the graphics hardware (e.g. applyColorState(), applyDepthState()). Thus, when ColorState::apply() is called, it in turn calls Renderer::applyColorState().

The class diagram in figure 30 illustrates how renderable entities are implemented in *Wasa*.

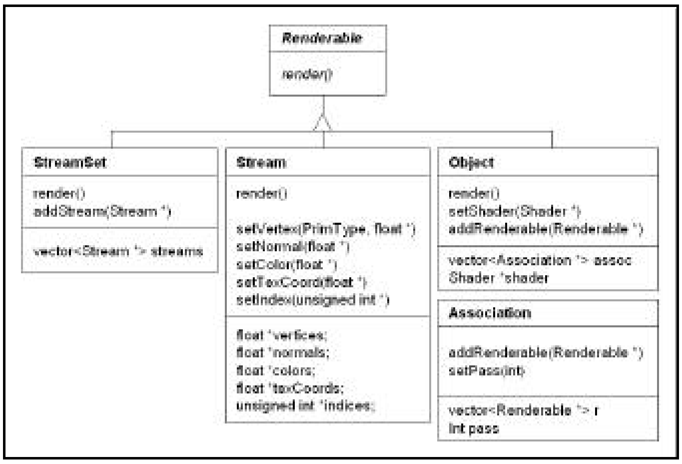

Figure 30. *Wasa* renderable entities.

Each entity that knows how to draw itself must implement the Renderable interface, which contains a single method, render(). A *Wasa* stream contains a list of floating point values that represent vertex positions together with a list of indices that specifies how the vertices are to be connected to form primitives. The stream can also optionally contain normals, colours and texture coordinates. The Renderer class exposes functionality for drawing streams, and this functionality is used when Stream::render() is called. All types of 3D files that *Wasa* can parse may contain multiple streams. Thus, when such a file is read, *Wasa* creates a number of StreamSet instances. Each such instance contains one or more streams. The Object class associates renderable entities with shaders. Each such object contains one Shader reference and a list of Association instances. Each association contains a list of renderable entities and a shader pass identifier. When the Object::render() method is called, the following happens: for each association, the corresponding shader pass is configured (using the Shader::configurePass() method). Then, each renderable entity in the association list is drawn (using the Renderable::render() method). Note that since the Association class holds references to Renderable instances, streams are not the only type of data that can be associated with a shader: any kind of renderable entity can be used, including other Object instances. This makes it possible to create very complex rendering procedures.

Each *Wasa* class that is to be exposed in the scripting interface (e.g., Tcl/Tk) has a corresponding interface class whose methods mirror one or all of the original class methods. When one of the mirror methods is called, the corresponding method in the real class is invoked. There are two main reasons for using this kind of design. The first is that not all of the methods of the original class may be appropriate to expose in the scripting interface. The second reason is that sometimes, data from the original class must be converted into a different format before it can be exchanged with the scripting language engine. The *SWIG* utility is used to generate a scripting language implementation of the interface classes. The following Tcl/Tk code implements a *Wasa* application that draws a textured 3D model.

```
proc wasaInit {} {
  StreamSetMgr_parseXML geometry-declarations.xml
  TextureMgr_parseXML texture-declarations.xml
  ShaderMgr_parseXML shader-declarations.xml
  ObjectMgr_parseXML object-declarations.xml
}

proc wasaDisplay {} {
  Renderer_setClearColor 0.1 0.2 0.3 1.0
  Renderer_clearBuffers

  Renderer_setViewTransform 0.1 0.4 1.5 0.1 0.4 0.0 0.0 1.0 0.0
  RenderableMgr_render [RenderableMgr_find horseObject]
}
```

When the *Wasa* application is started, the `wasaInit` procedure is invoked automatically. In the example above, this procedure parses a number of XML files to load streams, textures, shaders and renderable objects into *Wasa*. The XML files contain information about which data file to open and what internal *Wasa* name the data should be associated with (see below). Whenever the application window has to be redrawn, the `wasaDisplay` procedure is called automatically. In this example, it clears the window, sets an appropriate viewing transform and renders the renderable object named `horseObject`.

The contents of the `geometry-declarations.xml` file is

```
<?xml version="1.0" encoding='ISO-8859-1'?>
<wasa2>
  <streams path="c:\work\dev\wasa2\models">
    <stream file="cheval_sculpt.3ds" name="horseGeom" />
  </streams>
</wasa2>
```

The contents of this file specify that the 3D model contained in the file `cheval_sculpt.3ds` is to be loaded into a stream set and associated with the *Wasa* name `horseGeom`. Textures, shaders and renderable objects are specified and loaded in a similar way. For example, the file `object-declarations.xml` contains

```
<?xml version="1.0" encoding='ISO-8859-1'?>
<wasa2>
  <objects>
    <object file="object-horse.xml" name="horseObject" />
  </objects>
</wasa2>
```

Here, the renderable object defined in the data file `object-horse.xml` is loaded and associated with the internal *Wasa* name `horseObject`. Note that this is the name passed to the `RenderableMgr_render` procedure in the Tcl / Tk code above.

