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Exhibit Engineering
A new research perspective

Doctoral Dissertation 2010

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Abstract

Science museums define the objectives of their exhibitions in terms of visitor learning outcomes. Yet, exhibit designers lack theoretical and empirical research findings on which to base the creation of such educational environments. Here, this shortcoming is addressed through the development of tools and processes to guide the design of educational science exhibits. The guiding paradigm for this development is design-based research, which is characterised by an iterative cycle of design, enactment, and analysis. In the design phase, an educational intervention is planned and carried out based on a hypothesised learning process and the means of supporting it. In the enactment phase, the educational intervention is implemented (i.e. the planned lesson is taught, or the museum exhibit is opened to the public). Finally, the analysis phase establishes causality between emergent characteristics of the learning outcomes and the design characteristics of the intervention. The analysis process can yield two types of outcomes: Suggestions for the refinement of the specific design in question, and “humble” theory, which is theory that can guide the design of a category of educational interventions and predict the learning outcomes that these interventions can precipitate. Here, the design-based research approach is applied to a case: the biology exhibit *Cave Expedition*. In this approach, didactic theory is used as a tool to establish the relationship between content, medium and learner. The work proceeds in three steps: 1) an analysis of the design of *Cave Expedition*, using the notion of *museographic transposition* as a theoretical frame, 2) an analysis of the enactment of *Cave Expedition*, using the notion of *praxeology* as a tool to compare intended and observed visitor learning outcomes, and 3) a synthesis of the findings from the first two studies with findings from the literature to generate two types of results: a coherent series of suggestions for a design iteration of the studied exhibit as well as a more general normative model for exhibit engineering. Finally, another perspective on the generation of theoretical ideas for exhibit design is offered in a fourth and parallel research undertaking, namely the application of the notion of cultural border-crossing to a hypothetical case of exhibit design.

Summary

The present dissertation consists of four papers that address an important aspect of informal science education: The engineering of educational exhibits. The four papers are prefaced by an introduction that reviews the existing research literature on the subject. The review frames the guiding *problematique* of the work presented here, namely that the research-based development of tools and processes for use by science exhibit engineers in museums is missing from the field of museum research. In other words, although science museums define the objectives of their exhibitions in terms of visitor learning outcomes, exhibit engineering employees lack theoretical and empirical research findings on which to base the creation of such educational environments. As a first step towards addressing this shortcoming, a research approach is advocated which utilises didactics to investigate the process of exhibit engineering by considering the content, exhibit medium, and prospective learner as well as the relationships between them. This didactics approach is framed within a design-based research methodology, the utility of which is that in addition to directing the reflective analysis of the design and enactment of an educational intervention, the methodology can guide the prospective synthesis of theory.

The following three papers each represent a sequential step of the design-based approach towards the construction of a theoretical model for science exhibit design. These three papers deal with a specific case: The exhibit *Cave Expedition*, whose biological content is *the adaptations of the blind cave beetle to its environment of permanently dark caves*, and whose form is an *immersion exhibit*. The fourth and final paper is not directly a part of this sequence; instead, it may be seen as a parallel development which theoretically explores the applicability of education theory to immersion exhibit design.

The first paper *Museographic Transposition: The development of a museum exhibit on animal adaptations to darkness* is a retrospective analysis of the design of *Cave Expedition*. The aim was to achieve an understanding of the process of exhibit engineering by characterising the constraints and opportunities that influence it. Here, the theoretical notion of *museographic transposition* was used to track the changes in a specific body of biological knowledge (*the adaptations of the blind cave beetle to its environment of permanently dark caves*) through its development from the scientific context of

primary and secondary research literature to its physical manifestation in the exhibit. The analysis yielded a descriptive model of exhibit engineering as a three-stage process in which simultaneous processes of *epistemological* development and *museum-pedagogical* development resulted in the curatorial brief which formed the basis of the subsequent *museographic* development of the physical exhibit. The descriptive model allowed for the identification of two types of phenomena: Instances of non-reconciliation between the foundational biological and museographic organizations in the first phase of transformation, and instances of relaxation of epistemological vigilance in the second phase of transformation. The paper discusses the implications of these phenomena for the end product–the exhibit, and offers some perspectives on how the descriptive model of exhibit engineering may be used as a tool to optimise future cases of exhibit engineering.

The second paper *Analysis of the Educational Potential of a Science Museum Learning Environment: Visitors' experience with and understanding of an immersion exhibit* is an analysis of the enactment of the exhibit *Cave Expedition*, i.e. of visitors' interactions with and resulting understandings of the exhibit. The aim was to achieve an understanding of what kinds of learning outcomes the exhibit could precipitate among museum visitors in the light of what was known about the exhibit from the study of its design. First, the theoretical notion of *praxeology* was used to model the intended learning outcomes of the exhibit by considering the stated educational objectives for the exhibit in relation to its designed features (which were investigated in the first paper). Subsequently, the notion of praxeology was used to observe the actual visitor outcomes. Due to the high degree of consistency in visitors' interactions with and interpretations of the exhibit, a single observed praxeology was constructed and compared to the intended praxeology. The pattern of differences between the two praxeologies was analysed to pinpoint where and how divergences emerged. The results showed that the divergences were caused by exhibit inconsistencies which could be linked to two types of phenomena which influenced the exhibit design: Instances of non-reconciliation between the foundational biological and museographic organizations, and instances of relaxation of epistemological vigilance. The implications of this finding are discussed in terms of the educational potential, design, and driving conjecture of the exhibit.

The third paper *A Normative Model for Science Exhibit Design* represents the final, prospective phase in the development of a model for exhibit design. The paper constructs a theoretical, prescriptive model of exhibit engineering based on the analysis of the design and enactment of *Cave Expedition* presented in the first two papers. The construction of the model is further informed by current research findings from science education literature in general and museum research literature in particular. The model considers the following aspects of exhibit engineering: Content development, the mediation strategy inherent in the exhibit type, and the didactical relationship between the prospective learner and the exhibit. The utility of the model is exemplified in a description of a theoretical design iteration of the studied exhibit. Here, it is shown how the content (*the adaptations of the blind cave beetle to its environment of permanently dark caves*) can be developed according to the medium of an immersion exhibit, how the embodiment of that content can consider and address the prior knowledge of learners, and how the immersion-type exhibit can be organized to precipitate the intended visitor interactions and reflections. Finally, although the model of exhibit engineering was developed on the basis of investigations of a specific case and thus addresses the content and context of this case (the exhibit *Cave Expedition*), the property of the model as a paradigm case of a larger class of phenomena is discussed. Its theoretical contributions to the field of museum research are discussed on three levels: Domain theory, design framework, and design methodology.

The fourth paper *Designing Immersion Exhibits as Border-Crossing Environments* takes its point of departure in the dialectic between exhibit content and exhibit form. The aim is to provide an example of how science education theory, specifically the notion of *cultural border crossing*, can be utilised to guide the embodiment of specific biological content into a specific exhibit form. The argument proceeds by theoretically developing the notion of immersion exhibits as *microcultures*, using empirical and theoretical research findings from the research literature as evidence. Subsequently, the paper examines the implications of this for exhibit design, using a hypothetical immersion exhibit as a case. Finally, the paper discusses the generalisability of the findings as a paradigm case of applying education theory to exhibit development.

Summary in Danish

Nærværende afhandling består af fire artikler der behandler et vigtigt aspekt af uformelle naturvidenskabelige læringsmiljøer: Udstillings- og opstillingsudvikling. De fire artikler indledes med en introduktion, der gennemgår den eksisterende forskning om emnet. Denne gennemgang danner ramme for den problematik der behandles i de følgende artikler, nemlig den manglende forskningsbaserede udvikling af værktøjer og processer til anvendelse af udstillingsdesignere på naturvidenskabelige museer. Selv om naturvidenskabelige museer definerer målene for deres udstillinger som læringsmål, så mangler udstillingspersonalet altså de teoretiske og empiriske forskningsresultater som de kan basere deres udstillingsudvikling på. Som et første skridt i denne retning argumenteres der her for at betragte udstillingsudviklingsprocessen ved hjælp af en didaktisk forskningstilgang. En sådan tilgang analyserer det faglige indhold, den pågældende opstillingstype, og den potentielle lærende samt relationerne mellem dem. Denne didaktiske fremgangsmåde implementeres i en design-baseret forskningsmetodologi, der er kendetegnet ved samspillet mellem retrospektive og prospektive faser. Fordelen ved design-baseret forskning er, at den kan danne ramme for både en reflekterende analyse af en undervisningsinterventions design og implementering og en prospektiv teorisyntese.

Hver af de tre følgende artikler repræsenterer et trin i den design-baserede opbygning af en teoretisk model for opstillingsdesign. Alle tre artikler behandler en konkret case: Opstillingen *Cave Expedition*, hvis biologiske indhold er *den blinde grottebilles tilpasninger til sit permanent mørke miljø*, og hvis form er en såkaldt *immersion* opstilling. Den fjerde og sidste artikel er ikke direkte en del af denne sekvens, men snarere en parallel udvikling, der teoretisk undersøger hvordan en eksisterende lærings/undervisningsteori kan bidrage til udviklingen af en immersion opstilling.

Den første artikel, *Museographic Transposition: The development of a museum exhibit on animal adaptations to darkness*, er en retrospektiv analyse af designprocessen for *Cave Expedition*. Målet var at forstå processen ved at karakterisere de muligheder og begrænsninger, der påvirkede den. Det teoretiske begreb *museographic transposition* blev her anvendt til at påvise og spore ændringer i et specifikt biologisk vidensobjekt (*den blinde grottebilles tilpasninger til sit permanent mørke miljø*) gennem dets udvikling fra den videnskabelige kontekst, så som primær og sekundær forskningslitteratur,

til dets fysiske manifestation i opstillingen *Cave Expedition*. Gennem analysen udvikledes en deskriptiv model for opstillingsdesign som en tretrins proces, hvori to simultane processer – en epistemologisk og en museumspædagogisk udvikling – resulterede i et planlægningsdokument for den kommende opstilling. Indholdet i dette dokument dannede grundlag for den efterfølgende museografiske udvikling, som resulterede i opstillingen – den fysiske manifestation af det pågældende vidensobjekt. Den deskriptive model gjorde det muligt at identificere to typer af fænomener, der påvirkede opstillingsudviklingen. Den første type fænomen udgøres af tilfælde hvor der var uoverensstemmelser mellem de grundlæggende biologiske og museografiske vidensorganisationer. Dette fænomen optrådte i den første fase af processen. Den anden type fænomen kan beskrives som en lempelse af den epistemologiske årvågenhed, og optrådte i processens anden fase. Artiklen diskuterer disse fænomeners konsekvenser for slutproduktet, nemlig opstillingen, og giver nogle perspektiver på, hvordan modellen kan anvendes som et redskab til at optimere fremtidige tilfælde af opstillingsudvikling.

Den anden artikel, *Analysis of the Educational Potential of a Science Museum Learning Environment: Visitors' experience with and understanding of an immersion exhibit*, analyserer implementeringen af opstillingen *Cave Expedition*, dvs. de besøgendes interaktioner med opstillingen og deres deraf følgende fortolkninger af dens indhold. Målet var at forstå, hvilken slags læringsresultater opstillingen kunne afstedkomme blandt museumsgæster i forhold til dens design. Først blev det teoretiske *prakseologibegreb* benyttet til at modellere opstillingens tilsigtede læringsudbytte ved at betragte de opstillede læringsmål for opstillingen i forhold til dens designede karakteristika (som blev undersøgt i den første artikel). Derefter blev prakseologibegrebet anvendt til at observere de besøgendes faktiske læringsresultater. Fordi de besøgendes interaktioner med og fortolkninger af udstillingen var forholdsvis homogene, blev de beskrevet ved hjælp af en enkelt observeret prakseologi. Denne observerede prakseologi blev efterfølgende sammenlignet med den intenderede prakseologi. Forskellene mellem de to prakseologier blev analyseret for at indkredse, hvor og hvordan eventuelle diskrepanser var opstået. Resultaterne viste, at diskrepanserne var knyttet til to typer af fænomener fra opstillingens designproces: uoverensstemmelser mellem de biologiske og museografiske vidensorganisationer og lempelser af den epistemologiske årvågenhed. Konsekvenserne af dette forhold diskuteres i forhold til opstillingens undervisningspotentiale, design og bagvedliggende formodninger.

Den tredje artikel, *A Normative Model for Science Exhibit Design*, repræsenterer den fremadrettede fase i udviklingen af en model for opstillingsdesign. I artiklen konstrueres en teoretisk, præskriptiv model for opstillingsudvikling baseret på de analyser af design og implementering af opstillingen *Cave Expedition* som blev præsenteret i de første to artikler. Modellens konstruktion informeres yderligere af aktuelle forskningsresultater fra den naturvidenskabelige uddannelseslitteratur i almindelighed og museumsforskningslitteratur i særdeleshed. Modellen adresserer vigtige aspekter relateret til opstillingsudvikling, så som udvikling af indhold, den specifikke medieringsstrategi der er forbundet med den givne opstillingstype, og det didaktiske forhold mellem de potentielle lærende og opstillingen. Modellens anvendelighed eksemplificeres i en beskrivelse af en teoretisk design-iteration af den studerede case. Beskrivelsen viser hvordan det faglige indhold (*den blinde grottebilles tilpasninger til sit permanent mørke miljø*) kan udvikles i forhold til den valgte opstillingstype (en immersion opstilling), hvordan implementeringen af dette indhold kan overveje og tage højde for de lærendes forhåndsviden, og hvordan en immersion opstilling kan tilrettelægges så den afstedkommer de planlagte interaktioner og refleksioner hos de lærende. Endelig diskuteres det hvorvidt modellen for opstillingsdesign kan generaliseres. Selv om modellen er udviklet på grundlag af studier af en specifik case og dermed adresserer indholdet af og konteksten for den pågældende case (opstillingen *Cave Expedition*), kan denne case ses som eksemplarisk for en bredere klasse af fænomener. Modellens teoretiske bidrag til museumsforskningsfeltet diskuteres derfor på tre niveauer: *Domain theory*, *design framework*, og *design methodology*.

Den fjerde artikel, *Designing Immersion Exhibits as Border-Crossing Environments*, tager sit udgangspunkt i dialektikken mellem opstillingsindhold og -form. Formålet er at give et eksempel på, hvordan lærings/undervisningsteori, nærmere bestemt begrebet *cultural border-crossing*, kan bruges til at koordinere implementeringen af et specifikt biologisk indhold i en bestemt opstillingsform. Først udvikles den teoretiske idé at immersion opstillinger kan forstås som mikrokulturer. Denne udvikling sker på basis af empiriske og teoretiske forskningsresultater fra litteraturen. Implikationerne af dette analyseres efterfølgende ved hjælp af en hypotetisk case: en tænkt immersion opstilling. Endelig diskuteres det hvorvidt resultaterne er eksemplariske og dermed generaliserbare.

1 Introduction

The present dissertation comprises the main elements of my academic work during the last three years. It contains four papers, three of which have been accepted for publication in international, peer-reviewed journals and one which has been submitted for prospective publication. Each paper reflects a distinct phase of work in the design-based approach I took, and accordingly, they are placed in the sequence in which I wrote them. There is one exception: The last paper presented here was actually written concurrently with the second paper. However, it represents a “spin-off” project of a sort and is placed last in order to leave the flow of the first, second, and third papers uninterrupted. The papers appear here in substantially the same form as they were submitted for publication; only minor alterations have been made to improve the uniformity of the layout.

In the following section, I will offer my personal motivation for undertaking the research project reported here. Then, I will review the main findings from the research literature in order to situate the project within the field of museum exhibit research. This review will set the stage for an expression of my position on research pertaining to museum exhibit design. This statement will lead to a description of the objectives of the research project reported here and an outline of how each of the presented papers fits into this framework. Finally, I will present my conclusions and offer some perspectives.

1.1 Motivation

In 2001, I carried out a study on the design and implementation of a museum exhibition about songbirds and bird song (Mortensen, 2002). This work was the conclusion of my studies towards a M.Sc. in biology, and I approached the problem of designing an educational exhibition just as I would have approached any other problem during my studies: I looked to the research literature. This literature, alas, offered limited help. One initial reason for this might have been that the field of museum education research was unfamiliar territory to me and to my advisors; however, it soon became clear that the overwhelming focus of Anglophone science education research literature at that time was on formal, i.e. school- or classroom-based science education phenomena. Further, the literature that *was* available on science education phenomena in informal settings, i.e. museums or science centres, was rather general in scope and tended to focus on visitor learning rather than the mechanisms of how this learning was brought about.

The level of generality at which inquiries into museum education phenomena were located is perhaps understandable: It probably reflected an attempt to generate research findings that had applicability to the widest possible range of museum settings. On the other hand, the focus on *learning* to the exclusion of *teaching*, while perhaps influenced by the origins of museum research in the field of visitor studies, seemed ironic to me. This is because from a pragmatic perspective, the museum has very little influence on what kinds of learners choose to visit their exhibitions (except, perhaps in a very broad sense) but it has all the influence in the world on how those exhibitions are designed.

At any rate, I did manage to finish my research project and put together an exhibition on bird song – an undertaking which inspired my enduring fascination with the exhibition as a medium for science education. In the years following my graduation, I worked in various arenas for informal science education: The North Carolina Museum of Natural Sciences, the Honolulu Zoo, the Waikīkī Aquarium, and the National Aquarium of Ireland; playing various roles: Designer of educational materials, interactive tour guide, informal curriculum planner, education officer, exhibit designer. But throughout this period of time, I kept thinking that *someone* ought to develop theoretical or empirical knowledge about how to take a specific body of knowledge from the scientific context and make it teachable.