A Wasa shader specification looks similar to

```
<?xml version="1.0" encoding='ISO-8859-1'?>
<wasa2>
<shaderdef>
  <pass>
    <lighting enable="yes" />
    <light n="0" enable="yes" />
    <material diffuse="0.7 0.7 0.7 1.0"
              specular="1.0 1.0 1.0 1.0" />
    <texture enable="yes" name="wood" />
  </pass>
</shaderdef>
</wasa2>
```

In this example, the shader configures the renderer to use lighting and specifies a grey surface material. It also enables texturing and activates the texture with the *Wasa* name `wood`. The output of the example application is shown in figure 31.

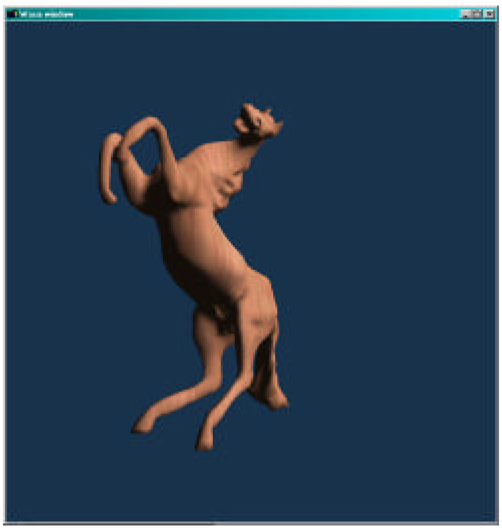

Figure 31. Output of the *Wasa* example application.

Teaching Computer Graphics using Wasa

I believe *Wasa* has a number of features that, in addition to allowing rapid prototyping of graphics applications, also makes it suitable as a tool for teaching computer graphics. Because the *Wasa* renderer state variables are given reasonable default values and only differing values have to be provided in shader files, the *functionality of the renderer can be exposed gradually*. In addition, the design of the renderer largely mirrors modern graphics hardware.

To see whether *Wasa* could be successfully used in teaching, I hosted a workshop entitled *3D Graphics For Dummies* in December 2002 (Taxén, 2003). The educational goal of the workshop was to help the participants acquire an understanding of the graphics hardware pipeline and the fundamental concepts of hierarchical transformations and animation.

The workshop had about 20 participants. It was approximately three hours long and was divided into two parts. The goal of the first part was to guide the participants in acquiring a theoretical understanding of the graphics pipeline, while the second part allowed the participants to apply their knowledge in practice. Thus, I began by attempting to guide the participants in developing a conceptual image of what components modern graphics hardware is likely to have, given that it has certain capabilities.

I started a *Wasa* program that draws an image of two triangles, one in wireframe (i.e., connected lines) and one filled with a white colour (I used a projector to allow the participants to see the output of the program). I then asked what the computer must be able to do in order generate such an image. After some discussion, the notion of a *rasterizer* was suggested: a component that takes vertices as input and generates sets of pixels (i.e., image elements) as output. At this point, I drew a text box containing the word *rasterizer* on a whiteboard. The next step was to show the participants a rotating wireframe model and ask how such a thing as rotation could be accomplished. This led to the notion of mathematical transformation of vertices. Thus, I drew a corresponding text box containing the word *transformation* on the whiteboard and connected it to the rasterizer. Concepts like *image plane projections*, *depth buffering*, *lighting*, *texturing*, *alpha blending*, *stenciling* and *environment mapping* were developed similarly. The end product was an image on the whiteboard illustrating the main components of modern graphics hardware (figure 32). The whole process took about one hour. Sometimes, the participants would "get stuck". In such cases, I asked them to attack the problem in groups of two. At other times, I would do "live" rewriting of my example programs in order to clarify a line of reasoning or in response to questions.

Figure 32. Developing an understanding of graphics hardware.

The goal of the second phase of the workshop was to allow the participants to apply the concepts from the first phase in practice. They were divided into groups of two and each group was presented with a computer running *Wasa*. In addition, each group was given a compendium containing a *Wasa* overview and twelve exercises. The aim of the exercises was to encourage the participants to solve a number of relevant problems related to the manipulation of the graphics components. The problems included:

- Move the camera and light sources to different positions and change their properties.
- Make a model rotate twice as fast.
- Add a texture to a model.

During this phase of the workshop, I would answer questions from the groups and guide them towards the solution of the problems if necessary. After two hours, most of the participants had successfully completed a majority of the exercises.

Although there was not enough time to do any detailed evaluation of the educational outcomes of the workshop (we were not allowed to continue beyond three hours), I have some anecdotal evidence that it was successful. All participants thought that the theory part was rewarding, although a few were concerned with the variations in tempo: the "flow" of my presentations of problems were interrupted by the comparatively long "awkward silences" when people were thinking. Furthermore, most participants expressed an understanding of the graphics pipeline and seemed to enjoy the exercises, although some thought the formulation of a few of the problems were a bit unclear.

Because I could not interview any of the workshop participants, it is impossible to draw any strong conclusions about the nature of the understanding they acquired. In addition, due to the time constraints, the participants were not given the opportunity to discuss their understandings with the entire group, nor were there time to talk about the participants' individual backgrounds and personal interests. However, I think the outcome of the workshop indicates that rich opportunities exist for using *Wasa* in the teaching of computer graphics. Also, at least for smaller groups, the methodology of "developing an image of the graphics hardware" seems very promising.

Discussion and Future Work

I believe the current implementation of *Wasa* can provide a necessary infrastructure for rapid prototyping of graphics-intensive museum exhibits. Shaders and object description files can be updated over the Internet without having to restart the system, which opens up the possibility for remote maintenance and redesign of graphics-intensive applications. *Wasa* also supports both modern graphics hardware and modern rendering algorithms. In addition, it is portable to a number of different operating systems.

However, some aspects of its design could be improved. Currently, the main issue is that *Wasa* is designed as an object-oriented class hierarchy. While such designs are easy to learn and use, they also are somewhat awkward to extend. Since one of the main reasons for developing *Wasa* was to support extensions and additions of new graphics algorithms, I believe it would be warranted to examine the possibilities of redesigning the architecture, e.g., as a collection of components (c.f. Gamma et al., 1995). Also, the current computer memory management is somewhat simplistic in nature, which ultimately may lead to unnecessarily inefficient applications.

CHAPTER 8

TOWARDS LIVING EXHIBITIONS

In the previous chapters of this monograph I have mentioned *living exhibitions* on many occasions. In this chapter I provide an overview of how the different aspects of my work could come together to realize that concept.

Ultimately, living exhibitions should be seen as *a novel way of approaching museum exhibition production*, an approach that involves visitor representatives as members of a multi-disciplinary design team that stays together throughout the production life cycle. For me personally, the main reason for attempting to implement this approach is that I believe that through cooperative design, *museums will have access to an additional way of learning about the thoughts and opinions of their audience and, in the long run, may obtain a richer range of ideas and suggestions than is typical in current exhibition design practice*. Today, when museums are struggling to keep their audiences, it is crucial to provide increased opportunities for communication between museum staff and visitor representatives, and I believe the living exhibition concept provides such an increased opportunity. However, simply stating that it is desirable to work with visitors would not be very helpful. Thus, acquiring knowledge about *how such a cooperative practice could be developed* is a vital aspect of my research.

In most variants of cooperative design, the construction of prototypes is seen as an important way of gradually achieving a fit between user needs and technology implementation. As I describe in chapter four, the construction of prototypes is also an important tool for developing a shared language between designers, developers and users. I do not believe the situation would be different in the museum domain and thus, prototyping of exhibitions is an important part of the living exhibition concept. As I describe in chapter three, prototyping is already used as part of formative evaluation of exhibitions under development. However, I believe that it would be fruitful to involve visitor representatives earlier in the design process, i.e., move the prototyping stage into the conceptual phase of museum exhibition production. I also believe that exhibitions should continue to evolve in response to feedback after they have been put on display. In other words, *by acquiring and responding to feedback and design suggestions from visitors continuously throughout the exhibition life cycle, museums may more easily be able meet the goals and desires of their audience.*

The purpose of this thesis project is not only to motivate the living exhibition concept, but also to take some initial steps towards realizing it. The KidStory work presented in chapter four suggests that cooperative design methodologies can provide a rich source of design suggestions and ideas, even when in cooperation with very young users. Furthermore, KidStory successfully managed to involve a large number of young children in cooperative design. These two features are important for cooperative museum work, because 1) museum audiences are typically very heterogeneous (necessitating the collection of opinions from a larger number of individuals), and 2) museum visitors often belong to a wide range of age groups, including young children.

In chapter six I describe how I used my experience from KidStory in the introduction of a cooperative evaluation methodology for museum exhibitions, which in practice provided both relevant evaluation data and a large number of design suggestions. In addition, the Museum of Science and Technology has independently adopted the workshop method, which is further indication of its usefulness. Thus, *museum exhibition design teams now have access to a cooperative-oriented methodology that could be used to evaluate their productions while they are on display, a methodology that also provides a broad range of design suggestions from visitors.*

However, cooperative design is not the only aspect of my work. I am also interested in how current research on museum learning and interaction principles can inspire museum exhibition design. As I describe in chapters two and three, many museum learning researchers are attempting to look beyond traditional communication models and treat audiences as less homogenous with respect to learning. Instead of focusing on the transfer of information between the exhibition designers and the audience, these researchers instead interest themselves in aspects of the individual visitor (or groups of heterogeneous visitors) to see how personal motivation, previous knowledge and the sociocultural and physical circumstances of a museum visit interact to create opportunities for subjective knowledge construction.

In chapter five, I describe how the educational aspects of the design of *The Well of Inventions* were inspired by this research. Instead of attempting to convey a specific message, the installation *attempts to encourage communication between visitors around a specific theme; a theme that relates to some of the host museum's most important artefacts*. This encouragement is manifest in a number of different design features. The installation design constitutes an attempt to provide a sense of mystery, both through its abstract audiovisual content and through its physical environment. In addition, the installation allows multiple visitors to interact simultaneously to, through collaboration, gradually uncover hidden audiovisual features. As I describe in chapter five, previous work I was involved in within the SHAPE project indicated that such an approach to interaction encourages both verbal and non-verbal communication between visitors, and this seems to be true for *The Well of Inventions* as well.