As it turns out (and as I was later to find out), *someone* had already done this. In the continental European tradition, *didactics* is defined as the science of knowledge dissemination of in any social group (e.g. Clément, 2000). The term *science* specifies both the process of gaining knowledge about this diffusion, and the organised body of knowledge gained by the process. Doing didactics is therefore not just conducting research to produce knowledge, but it is also arranging this knowledge into an organisation with an empirical basis and a theoretical superstructure (Chevallard, 2005, p. 22). Although didactics pertains to the diffusion of knowledge in any social group, formal science education settings have typically been the exclusive purview of didactics research, at least in the Anglophone literature. However, this may be gradually changing. For example, in 1997, Simonneaux and Jacobi published a research report which used the French notion of *didactic transposition* in case of exhibit design. Subsequently, Gouvêa de Sousa et al. (2002) employed the same notion to analyse the design of existing exhibits. And Laherto is using the German notion of *educational reconstruction* to prepare knowledge about nanotechnology for implementation in a science centre setting (Antti Laherto, pers. comm., 14-01-2010). I will discuss the use of didactics in informal learning settings more extensively throughout this dissertation.

1.2 Literature Review

To set the stage for a review of research literature pertinent to science exhibit design, I begin by defining the phrase. For the purposes of this review, I consider the term *science* to encompass all of the natural sciences. *Exhibit* is understood to mean the smallest unit of an exhibition which can be meaningfully understood on its own, although I shall also consider research pertaining to the *exhibition* which I define as a collection of artifacts arranged for public display. Finally, by *design* I mean the process by which the form and structure of an object, in the present case an exhibit or exhibition, is planned and created.

In this review, I include research pertaining to the planning and creation of exhibits or exhibitions that have a science-related content. Such exhibits and exhibitions are usually the purview of natural history museums, science centres, zoological and botanical gardens, aquaria, and related institutions. These types of institutions are typically unified by their common mission of science education. Accordingly, in the following I shall use the term *museum* to encompass the variety of institutions that deal with science education, and I shall consider exhibits and exhibitions as the media of education which are proper to these institutions.

The literature relevant to science exhibit design is a field of research that is widely, yet thinly addressed. Existing research on science exhibit design is reported in journals on the behaviour of museum visitors and other consumers such as *Visitor Studies* or *Environment and Behavior*, journals targeted directly towards museum practitioners such as *Curator* or *Museum Management and Curatorship*, and science education-related journals such as *International Journal of Science Education* or *Science Education.* As perhaps is indicated by the variety of journals in which research related to science exhibit design is reported, it does not, as a field of research, belong uniquely and exclusively in any one (extant) journal genre.

Procedure

To gather the literature included in this review, I initially conducted an online search using Google Scholar, a web-based search engine which targets academic literature. I used the search terms “science exhibit design” and “science exhibition design” with and without quotation marks, thereby targeting Anglophone literature, and I included literature published in 1990 and later. This procedure yielded a very wide variety of publications, so I discarded all papers which were not research reports and which were not published in peer-reviewed journals. I reviewed the remaining papers, and used the references in these papers as well as the “Cited by” and “Find related papers” functions in Google Scholar to find relevant papers which may not have come up in the original searches. The final result of this search was 54 papers published in the period 1990-2010.

Themes

Three themes are central to the body of the reviewed papers, namely the exhibit or exhibition *medium* itself, the *learner*, and the *content.* Together, these three themes encompass a number of subthemes as shown in Figure 1. The themes and subthemes are not mutually exclusive; nor can the reviewed papers as a rule be said to belong exclusively to one theme or subtheme. Instead, the themes are used to structure the following account in order to provide a coherent narrative of the field of research. To aid the reader, the subthemes are shown in bold the first time they are mentioned in a paragraph.

The Exhibit *Medium*

The theme *medium* characterises the research which has the primary objective of providing content-general guidelines about how to shape the exhibit/exhibition medium to support certain goals. These goals are often defined in terms of so-called **learning-related behaviours**, i.e. visitor behaviours that have been established as indicators of learning, and which are typically defined irrespectively of the content in question. The rationale for using behaviours as indicators of learning is that early attempts to document learning in museums using visitor recall of facts or pre-and post-visit cognitive tests were unsuccessful in documenting learning (Falk & Dierking, 2000). At the same time, the more consumer-related field of visitor studies had already established a tradition of using behavioural studies to document under which conditions museum visitor learning *may* occur (Loomis, 1988). As a consequence, the measurement of visitor patterns of action such as *attraction* (what percentage of visitors approaches an exhibit?), *holding time* (how much time do visitors spend looking at an exhibit?), and *engagement level* (degree to which the visitor pays attention to the exhibit) gained momentum as a way of characterising exhibits and exhibitions that promote learning. For example, Rubinstein et al. (1993) found that the exhibits that attracted the highest percentage of visitors were those that could be physically manipulated. A similar result was provided by Boisvert and Slez (1995), who found that among the exhibit variables high/low interactivity, concrete/abstract presentation, and simple/complex information presented, visitor engagement level and holding power were consistently highest for exhibits that had high levels of interaction. Sandifer (2003) went beyond the interactive/non-interactive distinction by considering how four different characteristics of interactive exhibits, technological novelty, user-centeredness, sensory stimulation, and open-endedness helped account for visitor holding time.

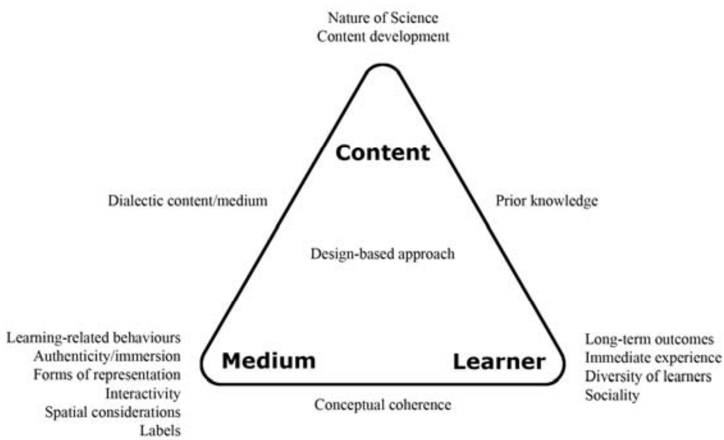

Figure 1.1. The reviewed literature on science exhibit design had three central themes: Medium, Learner, and Content. The three themes encompass sixteen subthemes which are related to one, two, or all three themes. For example, the subtheme Nature of Science is a subset of the theme Content, while the subtheme Dialectic content/medium is located at the intersection between the themes Content and Medium.

Sandifer's findings, namely that technological novelty and open-endedness were significantly correlated with holding time, contributes to the line of research that further clarifies the relationship between exhibit **interactivity** and visitor behavioural goals. While the variables of interactive exhibits studied by Sandifer were unable to account for the majority (79%) of the variance in visitor holding time, Anderson et al. (2002) established that tactile and kinaesthetic experiences, such as those connected to interactive exhibits, in many instances contributed to the formation of strong memories of exhibition visits among children. Interactive exhibits must be designed carefully, though; research by Henderlong and Paris (1996) emphasises the importance of striking the right level of challenge in order to motivate children to interact with exhibit tasks. Allen (2004) echoes this caution, stating that exhibits may have an optimal level of interactivity and advocating for formative evaluation as a way of iteratively reaching this level. And finally, in line with these findings, Heath et al. (2005) point out that designing for enhanced interactivity may be detrimental to the social interaction and collaboration of museum visitors. This last result is discussed later, in relation to the subtheme **sociality**.

Another line of research based on **learning-related behaviours** is that pursued by proponents of the exhibit or exhibition quality of **immersion**. In this body of work, immersion is defined as the experience of feeling engrossed, absorbed, or deeply involved in an exhibit, often (but not always) through the illusion of relocating the visitor to a different time and place (Bitgood, 1990). Harvey et al. (1998a; 1998b) theorised about the characteristics of exhibits and exhibitions promoting a feeling of immersion by applying key features of virtual reality to the exhibition setting. A subsequent investigation showed that incorporating immersion features into an existing exhibition significantly increased time spent by visitors in the exhibition. Furthermore, the investigation indicated a number of exhibit characteristics that measurably contributed to visitors' sense of immersion, including three-dimensional objects, interaction, multisensory stimulation, and role-playing. Another aspect of immersion was studied by Johnston (1998), who found that among 30 exhibit variables with significant effect on zoo exhibit viewing time, exhibit naturalism was the most important. In other words, the degree to which an exhibit looked like a natural habitat had a stronger effect on visitor viewing time than other variables such as the visibility or proximity of the animals in the exhibit. Such **authenticity** was also found by Ash (2004) and Tunnicliffe (2000) (see also Soren, 2009) to be an important characteristic of museum exhibits in terms of eliciting content-related dialogue among visitors; these findings are discussed later under the main themes *learner* and *content*.

Finally, on the topic of exhibit design based on the elicitation of **learning-related behaviours**, Borun et al. studied family behaviour at exhibits in four museums. A number of physical and verbal behaviours observed at these exhibits were found to have a clear relationship with learning, indicating that if these behaviours are observed at an exhibit, it can be inferred that learning is taking place (Borun et al., 1996). The researchers subsequently utilised these findings to propose seven exhibit characteristics that can promote family learning (Borun & Dritsas, 1997). These characteristics are discussed further under the subheading **sociality**; here it may be noted that the significant correlation between learning and certain behaviours found by Borun et al. (1996) lends some credence to the notion of designing educational exhibits on the basis of eliciting certain behaviours.

In a position statement, Gilbert (1995) offers a critique of the **learning-related behaviour** approach to exhibit design, stating that the level of assumption involved in interpreting visitor behaviours as evidence of learning is far too high. Instead, Gilbert advocates for a different approach to exhibit design, including the consideration of the **form of representation** embodied by the exhibit. A study by Stevens and Hall (1997) lends support to the salience of this approach, illustrating how providing multiple forms of representation of a single phenomenon in a science centre exhibit significantly enhances visitors' interactions with it. Gilbert and Stocklmayer (2001) lay further groundwork for the forms of representation approach by theoretically outlining how exhibit design can be refined by distinguishing between demonstrations of phenomena and analogical representations, and a subsequent study shows that this distinction indeed has an influence on the educational outcomes of the respective exhibits (Afonso & Gilbert, 2007).

Falcão et al. (2004) differentiated between synthetic [1] and analytic [2] models for representing astronomical phenomena in a science museum, and investigated children's understanding of these phenomena as a result of their interactions with exhibits based on such models. The investigation shows that exhibits that employ synthetic models tend to constrain and direct children's understandings towards a more scientific view which can subsequently be contextualised by exhibits that employ the analytic models. This finding, that exhibits with different **representation forms** may supplement each other, lends support to the suggestion that exhibits should be grouped in clusters that can mutually support a common theme (Afonso & Gilbert, 2007). This notion is discussed further in relation to the subtheme **conceptual coherence**.

The **spatial structure** of exhibitions has been the subject of a limited number of studies. By studying four different layouts of a travelling exhibition, Rubenstein et al. established that changes in spatial structure significantly affected the effectiveness of an exhibition (Rubenstein et al., 1993). Specifically, factors such as visibility, competition from other exhibits, and accessibility were found to affect visitor behaviour. These findings are supported by a study by Peponis et al. (2004), who found that the line-of-sight accessibility of an exhibit influenced that exhibit's attraction power. Furthermore, the longer visitors stayed at an exhibit, the more they became aware of other individual exhibits visible from that location. There are two important implications of these findings: That the more critical exhibits should be positioned in the more visibly accessible locations and their visibility from other critical exhibits should be considered; and that good individual exhibit design should be relatively independent of the sequence of other individual exhibits that are engaged by visitors. However, on further study, Peponis et al. found that labelling conceptual clusters of exhibits significantly affected the paths of visitors. In other words, providing clusters of conceptually related exhibits with labels had the effect of changing visitors' spatial movements towards a more sequenced exploration. This last finding is discussed further in relation to the subtheme **conceptual coherence**.

Finally, the design of text **labels** is an aspect of exhibit design that has been the subject of some study. After years of disagreement in the museum research field about whether museum visitors actually read labels, McManus (1989) definitively established that this was the case. As a consequence, the role of label design began to be taken more seriously. Borun and Adams (1991) took their point of departure in visitors' naïve notions or misconceptions, and iteratively designed label text for interactive exhibits to target those naïve notions. First attempts showed that labels that presented sequential information, i.e. first operating instructions for the exhibit, then a description of the phenomenon on display, and finally an explanation of the scientific concepts, were unsuccessful in addressing commonly held conceptions about gravity. The empirically refined approach to label writing arrived at by Borun and Adams included using questions to provide the visitors with strong textual links between the operating instructions and the concepts being shown. The salience of the question-posing approach to label design is supported by a study by Hohenstein and Tran (2007) who found that carefully designed question-posing was the label feature among those tested that stimulated the highest number of visitor conversations (see also Gutwill, 2006). Another label feature tested by Hohenstein and Tran was that of text simplification, and while these researchers were not able to measure an effect of this approach, a study conducted by Ravelli (1996) showed that linguistic refinement and simplification of exhibit texts did indeed improve visitors' comprehension of exhibit content. Finally, in a more macroscopic approach to the purpose of exhibit texts, Falk (1997) found that providing visitors with cues as to the overarching concepts presented in two exhibitions by labelling exhibit clusters with their intended messages resulted in significant increases in concept development among those visitors. This finding will be discussed further in relation to the subtheme **conceptual coherence**.

The intersection of the themes *Medium* and *Learner*

At the intersection between the themes *medium* and *learner* is found research that seeks to establish strong connections between exhibit/exhibition design and visitor learning outcomes. The emphasis of the work reviewed here is equally on features of the exhibition and characteristics of the outcomes it can precipitate among visitors. The main subtheme in this work is the notion of providing the visitor with **conceptual coherence** in the layout of an exhibition. Open-plan exhibitions present numerous alternative ways of assembling the contents of individual exhibits into narrative sequences (Peponis et al., 2004). Accordingly, conceptual coherence is often embodied in cues as to the thematic clustering of exhibits. Feher (1990) argues that no individual exhibit by itself can carry the entire intended conceptual message, and advocates that to support the generalisation of scientific concepts, multiple related exhibits are necessary. Thus, the neighbouring exhibits in the immediate surroundings of an exhibit are important for creating and holding visitor attention (Boisvert & Slez, 1995). Falk (1997) found that the presence of consistent, reinforcing conceptual organisers on every exhibit element to indicate their conceptual affiliation facilitated understanding of the exhibition's main messages. As mentioned in the preceding, a similar finding was made by Peponis et al. (2004); the central notion in these findings is that grouping exhibits in appropriately labelled conceptual clusters may compensate for the random pattern of visitor utilisation.

In a more holistic approach to providing **conceptual coherence**, Schauble and Bartlett (1997) advocate a so-called “funnel approach” to exhibition design. In this approach, major exhibition components are designed to engage visitors immediately into entry-level activities that target broad scientific concepts that can be learnt cumulatively. Beyond this initial attraction area the exhibition layout should include quieter areas with options for progressively deeper interactions, culminating at the end of the “funnel” with opportunities for repeat visitors. In this way, the advocated “funnel approach” allows for the gradual building of coherent scientific concepts (Schauble & Bartlett, 1997).

However, while advocating for the principle of **conceptual coherence**, Allen (2004) cautions that such coherence may be difficult to attain in exhibition design. She goes on to outline attempts to create such coherence through exhibition design measures at a science centre; some of which succeeded but some of which failed. Allen states that one of the reasons it may be difficult to create coherence across multiple exhibits is that visitors tend to learn in a concrete, literal way at exhibits, and concludes that museum researchers still face many challenges in this regard.

The *Learners* in the Exhibit

This research theme, i.e. studies of museum visitors and their learning outcomes across content and exhibit medium, seems to be dominant within museum research reported in the mainstream science education literature. One reason for this may be the inability of early museum research to document cognitive gains in visitors as a result of their exhibition visits; this inability may have shifted the focus of the research towards less specific objectives as expressed in the influential text *Learning from Museums*:

> In museums […] we have framed the question as, what does an individual learn as a consequence of visiting this museum […] or seeing this exhibition? The better, more realistic question is, how does this museum […] or exhibition contribute to what someone knows, believes, feels, or is capable of doing? (Falk & Dierking, 2000, p. 11-12).

One approach to investigating this question is to focus on **long-term outcomes** such as visitors’ memories in relation to exhibition visits.

In this line of inquiry, Stevenson (1991) found that several months after their visit to a science centre exhibition, a majority of visitors were able to recall in great detail what had occurred during their visit. The visitors remembered not only what they did, but also how they felt and thought about the exhibits, and many visitors also showed evidence of having related their experiences to what they already knew or had experienced since the visit. Conversely, Ansbacher (1999) and Stocklmayer and Gilbert (2002) emphasise the importance of pre-existing memories in the meaning-making process that takes place in a museum exhibition, and Anderson et al. (2002) provided evidence that these pre-existing memories can be strong mediators of learning. Taken together, the message of these studies is that long-term memories play a significant role, both in conditioning what kinds of experiences exhibition visitors have, but also in shaping subsequent experiences outside the museum context.