The evaluation of *The Well of Inventions*, summarized in chapter six, suggests that the installation has many desirable features. It generates an interest, provokes discussions and encourages visitors to interact with it for extended periods of time. However, the evaluation also indicates a need to more clearly communicate the goals of the installation. I am inclined to think that visitors approach museum visits with a number of expectations of the nature of the museum's artefacts, content and didactics. When an exhibit does not meet these expectations, it may be perceived as confusing and purposeless. Thus, an important challenge for future developments of *The Well of Inventions* is how to address this issue.

The final component of the living exhibition concept is technology. Public display of modern and impressive technology is an important way for museums to attract audiences, yet there are few studies of how such technologies are used and how they influence the opportunities for learning (Falk & Dierking, 2000, p 191). I believe that technology can be a fundamental part of novel museum exhibition designs, and *The Well of Inventions* represents an attempt at developing such a technology design. However, the living exhibition concept implies that the design (and by extension, the technological implementation) of exhibitions will vary throughout their life cycle, which introduces further technology constraints. The supporting systems have to be robust and modern, yet easily modifiable, extendable and adaptable. As I describe in chapter seven, I have not been able to find an application framework for the production of graphics-intensive applications that implements all these features, which necessitated the development of *Wasa*. As my doctoral project proceeds, I intend to further develop *Wasa* and ultimately offer it as a graphics platform for future exhibition productions. However, I do not think that presenting interesting technology should be the ultimate goal of museum exhibitions. Rather, the technology should be seen as a tool that could be used to achieve the goals of the exhibition. Thus, I believe that in cooperative design of exhibitions, technology should be one of a number of resources that the design team can utilize.

The living exhibition concept shares many aspects of other cooperative design projects, but it is also different in a number of ways. Most previous cooperative design projects have dealt with office or workplace settings, whereas my work focuses on museums. From the perspective of the visitor, museums are probably seldom thought of as a workplace (although school visits may be characterized as such), and the goal of museum visits is often the production of individual knowledge rather than the production of artefacts. As a result, the activities that take place in a museum are very heterogeneous and are carried out by large numbers of visitors, so *in cooperative design of museum exhibitions the "users" that are invited to be part of the design team are necessarily a subset of the museum's entire audience*. Thus, one underlying assumption of my work is that these persons, in some way, are able to represent larger museum audiences. This is an issue I intend to examine in greater detail in my doctoral project.

My work can be seen as containing elements of action research. The fundamental question for any such research is whether there are good reasons for initiating it, i.e., whether the process the researcher intends to study would take place without the initiation of an action research programme (Wallén, 1996, pp. 111-115). In my literature review, have not come across any previous research study of cooperative design within the museum domain, which suggests that such projects may be rare. Thus, I believe that from an action research perspective, it is warranted to initiate such a project. However, *my work does not necessarily challenge current museum production practices*. In working with smaller exhibits that can co-exist with (or be a part of) the partner museums' own productions, my research can be viewed as an experiment or proof-of-concept whose results can be used or discarded as desired. A further difference between typical action research and my work is that *I do not perceive my research as explicitly favouring any specific interest group*. Rather, its aim is to develop a method for increasing the opportunities for communication between two such groups: those of museum professionals and visitors.

The main drawback of cooperative design seems to be that sustainability is difficult to achieve, i.e., the cooperative design process rarely continues beyond the conclusion of the researchers' involvement. In the case of living exhibitions, I do not believe that it is my task to attempt to introduce a sustainable cooperative design practice. Rather, my aim is to provide an alternative methodology for museums to use as they see fit. Whether or not it will be independently adopted by museums remains to be seen.

Conclusion

This thesis introduces the concept of *living exhibitions*: continuously evolving exhibitions that are cooperatively developed and evaluated by teams of museum professionals and visitor representatives. I have argued that the living exhibition design process should draw its inspiration from multiple resources, including results from current research on museum learning, interaction principles and technology. As a case-in-point, I provide a description of how such results have inspired the design of *The Well of Inventions*, a public installation at the Museum of Science and Technology in Stockholm. Furthermore, the thesis provides a description of how an evaluation methodology from cooperative design was adopted and successfully applied within the museum domain. Thus, the thesis provides the first steps towards realising an exhibition design practice that has the potential to increase the opportunities for communication between museum professionals and their audience.

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APPENDIX A

STATEMENTS FROM THE WORKSHOPS

This appendix contains the 242 Post-It statements provided by the participants in the three sessions that evaluated *The Well of Inventions*. I translated the statements into English from the Swedish originals. Note group headings are in bold face.

Workshop 1 – 20 November 2002

Number of statements related to positive aspects:	25
Number of statements related to negative aspects:	25
Total:	50

Positive Aspects

Samarbete	**Cooperation**
Samarbete bra idé att få besökare att upptäcka saker tillsammans	Cooperation is a good idea to get visitors to discover things together
Kul att interagera med andra	Fun to interact with others
Utrymme för flera användare – leder till samarbete och utforskning, söka förståelse	Space for several users – leads to cooperation and exploration, seek understanding

Grafik/ljud	**Graphics/sound**
Kombination ljud-grafik	Combination sound-graphics
Bra vattensimul.	Good watersimul.
Fantastisk grafik och ljud	Fantastic graphics and sound
Koppling mellan grafik och ljud	Connection between graphics and sound
Ljudet	The sound
Grafiken	The graphics

Verklighetstroget	**Realistic**
Bra verklighetstrogen simulering	Good realistic simulation
Naturtrogenhet utan att bli "tråkigt"	Realistic without becoming "boring"

Estetiskt	**Aesthetic**
Upplevelsen estetiskt (bild och ljud)	The experience aesthetically (image and sound)
Estetiskt tilltalande	Aesthetically attractive

Fängslande	**Fascinating**
Kul att leka med	Fun to play with
Avstressande, rekreation. Filosofiskt vackert mentalt. Inbjuder till ("tyst") dialog med människor man aldrig skulle pratat med annars. Alla åldrar. Flera sinnen.	Non-stress, recreation. Philosophically beautiful mentally. Invites ("silent") dialogue with people one never would have spoken to otherwise. All ages.

	Multiple senses.
Utställnings rummet [sic] passar bra ihop med installationen	The exhibition space fits the installation well
Blir fångad – svårt att sluta	Becomes captivated – difficult to stop
Spännande ämne (borde inte skiftnyckeln vara med), men... pedagogiken	Exciting subject (should not the wrench be present), but... the pedagogy
Den visuella, rumsliga och auditiva upplevelsen är suggestiv	The visual, spatial and auditory experience is suggestive
Miljön som helhet är spännande	The environment as a whole is exciting
Spännande grepp; att blanda "realitet" och "fantasi"	Exciting approach; to mix "reality" and "fantasy"
Intressant att försöka få saker att hända	Interesting to try to make things happen
Fängslande. Vackert. Tekniskt imponerande. Pedagogiskt / genomtänkt. Filosofiskt (visas genom texterna)	Fascinating. Beautiful. Technically impressive. Pedagogical / thought through. Philosophical (shown through the texts)

Övrigt	**Other aspects**
Gränssnittet är bordsformat – mer spatialt och taktilt än på vanlig skärm	The interface is table-shaped – more spatial and tactile than an ordinary screen
Kombinationen Mixed reality + Museet verkar väldigt utvecklingsbar	The combination Mixed reality + The museum seems very developable

Negative Aspects

Runtomkring	**Around**
Lite rörigt runtomkring planeringen i lokalen	A bit messy around the planning of the environment
Mörkt	Dark

Pedagogik	**Pedagogy**
Svårt att se innehållet, om avsikten också är att informera pedagogiskt om uppfinningar	Difficult to see the content, if the goal is to inform pedagogically about inventions
Man får inte veta vem som gjort det,	One is not told who did it, in what

i vilket sammanhang, vad det heter, vad det vill lära / ge för upplevelse	connection, what it is called, what kind of experience it wants to teach / give
Oklart vad man ska lära	Unclear what one is supposed to learn
Vad lär man sig, upptäcker eller utforskar man egentligen	What does one really learn, discover or explore
Pedagogiska målet kunde vara tydligare	The pedagogical goal could be clearer

Samarbete/samverkan	**Collaboration/cooperation**
Svårt att förstå att man vinner något nytt med samarbete / samverkan	Difficult to see that one gains something new by collaboration / cooperation
Syftet med samarbete? Varför kan flera interagera? Vad är mervärdet med samarbetet	The purpose of collaboration? Why can several persons interact? What does one gain through collaboration
Interaktionen ger alltför slumpmässig effekt – minskar förståelsen av sambanden mellan de olika elementen	The interaction gives a too random effect – reduces the understanding of the connection between the different elements

Tekniken	**Technology**
Tekniska problem: bollarna styr åt fel håll	Technical problems: the balls steer in the wrong direction
Musen gick åt motsatt håll – förvirrande (säkerligen inte tänkt att vara så)	The mouse went in the opposite direction (surely not meant to be that way)
Begränsade interaktionsmöjligheter – ingen utveckling – mer händelser behövs	Limited interaction possibilities – no development – more events are needed
Riktning på rullboll i förhållande till rörelse	Trackball direction in relation to movement
Interaktion med "egna" bollen navigationen känns "omvänd"	The interaction with "one's own" ball the navigation feels "backwards"

Mål?	**Goal?**
Mål för interaktionen saknas – stimulerar inte att vilja göra "en gång till" (liksom ett spel)	Goal for the interaction is missing – does not stimulate to want to do "one more time" (as with a game)