A different approach to studying the outcomes of interactions between exhibits and visitors is that of investigating the **immediate experiences** of visitors. Due to the self-directed and interactive nature of many science exhibits, it may be more meaningful to study learning in the immediate experience with the exhibit rather than as a consequence of a museum visit (Rahm, 2004). For example, Tulley and Lucas (1991) used observations of visitors' interactions with an exhibit (assembling a large-scale lock and key kit) to investigate visitors' facility of task and their subsequent understanding of how a lock works. The only variable that could explain facility of task and explanation was whether the visitors in question had watched others assemble the lock before they themselves tried. This result would not have been forthcoming from a study of visitor long-term understanding, and implies that watching or listening in on other visitors may have an important role to play in museum visitors' immediate sense-making. A study by Rahm (2004) supports and expands this finding. Rahm investigated how meaning-making took place among a group of adolescents and a curator in their interaction with an interactive museum exhibit. The study revealed that several modes of meaning-making (i.e. listening in on other conversations, manipulating the exhibit, observing, speaking etc.) were in play during the complex exhibit experience (see also Dufresne-Tassé & Lefebvre, 1994). Rahm interprets her findings to indicate that exhibit design should support visitor engagements over longer periods of time, which would allow for the use of the full range of the visitor's meaning-making tool kit.

Following a similar line of reasoning, Allen (1997) studied the effect of inquiry activities on visitors' **immediate experience** and understanding of a science centre exhibit. She provided visitors with opportunities to conduct inquiry-based activities related to coloured shadows and prompted them to provide explanations for related phenomena. Visitors' resulting explanations generally showed consistency and logic, providing support for the idea that extended engagements with exhibits support meaning-making activities. Afonso and Gilbert (2007) recommend that in order to constructively shape visitors' immediate exhibit experiences, the exhibit should be designed to closely relate to visitors' everyday situations. This finding is related to the utilisation of **prior knowledge** in exhibit design, which is discussed in later sections.

A related line of research deals with the **diversity of learners**. Anderson et al. (2002) found evidence that museum visits lead to diverse, highly individualistic, and idiosyncratic outcomes among children; the challenge for museums is to cater to such diversity of learners without losing sight of their educational responsibilities (Allen, 2004). Among visitor variables that have been studied in this regard are learner developmental level and visitor agenda. Henderlong and Paris (1996) established the importance of providing children with exhibit design with an appropriate level of challenge, and Marek et al. (2002) offer additional evidence that exhibit experiences that result from a careful matching of the cognitive level of the exhibit and the learner lead to increased conceptual understanding. This finding implies that exhibit designers must decide whether they are trying to deliver conceptual understanding to museum visitors, and if so, which cognitive level they are aiming at in their design (Marek et al., 2002; see also Schauble & Bartlett, 1997).

Umiker-Sebeok (1994) found that the meaning-making that took place in visitors' interactions with museum exhibits was strongly influenced by visitors' individual reception strategies. Umiker-Sebeok found evidence for four different reception strategies: pragmatic, critical, utopian, and diversionary, and showed how non-alignment between visitor reception strategy and perceived exhibit type could lead to frustrations and disappointment, and as a result, to a lower than expected frequency of exhibit engagement. Another aspect of the **diversity of learners** was investigated by Sandifer (1997) who found that visitors' agendas had a strong influence on their time-based behaviours in a science centre. Visitors with learning-oriented agendas (typically families) tended to spend more time on interactions with exhibits than visitors with more entertainment-oriented agendas (typically non-families). According to Borun and Dritsas (1997), exhibit design can be directly targeted towards family learning by being “multimodal”, i.e. appealing to different learning styles and levels of knowledge. For example, exhibit components which appealed simultaneously to visual, verbal, and kinaesthetic learners had increased attraction power, holding power, and communication power (Borun & Dritsas, 1997). However, Rahm (2004) discusses how multimodality in itself does not ensure visitor meaning-making and advocates an iterative approach to exhibit design to shed light on the complexity of the learning process among diverse learners (see also Gutwill-Wise & Allen, 2002).

Related to the research on designing for a **diversity of learners** is the line of inquiry that deals with designing for **sociality**. Falk and Dierking (2000) assert that a museum visit is at heart a social event, and accordingly, that museums should support social learning activities. What are the implications of this for exhibition and exhibit design? As mentioned in the preceding, Borun et al. (Borun et al., 1996; Borun & Dritsas, 1997) established seven exhibit characteristics associated with family learning: multi-sided, multi-user, accessible, multi-outcome, multi-modal, readable, and relevant (see Borun & Dritsas, 1997 for an explanation). These exhibit characteristics were found to promote certain learning-related behaviours among family groups visiting museums.

In a later study, Ash (2003) studied the dialogic inquiry of family groups in an exhibition and found various ways of negotiating objects and signage. These negotiations occurred within the multiple zones of proximal development of the various family members, and while Ash makes no recommendations regarding exhibition or exhibit design on the basis of her findings, it seems clear that designing for **sociality** would promote family negotiations of meaning. In a subsequent paper, Ash (2004) uses the notion of zone of proximal development to examine family group conversations at dioramas; here she advocates designing for multiple entry points using scientific themes. In other words, exhibit design should address children’s interests and provide parents with the kinds of ideas, questions and explanations that allow them to assist their children in constructing scientific understanding. At the same time, exhibit design may address more expert learners’ zones of proximal development by providing higher-level entry points. This approach obviously requires knowledge of learner’s ideas, conceptions, and typical questions related to the content matter; a related line of inquiry deals with learners' **prior knowledge** and will be discussed under the subtheme of that name.

Finally, Heath et al. (2005) studied the effect of computer-based exhibits on visitor-exhibit interactivity and found that although new technologies are appealing to museum visitors, the kind of interaction they achieve may undermine social interactions among visitors such as co-participation and collaboration. Accordingly, these researchers recommend that in designing exhibits, we should rethink our conceptions of the visitor, breaking free from individualistic models and placing the social and interactional at heart. In a subsequent paper, Meisner et al. (2007) examine another aspect of museum **sociality**, performance, as a means of co-participation in exhibitions. These researchers find performance to be an effective way of creating engagement and participation with exhibits, and recommend that exhibit engineers promote such activities by equipping exhibits with large interfaces and displays, providing exhibits with ample, delineated floor space, considering lines of sight to accommodate simultaneous views of exhibit and performing visitors, and carefully considering the content and structure of the exhibit itself.

The intersection of the themes *Learner* and *Content*

At the intersection of the themes learner and content is found a line of research guided by the Ausubelian maxim: *The most important single factor influencing learning is what the learner already knows. Ascertain this and teach accordingly*. This body of work addresses learners' **prior knowledge** and pre- and misconceptions as a means to develop exhibit content or analyse the educational outcomes from exhibit interactions.

Examples of research that ascertains the **prior knowledge** of visitors as preparation for exhibit engineering are Guichard (1995) and Ballantyne (2004). Guichard used *didactic diagnostics* as a means to not only establish the range of children's and adults' prior knowledge about a given content (human bones and joints), but to ascertain how their preconceptions of the content could be addressed in exhibit design. In a later paper, Ballantyne (2004) examined students' knowledge of the nature and importance of marine environments. Ballantyne ascertained that students held a number of incorrect or partially incorrect conceptions about the marine environment, and made several suggestions as to how informal learning environments such as aquaria could address such conceptions.

Examples of research that uses the notion of **prior knowledge** to analyse exhibit learning outcomes are more plentiful. However, the findings of such studies are not always in agreement with each other, indicating that generalisations across populations of visitors and content matter should be made with great care. For example, Tulley and Lucas (1991) predicted that prior knowledge of how a lock works would significantly influence the amount of time it took visitors to assemble a large-scale lock and key in an exhibit. Yet, the only aspect of prior knowledge that measurably shortened the time of assembly was whether the visitor in question had witnessed another visitor assemble the lock prior to their own experience. In a later study, Kerrison and Rex (1994) found that when stating the results of their experimentation with an interactive science exhibit, primary school children referred to their expectations of what would happen rather than their recent experience with the exhibit. Allen (1997) found somewhat similar results in her study of visitors' scientific inquiry activities at an exhibit. Even though visitors' lines of reasoning showed consistency and logic when asked to explain a phenomenon, they very rarely revised their explanation of a scientific phenomenon when confronted with disconfirming evidence. Finally, Falk and Storksdieck (2005) investigated visitor learning from a science centre exhibition and found that the lower the level of entering knowledge, the higher the cognitive gains as a result of visiting the exhibition. In other words, the most learning occurred in the visitors with the lowest level of entering knowledge. Together, these studies illustrate that the relationship between prior knowledge and subsequent learning is not straightforward, and that the often-stated role of exhibitions as ideal settings for addressing preconceptions is perhaps overly simplistic.

The Exhibit *Content*

The studies that have been conducted on exhibit and exhibition content tend to be rather macroscopic in focus. For example, Macdonald and Silverstone (1992) discuss the role of museums in society, pointing out that an important contribution could be improving the ability of the public to evaluate and make informed decisions about scientific questions. Macdonald and Silverstone undertook a case study of a museum exhibition on food and found that certain strategies used by the exhibition engineers to promote public understanding of the science content actually constrained the ability of the exhibition to represent scientific controversy and the **nature of science**. Endersby (1997) reached a similar conclusion, emphasising the problematic aspects of using a single, realistic visual language in exhibitions to describe two very different things, namely broadly accepted scientific facts and more speculative, controversial hypotheses. Both studies advocate that museums adopt a more process-oriented model of science, rather than displaying just the products of science. An example of how exhibit content can be developed with such goals in mind is offered by Simonneaux and Jacobi (1997). However, the issue seems to persist: In a recent study which surveyed exhibition engineers from 30 Nordic science centres, Davidsson and Jakobsson (2007) found evidence that current science centre exhibitions continue to portray science in an unproblematic, product-oriented way.