Feedback – får jag egentligen något att hända?	Feedback – do I really cause something to happen?
Vart leder det, varför?	Where does it lead to, why?
Kan vara svårt att förstå vad den går ut på	Can be difficult to understand what its purpose is
Förstod inte kopplingen mellan föremålen, ursprung, historia...	Did not understand the connection between the objects, origin, history...
Svårt att koppla ihop texterna med installationen	Difficult to connect the texts to the installation

Realism	**Realism**
Saknar fotorealism	Does not have photorealism
Djupdimensionen i brunnen ser orealistisk ut	The depth dimension in the well looks unrealistic
Skärmarna utanför verkar inte "synas"	The scrrens outside does not appear to "be visible"
För snabba rörelser hos föremålen i vattnet – "nervöst"	Too quick movement of the objects in the water – "nervous"

Workshop 2 – 26 November 2002

Number of statements related to positive aspects:	29
Number of statements related to negative aspects:	24
Total:	53

Positive Aspects

Ideén [sic]	**The idea**
Nytt	New
Ideén [sic]	The idea
Lite smarta idéer	Some smart ideas
Iden [sic]	The idea
Ideén [sic]	The idea

Roligt	**Fun**
Roligt att man inte bara skulle titta på den...	Fun that one was not only supposed to watch it
Kul att bara leka	Fun to just play
Rolig + fin. Att man kunde se de olika skikten	Fun + beautiful. That one could see the different layers

Teknik	**Technology**
Ny teknik	New technology
Tekniken	The technology

Insikt	**Insight**
Skapar insikt	Generates insight
Får en att tänka vad man egentligen håller på med	Causes one to think about what it really is one is doing

Lätt	**Easy**
Lättanvänt	Easy to use
Markören var enkel att använda	The cursor was easy to use

Grafik	**Graphics**
Konstverk (vetenskap och konst)	Work of art (science and art)
Grafiken såg bra ut	The graphics looked good
Bra grafik	Good graphics
Såg verkligt ut	Looked realistic
Bra grafik. Snyggt gjort	Good graphics. Nicely done

Ljud	Sound
Ljudet	The sound
Ljudet	The sound
Ljudet	The sound
Bra kvalitet på ljudet	High quality sound
Klart ljud	Clear sound
Ljud	Sound

Grafik och ljud	Graphics and sound
Rätt grymt ljud! Grafiken var grym.	Pretty awsome sound! The graphics were awsome.
Påverkbart (skapar aktivitet). Bild. Ljud	Possible to influence (creates activity). Image. Sound.

	(Not grouped under any heading)
Miljön	The environment
Samverkan (flera kan samverka)	Cooperation (several can cooperate)

Negative Aspects

Handling	Plot
Beskrivning?	Description?
Man måste vara lite teknisk för att förstå...	One has to be a bit technical to understand...
Svårtolkat	Difficult to interpret
Måste nästan vara tekniker för att förstå. Svårlärlig [sic] / förståerlig[sic]	Almost have to be a technician to understand. Difficult to learn / understand
Den virtuella illustration [sic] saknade handling.	The virtual illustration lacked a plot
Varför? Syftet? Vad skall uppnå [sic]?	Why? Purpose? What to achieve?

Overkligt	Unrealistic
Artificiellt	Artificial
Overklighet [sic]	Unrealistic

Miljön	The environment
Omgivningen (runt omkring)	The environment (around)
Det var lite mörkt, så man snubblade	It was a bit dark, so one tripped over

på "sladdarna"	the "cables"
Stolen	The chair

Grafik	**Graphics**
Grafik tydligare	Graphics more clear
Vart [sic] rörigt när alla höll på	Became messy when everyone went on
En boll var inte så tydlig	One ball was not very clear

Ljud	**Sound**
"Segt ljud"	"Sticky sound"
Ljudet var lite högt	The sound was a bit loud
Ljudet var lite efter	The sound was a bit behind
Lite för högt ljud	The sound was a bit too loud
Ljudet	The sound
Ljudet blev lite jobbigt efter en stund.	The sound became a bit tiring after a while.
Ljud tydligare	Sound clearer
Svårt och [sic] relatera ljuden till föremålen	Difficult to relate the sounds to the objects

	(Not grouped under any heading)
Använda händerna	Use of hands
Inte så värst intressant	Not very interesting

Workshop 3 – 3 December 2002

Number of statements related to positive aspects:	67
Number of statements related to negative aspects:	72
Total:	139

Positive Aspects

Grafik	**Graphics**
Roliga effekter	Fun effects
Snygg grafik	Good-looking graphics
Snygg grafik	Good-looking graphics
Snygg grafik	Good-looking graphics
Snyggt gjort	Well done
Snyggt gjort	Well done
Bra grafik	Good graphics
Tuffa effekter	Cool effects
Bra rent tekniskt	Good from a technical point of view
Hi-tech	Hi-tech
Snygg	Good-looking
Grafiken	The graphics
Härlig upplösning	Wonderful resolution
Intressant simulering	Interesting simulation
Bra bild!	Good image!
Tufft ljud kändes som om vattnet var runt omkring en	Cool sound felt like one was surrounded by the water
Bra rent tekniskt, cool grej	Good from a technical point of view, cool thing
Snyggt att titta på	Nice to watch

Ljud	**Sound**
Bra ljud	Good sound
Bra ljud	Good sound
Bra ljud	Good sound
Bra ljud	Good sound
Bra ljud	Good sound
Bra ljud	Good sound
Bra ljud	Good sound
Bra ljud	Good sound
Härligt ljud och grafik	Wonderful sound and graphics

Bra ljud och grafik	Good sound and graphics
Verkligt ljud!	Realistic sound!
Bra ljud och bild	Good sound and image
Stort och rymligt i lokalen	Large and spacious environment
Välarbetat bild och ljud	Well worked through image and sound
Ljudet	The sound
Snyggt, bra ljud	Good-looking, Good sound

Kul	**Fun**
Tufft	Cool
Tufft	Cool
Tuff	Cool
Roligt	Fun
Roligt!	Fun!
Rolig	Fun
Kul idé	Fun idea
Häftig	Cool
Trevligt med sittbänkar	Nice with places to sit
Det var häftigt	It was cool

Mysfaktor	**Cosiness factor**
Åskådarhyllan	The platform for on -lookers
Trevligt rum	Nice room
Lugnt och skönt. Stämning	Nice and quiet. Atmosphere
Härlig upplevelse	Wonderful experience
Trevligt utrymme	Nice environment
Stämningsfullt	Atmospheric
Tufft i det svarta rummet	Cool in the black room
Mysigt	Cosy
Möjligheten att se vart allt kom ifrån (datorerna)	The opportunity to see where everything came from (the computers)
Mysigt och stämningsfullt	Cosy and atmospheric
Bra stämnings fram kallande [sic]	Creates a good atmosphere

Lek själv	**Play yourself**
Man kunde ju peta och spela på den där stimulerande skärmen.	One could poke and play on that stimulating screen.
Roligt med simulering	Fun with simulation

Lätt att se vad som hände när man rullade på kulan	Easy to see what happened when one rolled the ball
Bra att man kunde få testa den	Good that one was allowed to test it
Interaktionen vid brunnen	The interaction at the well
Bra att använda datorsimulering som är trovärdig	Good to use believable computer simulation
Kul att man fick röra och påverka den	Fun that one was allowed to touch and influence it
Bra att låta besökarna tänka själva	Good to allow the visitors to think for themselves
Kul idé med olika sorters propellrar	Good idea with different sorts of propellers

	(Not grouped under any heading)
Få datorer krävs, ett plus	Few computers needed, a plus
Annorlunda	Different
Bra guide	Good guide

Negative Aspects

Syfte	**Purpose**
Svårt att fatta	Difficult to understand
Varför?	Why?
Lite svårt att förstå vad man skulle göra	A bit hard to understand what one was supposed to do
Luddigt syfte	Fuzzy purpose
Luddigt syfte	Fuzzy purpose
Luddigt syfte	Fuzzy purpose
Otydligt budskap	Unclear message
Hur kommer man vidare?	How does one move on?
För rolig och avanserad [sic] för att framhäva syftet	Too much fun and advanced to bring out the purpose
Mer info i datasimuleringsrummet te.x [sic] diskussionsfrågor	More info in the computer simulation room e.g., discussion questions
Hur får man poäng? Hur vinner man?	How does one score points? How does one win?
Sämre förklarat vad man skulle göra!	Poorly explained what one should do!
Vad var syftet med det	What was the purpose of it
Svårt att förstå syftet med	Hard to understand the purpose of

animeringen (spelet)	the animation (the game)
Man fatta [sic] inget	One didn't understand anything
Svårt att förstå	Hard to understand
Syfte?	Purpose?
Syfte?	Purpose?
Oklart syfte	Unclear purpose
Oklart syfte!	Unclear purpose!
Oförståerlig [sic]	Non-understandable
Oförståerlig [sic]	Non-understandable
Vad var grejen? Syfte?	What was the thing? Purpose?
Inget syfte	No purpose
Långsökt	Far fetched
Lite långsökt att markörerna har en vind/under vatten rörelse styrka [sic] (bättre beskrivning)	A bit far fetched that the cursors have a wind/underwater movement strength (better description)
Inte särskilt nyskapande kanske	Not very novel perhaps
Inte så ny skapande [sic]	Not very novel

Saknas	**Missing**
Saknades speakerröst	Speaker voice was missing
Ej tillräckligt informativt	Not informative enough
Touchscreen det skulle vara bra men säkert dyrt	Touchscreen that should be nice but probably expensive
Skulle vart [sic] touchscreen	Should've been touchscreen
Skulle vara kul med touchscreen	Would be fun with touchscreen
Vore häftigare med TOUCHSCREEN	Would be cooler with TOUCHSCREEN
Synd att man inte kunde få se datorerna som styrde prylen lite mera. Dom verkade intressanta.	Pity that one couldn't get to see the computers that ran the thing a bit more. They seemed interesting.