Another approach taken towards exhibit and exhibition content is an institutional perspective on **content development**. In this perspective, exhibition planning is studied as a negotiation of differences of opinion among exhibition engineering team members. Often, these negotiations devolve into a competition which can ultimately undermine the quality of the end product, the exhibition (Lindauer, 2005). Lindauer suggests adopting a curriculum theory approach in order to reach a consensus about the intended visitor outcomes and to construct a shared game plan about how to reach this goal. In a subsequent publication, Lee (2007) critiques this approach, stating that while curriculum theories can inform exhibition development, they do not suffice by themselves to understand the collaborative process. Rather, Lee suggests, the process should be understood as the nexus of different cultures. Neither of these studies seems to have direct implications for exhibit or exhibition design; rather, their contribution lies in suggesting how to conceptualise and manage aspects of the design process.

The intersection of the themes *Content* and *Medium*

Content and medium are arguably the two main ingredients in exhibits and exhibitions, yet there are very few studies that deal with the **dialectic** between them. In his text *The Design of Educational Exhibits*, Miles states that

> Selecting the right medium [for a given content] is one of the key activities in exhibition design. This is not a straightforward matter, however, and there are few rules to guide the selection process (Miles, 1988, p. 78).

Judging by the small number of studies that systematically deal with the selection process, this state of affairs seems to persist. In an epistemology-oriented approach, Schauble and Bartlett (1997) discuss how biological knowledge is slowly constructed by children in a cumulative fashion, while physics knowledge is much more prone to misconceptions. Accordingly, Schauble and Bartlett argue, exhibition design should address the peculiarities of the content, for example by embodying biological content in experiential, more immersive environments and embodying physics content in interactive exhibits that help children develop sound intuitions that can form the basis for later instruction.

Tunnicliffe and Laterveer-de Beer (2002) studied the relationship between exhibition design and content learning in an exhibition about animal skeletons and locomotion. They found that the chosen design, namely arranging animal skeletons according to different forms of locomotion, was relatively unsuccessful in engendering understanding about skeleton structure and function. One reason for this was that the level of prior knowledge assumed by the exhibition engineers was too high. However, neither content nor medium was systematically varied in this study. Finally, Ash (2004) mentioned in passing that the historical role of dioramas was to promote conservational attitudes by portraying aspects of biodiversity, perhaps implying that the diorama is most suited to mediate ecological relationships.

The intersection of the themes *Medium, Learner* and *Content*

The final section of the present literature review describes the studies that consider the interaction between medium, learner, and content. In other words, these studies make systematic observations of how a particular content, embodied in a particular form, can elicit particular learning outcomes. An important example of such work is the study by Falcão et al. (2004), in which the exhibits in question were conceptualised as *teaching models* by considering the astronomy knowledge that the exhibits were intended to mediate as well as the mechanics of how the interactive components were intended to do so. These teaching models were subsequently compared to the models formed by students who had interacted with the exhibits as a means to investigate the relationship between content, medium, and learning outcome. In a related approach, Botelho and Morais (2006) studied student's interactions with two science exhibits as a means to understand the relationship between procedure (what the students *did* during their interaction) and understanding (how the students *interpreted* their interaction). Both of these studies found instances of divergences between intended and observed learning outcomes and were able to trace these divergences back to design features of the exhibits in question. To sum up, these studies studied *learning in context*, and even though the two cited studies do not refer to themselves as such, they address many of the requirements inherent in a **design-based research approach**. This approach is increasingly being advocated by museum researchers (e.g. Schauble et al., 1997; Hsi et al., 2004; Falk & Storksdieck, 2005) as a means to understand and manage the complexity of exhibit design.

Summary of findings

My main objective with this review was to take an evidence-based approach to theoretical and empirical research on science exhibit design. For this reason, I focused on research reports published in peer-reviewed journals, and excluded the substantial, but more review-based literature on exhibit design that has been published in books. However, it is clear from the preceding review that scientific investigations of science exhibit design and the implications of these investigations are of a quite varied nature. The following list sums up the main findings:

- Exhibit design should
    - incorporate interactivity without interfering with social interactions
    - match cognitive level and level of challenge to the intended visitors
    - support engagement over longer periods of time
    - relate content to everyday situations
    - appeal to different learning styles and levels
    - allow for social interactions and performance
    - incorporate naturalism, multisensory stimulation, and role-playing
- The location of conceptually important exhibits should be considered
- Exhibit labels should include question-posing and be linguistically simple

- Grouping exhibits in appropriately labelled conceptual clusters that include different forms of representation may enhance learning outcomes
- Memories play a significant role in shaping experiences both in- and outside the museum
- Didactic diagnostics may pinpoint important preconceptions, but it is not yet clear how exactly exhibit design can target these
- Exhibits should portray the process, rather than the products, of science
- The relationship between content and medium is not fully understood
- A design-based approach to exhibit design is advocated

1.3 Position Statement

The emphasis of the reviewed literature in relation to the three main themes (medium, learner, and content) and the intersections between them is on investigations regarding the medium and the learner, respectively (Figure 1.2). As mentioned in the preceding, the prevalence of these types of approaches may be due to the objective of generating as widely generalisable findings as possible. Yet, in the words of Schauble et al. (2002, p. 426),

> …the past 30 years of cognitive psychology demonstrate that thinking and problem solving are always modulated by the content domain and task at hand. Although it is possible to describe general strategies for supporting learning, general strategies are relatively prone to error…

The result of the tendency described above is that the research-based development of tools and processes for use by exhibit engineers is missing from the field of museum research. To wit, the summary of findings listed in the preceding does not provide any real guidelines for exhibit engineers as to how to go about selecting the appropriate body of knowledge regarding the scientific content, or how to transform this content into the three-dimensional educational installations that comprise an exhibition. In order to take the educational objectives of museums seriously, and thus to conduct research that can inform exhibit development, I propose using a didactical approach.

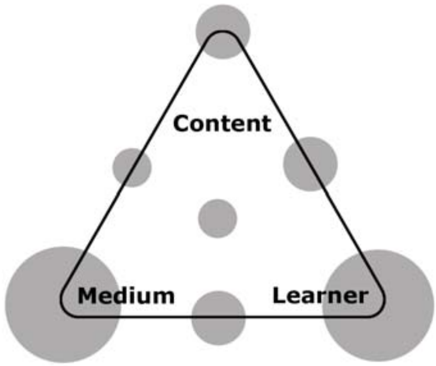

Figure 1.2 The emphasis of the reviewed literature on science exhibit design. The area of the grey circles is proportional to the number of times the particular theme or intersection between themes was treated in the 54 reviewed papers.

Didactics is defined as the science of the dissemination of knowledge in any social group (Clément, 2000), and can be symbolised by a triangle which relates knowledge, learner, and teacher. Didactics deals not only with the points of this triangle, but especially with the relationships between them. The points represent the conceptual structure and epistemology of the content domain (the *knowledge* point), the various psychologies of learning (the *student* point), and the teaching models (the *teacher* point) (Figure 1.3 A). The areas between the points relate to the following didactical concepts (Astolfi et al., 1997):

- Development of content
- Strategies of appropriation
- Didactical interactions
- The construction of didactic situations

Considering exhibit development as a problem of didactics leads to the re-statement of the didactic triangle as a *museographic* triangle (Figure 1.3 B). In this perspective, exhibition development becomes an undertaking that must account for content development (the selection and development of knowledge in relation to the chosen exhibit medium), prospective learner-exhibit interactions (the precise planning of the intended relationship between exhibit features and visitor actions and reflections), and appropriation strategies (e.g. representation forms, prior knowledge, or epistemological obstacles). Collectively, these domains constitute the construction of the exhibit.

What are the implications of considering exhibit development a problem of didactics? First of all, it points to an important issue with the existing research on science exhibit design (as expressed in Figure 1.2), namely that the strong focus on single variables such as the medium or the learner makes this research unable to account for the complexity of exhibit design. This does not suggest that the existing research has not made important contributions. On the contrary, comparing the diagram outlining the emphasis of the existing research (Figure 1.2) with the museographic triangle (Figure 1.3 B) demonstrates how the existing research may inform the development of a framework of *museum didactics*.