Mörker	**Darkness**
STYRKNAPPARNA SYNTES INTE I MÖRKRET.	THE CONTROL BUTTONS WEREN'T VISIBLE IN THE DARKNESS.
Mörka färger, man blir så ledsen.	Dark colours, one becomes so sad.
Det var lite mörkt och trångt...	It was a bit dark and crowded...
För mörkt i rummet	Too dark in the room

Att göra	**To do**
Lite för litet utrymme	A bit too little space
För lite saker att göra	Too few things to do
Liten utställning	Small exhibition
För liten utstsällning	Too small exhibition
För lite tid att kolla allt	Too short time to check out everything
Ganska liten utställning	Quite small exhibition

	(Grouped but without heading)
INFORMATIONSSKÄRMARNA	THE INFORMATION SCREENS
Svårt att se vilken "boll" som man styrde.	Hard to see which "ball" one was controlling.
För mycket småsaker. Pill...	Too many smallish things. Picking...
Stolarna	The chairs
Datorerna med en massa text var tråkiga.	The computers with a lot of text were boring.
Svårt att se att det var både över och under vattenytan	Hard to see that it was both above and below the watersurface
Syntes ej när de kom åvanför [sic] vattenytan	Weren't visible when they came above the water surface

	(Grouped but without heading)
Svårt att förstå den utan guide	Hard to understand it without a guide
Långtråkigt	Boring
Tråkigt i längden	In time it becomes boring
Ganska ointressant	Rather uninteresting
För lång text på skärmarna	Too long text on the screens
För rörigt	Too messy
Rörigt på skärmen	Messy on the screen
Ta bort det där tråkiga datorspelet	Remove that boring computer game
Skulle vart [sic] mer som ett spel, dvs en tävling på nåt [sic] sätt	Should've been more like a game, i.e., a contest of some sort
Kräver en guide som berattar [sic] för att det ska bli bra	Requires a guide that tells the story in order to be good
Man gick förbi texten	One walked past the text
Mer interaktivt med datorerna utanför som beskrev det hela	More interaction with the computers outside that described the whole thing

Enformig	Monotonous
Vissa grejjer [sic] funkade inte	Some things didn't work
Utställningen höll ej förväntnig [sic] trodde på större, mer grejer [sic]	The exhibition didn't meet expectations, believed there would be more, larger, stuff
Lite kort "utvecklingsstadium" för objekten i sjön	A bit short "development stage" for the objects in the lake

	(Grouped but without heading)
Komplicerat	Complicated
Datorerna och programmerandet	The computers and the programming
Bryr sig barn om fysiken bakom simuleringen	Do children care about the physics behind the simulation
Fantasilösa datorer som berättade om grafik och grejer [sic]. Dom var lite tråkiga.	Non-imaginative computers that told you about graphics and stuff. They were a bit boring.

APPENDIX B

MAIN PUBLICATIONS

Journal Articles

Taxén, G. and Naeve, A. (2002). A System for Exploring Open Issues in VR-Based Education. *Computers and Graphics*, 26(2002), pp. 593-598.

Taxén, G., Druin, A., Fast, C., Kjellin, M. (2001). KidStory: A design partnership with children. *Behaviour and Information Technology*, 20(2), April-March 2001, pp. 119-125.

Refereed Conference Papers (first author)

Taxén, G. (2003) Teaching Computer Graphics Constructively. To appear in *SIGGRAPH 2003 Conference Abstracts & Applications*.

Taxén, G. and Naeve, A. (2001). CyberMath: Exploring Open Issues in VR-Based Education. In *SIGGRAPH 2001 Conference Abstracts & Applications*, pp. 49-51.

Refereed Conference Papers (co-author)

Fraser M., Stanton, D., Ng, K. H., Benford, S., O'Malley, C., Bowers, J., **Taxén, G**, Ferris, K., Hindmarsh, J. (2003). Assembling History: Achieving Coherent Experiences with Diverse Technologies. To appear in *Proceedings of ECSCW 2003*.

Hourcade, J.P., Bederson, B.B., Druin, A., **Taxén, G**. (2002). KidPad: Collaborative Storytelling for Children. In *ACM 2002 Extended Abstracts on Human Factors in Computing Systems (CHI '02)*, pp. 500-501.

Alborzi, H., Druin A., Montemayor, J., Platner, M., Porteous J., Sherman, L., Boltman A., **Taxén, G**, Best J., Hammer, J., Kruskal, A., Lal A., Plaisant Schwenn, T., Sumida, L., Wagner R. and Hendler, J. (2000). Designing StoryRooms: Interactive Storytelling Spaces for Children. In *Proceedings of the ACM Symposium on Designing Interactive Systems*, pp. 95-104.

Benford, S., Bederson, B., Åkesson, K.-P., Bayon, V., Druin, A., Hansson, P., Hourcade, J. P., Ingram, R., Neale, H., O'Malley, C., Simsarian, K., Stanton, D., Sundblad, Y. and **Taxén, G**. (2000). Designing Storytelling Technologies to Encourage Collaboration Between Young Children. In *Proceedings of CHI 2000*, pp. 556-563.

Technical Reports

Taxén, G. (2002). *Guilds: Communities in Ultima Online*. TRITA-NA-D0208, CID, February 2002.