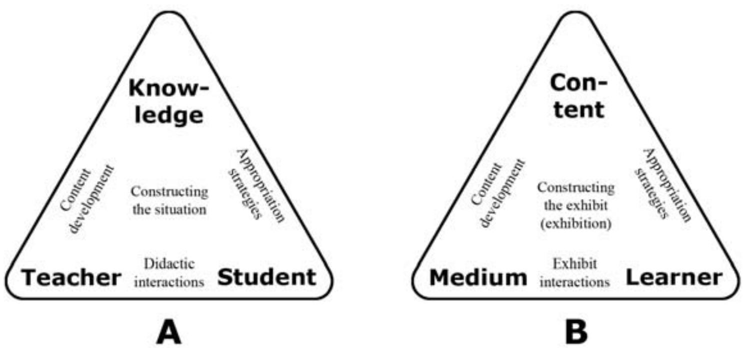

Figure 1.3 The didactic triangle (A) (from Astolfi et al., 1997) and the corresponding *museographic* triangle (B).

A second implication of considering exhibit development a didactical problem is related to the nature of didactics as a design science. Chevallard reminds us that doing didactics is not just conducting research to produce knowledge, but it is also arranging this knowledge into an organisation with an empirical basis and a theoretical superstructure (2005, p. 22). Applying didactics to the development of informal science learning environments such as exhibits accordingly entails that we, as researchers, change our approach to science teaching and learning from the scientific study of naturally occurring phenomena to that of a design enterprise (Schauble & Bartlett, 1997).

What form, then, should this design enterprise take? Several researchers in the field of informal science education (e.g. Schauble et al., 1997; Hsi et al., 2004; Falk & Storksdieck, 2005) point to a paradigm known as a *design-based research*, which is characterised by the following five qualities:

1. The central goals of designing educational environments and developing educational "prototheories" are intertwined,
2. Development and research take place through cycles of design, enactment, analysis, and redesign,
3. Research on educational designs must lead to sharable theories that help communicate the implications to practitioners,
4. Research must account for how designs function in authentic settings, and
5. The development of such accounts relies on methods that can document and connect processes of enactment to outcomes of interest (The Design-Based Research Collective, 2003, p. 5).

In practice, design-based research proceeds in iterative cycles of design, enactment, analysis, and redesign (Figure 1.4). This cycle embodies the two faces of design-based research: prospective and reflective. The prospective nature of the approach is apparent in the design phase where an educational intervention is constructed based on a hypothesised learning process and the means of supporting it. This design is thus a testable conjecture about the means of supporting a learning objective (Cobb et al., 2003). The reflective nature of the approach is apparent in the analysis phase, where findings from the preceding steps are analysed to form a coherent evaluation of the results. This evaluation may then be synthesised with relevant extracts of education theory to create a refined hypothesis (a "proto-theory") for the construction of the educational intervention, which then forms the basis for a new, prospective (re-)design phase. The following sections describe how this approach is used together with didactic theory in order to construct a proto-theoretical model for the design of science exhibits.

1.4 Objectives

The present research project takes a design-based research approach to exhibit design, using didactic theory, specifically the Theory of Didactic Transposition (Chevallard, 1991) and the Anthropological Theory of Didactics (e.g. Chevallard, 2005) to analyse, understand, and make predictions about the exhibit design and enactment processes. The objective of the work presented here is to examine a single case of exhibit design and enactment in order to develop a theoretical model for how the process can be systematised and improved.

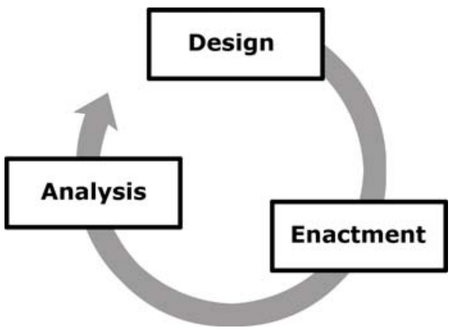

Figure 1.4 The iterative cycle that characterises design-based research.

The research questions addressed by this work are the following:

1. What is the nature of the constraints and opportunities which govern the design of a science exhibit which features a specific object of knowledge?
2. What is the relationship between the designed characteristics of a science exhibit and the subsequent visitor interactions with and understandings of that exhibit, using the stated learning objectives for the exhibit as a measure of how well the exhibit performs?
3. How can the relationship between content, learner, and exhibit medium be conceptualised in a form that can optimise exhibit design?

Research questions 1 and 2 are reflective in nature, and are addressed in the first two papers presented in the following chapters. They correspond to the design and enactment phases of the design-based research cycle (Figure 1.4). Research question 3 is prospective in nature, and is addressed by the third of the presented papers. This paper embodies the analysis phase of the design-based research cycle (Figure 1.4), and also addresses the design by presenting a theoretical redesign of the exhibit in question. Finally, the fourth paper presented here is an alternative perspective on exhibit design which draws on design- and enactment-related findings reported in the museum research literature to illustrate the theoretical generation of ideas for exhibit design.

1.5 Overview of the presented papers

Museographic Transposition: The development of a museum exhibit on animal adaptations to darkness

This paper investigates the development of a biology exhibit (*Cave Expedition*) in an attempt to characterise the design process and point out the inherent constraints and opportunities that shape the end product–the exhibit. The paper offers three main contributions to the field of museum research. First, the study presents and exemplifies an analytical method (*museographic transposition*) applicable to the development of new exhibits as well as the post hoc analysis of existing exhibits. Taking its point of departure in the biological body of knowledge to be transposed and mapping the changes in this body of knowledge as it is transposed to the new context and modality of the exhibit, the method enables the systematic tracking of the epistemological and semiotic changes in a body of knowledge in the exhibit development process. This method along with the findings it yields here are the first-order results of the first paper.

The descriptive model of exhibit engineering synthesised from the analysis of museographic transposition is the second contribution of this work. The model constitutes an important step towards systematic studies of the processes and mechanics of exhibit engineering. It emphasises the dialectic relationship between scientific knowledge and museographic form and ultimately, the importance of optimising the fit between object of knowledge to-be-exhibited and exhibit genre. The model constitutes the second-order result of this study.

Finally, a third-order contribution of this study to the field of museum research is the foundation that is laid for a normative model of exhibit engineering. This foundation is expanded in the second paper which investigates visitor interactions with and understanding of the exhibit in question.

Analysis of the Educational Potential of a Science Museum Learning Environment: Visitors' experience with and understanding of an immersion exhibit

This paper investigates the connections between the design of an exhibit (*Cave Expedition*) and visitors' interactions with it. It examines in detail how an immersion exhibit works, i.e. how it mediates its biological message to museum visitors. The paper offers two main contributions to the field of museum research. First, the analytical method used in this study (the notion of *praxeology* from the Anthropological Theory of Didactics) seems promising as a way of connecting the practical and theoretical aspects of what visitors do in an exhibit to aspects of the exhibit's design. In this sense, the study presented in the second paper provides a strong tool for the analysis of the educational potential of science exhibits.

The second contribution of this paper is towards the construction of a normative model for science exhibit engineering. The study links elements of the visitors' learning outcomes to elements of the design, and thus to certain of the constraints that influenced the design. The establishment of these links marks the completion of the description of exhibit design and enactment, and sets the stage for a shift towards the prescriptive or normative perspective taken in the following paper.

A Normative Model for Science Exhibit Design

This paper represents the final phase in the development of a model for exhibit design. The paper constructs a theoretical, prescriptive model of exhibit engineering based on the analysis of the design and enactment of *Cave Expedition* presented in the first two papers. The construction of the model is further informed by current research findings from science education literature in general and museum research literature in particular. The utility of the model is exemplified in a description of a theoretical design iteration of the studied exhibit. Here, it is shown how biological content can be developed according to the medium of an immersion exhibit, how the embodiment of that content can consider and address the prior knowledge of learners, and how an immersion-type exhibit can be organized to precipitate the intended visitor interactions and reflections. Finally, although the model of exhibit engineering was developed on the basis of investigations of a specific case and thus addresses the content and context of this case, the property of the model as a paradigm case of a larger class of phenomena is discussed. It offers contributions to the field of museum research on three levels: Domain theory, design framework, and design methodology.

Designing Immersion Exhibits as Border-Crossing Environments

This final paper is more loosely connected to the main core of the research presented here. The paper illustrates how education theory (the notion of *cultural border-crossing*) can be used to analyse and synthesise design guidelines for a special exhibit form: Immersion exhibits. The application of the notion of border-crossing to the design of immersion exhibits yields constructive and systematic ideas on how to create exhibits that appeal to a broad range of visitors, thus exemplifying the merit of applying education theory to a field which is to some extent still governed by tacit experience and professional know-how. This is the main contribution of this paper to the field of museum research.

1.6 Conclusions

In conclusion, the work presented here dealt with the following research questions:

1. What is the nature of the constraints and opportunities which govern the design of a science exhibit which features a specific object of knowledge?
2. What is the relationship between the designed characteristics of a science exhibit and the subsequent visitor interactions with and understandings of that exhibit, using the stated learning objectives for the exhibit as a measure of how well the exhibit performs?
3. How can the relationship between content, learner, and exhibit medium be conceptualised in a form that can optimise exhibit design?

The exploration of the first research question elucidated certain characteristic phenomena which influenced a case of exhibit engineering. These phenomena were epistemological, museum-pedagogical, and practical in nature, and to a large extent governed the exhibit engineering process. In particular, the dialectic between the epistemological specificities of the biological object of knowledge to-be-exhibited and the museum-pedagogical characteristics of the chosen immersive exhibit form strongly constrained, but also provided opportunities for the engineering process. This study emphasised the need for an increased degree of control over the exhibit engineering process.

The degree of interaction between biological content and exhibit form was further explored in the case of hypothetical exhibit engineering leading to the subsequent conceptualisation of the association between content and form as a relationship of co-determination.

The exploration of the second research question found a causal relationship between the design of the exhibit and visitors' subsequent experiences with it. Specifically, characteristics of the visitors' interactions with and interpretations of the exhibit were traceable to characteristics of its design and to the phenomena that influenced the design. This study emphasised the need for a more fine-grained perspective on the desired outcomes of visitors' exhibit interactions.

The exploration of the third research question formed the last investigation in a coherent sequence which contributed towards the development of a theoretical model for exhibit engineering. The developed model proposes the use of praxeology as a means to organize the desired learning outcomes of an educational exhibit. It proposes the idea of using the researcher's praxeology as a template for museographic transposition as a measure of control during the exhibit engineering process. And finally, it proposes the carefully defined procedures of framing, staging, and execution as guidelines for the engineering process itself.

1.7 Perspectives

The model developed through the work presented here constitutes, to my knowledge, the first instance of an exhaustive, cohesive prescriptive model for science exhibit engineering in the Anglophone research literature. It is exhaustive in the sense that it addresses the development of content, the strategies of appropriation, and the mechanisms of the didactic interactions of the prospective exhibit. It is cohesive because it accounts for the combination of these domains in the process of exhibit engineering. And it is prescriptive because it goes beyond describing existing practice, drawing on current research to make claims about what prospective practice should be. The next step in this line of research is accordingly to validate the model by carefully testing it in practice.

Given the long history of museum research, why has such a model not been developed already? A possible answer to that question may be that it has – only not in the Anglophone research literature. It is beyond my present capabilities to carry out a review of French, German, Spanish or Portuguese-language literature, yet as may be apparent from the references cited in the four papers that comprise this dissertation, I have occasionally come across highly relevant literature in these languages and done my best to draw on the findings presented in them. This could suggest that the line of inquiry related to museum didactics already exists outside the sphere of Anglophone research.

Another reason that a prescriptive model of exhibit engineering such as the one presented here has not been forthcoming in the Anglophone research literature is the somewhat puzzling focus of many science education research journals on the learning aspect of science education. Although the dictionary definition of the term education is *any act or experience that imparts knowledge or skills,* the leading journals seem to have a very strong emphasis on the imparted knowledge or skills, almost to the exclusion of the mechanisms designed to impart them. Certainly, I have encountered this emphasis, expressed as an acceptance criterion, in my attempts to publish some of the work presented here. However, it seems that change is afoot: More and more, science education researchers are turning towards design-based methods. And the leading European science education journal, *International Journal of Science Education* has just announced plans to publish a special section on informal science education research. Perhaps in the future we shall see the focus of this research shift towards a more balanced approach to the dialectic between teaching and learning.

Finally, my objective in undertaking the present research project was always primarily to provide science exhibit engineers with theoretically grounded, empirically validated tools for exhibit design. However, after having completed the project, I find I have no illusions that the work presented herein is practically applicable for exhibit engineers in its present form. Accordingly, I believe that an important next step is to explore avenues of making the relevant aspects of my work accessible to science education practitioners. This could entail giving workshops (I have already had some success with this), attending and giving presentations at conferences for museum practitioners, and authoring handbooks. As I write this, the future seems bright with research opportunities in informal science education.

Marianne Mortensen

June 13, 2010

1.8 Notes

1. Synthetic, i.e. deals with more than one variable at a time.

2. Analytic, i.e. fragments the phenomena and isolates one specific variable.

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2 Museographic Transposition

The development of a museum exhibit on animal adaptations to darkness

Marianne Foss Mortensen

Abstract. Science museums define the objectives of their exhibitions in terms of visitor learning outcomes, yet exhibition engineering staff lack theoretical and empirical research findings on which to base the creation of these educational environments. Here, a first step towards providing such research is reported. Museographic transposition was used as an analytical framework to investigate the development of an existing museum exhibit on animal adaptations to darkness. The analysis yielded a descriptive model of exhibition engineering as a three-stage process in which simultaneous processes of epistemological development and museum-pedagogical development result in the curatorial brief which forms the basis of the subsequent museographic development of the physical exhibit. Examples are discussed which illustrate the use of the model in identifying exhibition inconsistencies, but also in generating new ideas for exhibition engineering. The potential for further developing the model is discussed. **Education & Didactique 4(1), 119-137, 2010. Reprinted here with permission.**

2.1 Introduction

The objectives of science museums are often stated in terms of visitor educational outcomes, and the primary medium of a museum's education activities is the exhibition (Lord, 2002, p. 1). In spite of this educational emphasis, there is little research available to exhibition creators on how to achieve such goals, and exhibition engineering (the process of originating, developing, and implementing an exhibition) thus remains largely based on the tacit professional knowledge of museum staff rather than theoretical underpinnings or empirical evidence.

The sheer quantity of museum research that has been carried out in the last decades seems to contradict this statement. However, the applicability of this work to exhibition engineering is restricted by two characteristics: first, the focus of this work is typically the visitor rather than the exhibition. Second, the research seeks to describe strategies for supporting museum learning that are broadly generalisable and thus often somewhat removed of the exhibition's content.

It is not surprising that museum research devotes considerable attention to the visitor; after all, they are the raison d'être of any museum exhibition. However, the physical exhibition, not the visitor, is the only thing over which the exhibition engineer has direct control (Ansbacher, 1999), and thus the application of research findings pertaining to the visitor can only indirectly influence exhibition engineering. Furthermore, the underlying assumption of finding content-independent educational strategies is that incorporating these strategies into exhibition design will precipitate visitor learning regardless of the subject matter of the exhibition. Yet, research shows that thinking and problem solving are always modulated by the content of the task at hand (Schauble et al., 2002), and exhibition engineering can thus not ignore the specific content that is to be exhibited. In order to conduct research that is applicable to the engineering of educational exhibitions, a different approach is needed: one may say that besides museum *pedagogy*, museum *didactics* is needed.

Aims

This paper aims to present and exemplify a framework for the content-based analysis of exhibition engineering using as a case an existing exhibition unit at a Danish science centre. The analysis will yield a descriptive model of exhibition development which both encompasses and manages the complexity of the process. Specifically, the model will be used to answer the following research question: What is the nature of the constraints and opportunities which govern the putting-into-exhibition of a specific object of knowledge? More generally, the potential of the model for improving and innovating exhibition engineering will be assessed and discussed. Finally and perhaps most important, the descriptive model will form the first component of a larger research project intended to provide a prescriptive model for exhibition engineering. The findings presented here will thus inform the next step of this process, the investigation of visitor interactions with and understanding of the exhibition unit in question.

2.2 Theoretical Framework

Knowledge Transformation in the Exhibition Engineering Process

The theory of didactic transposition (Chevallard, 1991) originated in the didactics of mathematics but has since then been extended to other disciplines. It will be considered and developed here as a framework for analysing the process of exhibition engineering. The most important assumption of this theory is that the minimal unity of analysis of any didactic situation cannot be limited to how the learner learns, but must consider the process which makes an object of teaching from an object of knowledge to be taught (Chevallard, 1991); a process which involves a deconstruction and a rebuilding of the different components of knowledge with the aim of making it teachable (Bosch & Gascón, 2006). By emphasising the transformation of an object of knowledge in its passage from the scientific context to the teaching context, the framework of didactic transposition at the same time suggests an inquiry into this transformation and provides the primary means to perform the inquiry. It offers a method to exercise or gauge *epistemological vigilance* (Chevallard, 1991), i.e. the consistency of the relationship between the created didactic object of knowledge and its scientific origin.

Consider the following example of didactic transposition: a cell biologist may perceive of an animal cell as any member of a highly diverse group, e.g. red blood cells, liver cells, or epidermal cells. However, Clément (2007) found that primary school textbook illustrations often show a decidedly didactic object: a prototypical version of an animal cell which combines the attributes of many different types of cells without corresponding exactly to any single type. The deconstruction and reconstruction of knowledge involved in the creation of this didactic object serves the purpose of establishing the general domain of the animal cell; a general domain into which children can then progressively integrate singular types of animal cells possessing both the general attributes as well as more specific ones (Clément, 2007). However, upon further analysis, Clément found that animal cells in many textbooks are illustrated as singular, isolated cells, which does not reflect the multicellular nature of animal tissue. Clément suggests that this shortcoming could be an obstacle to learning; in the present case, it may be thought of as an example of a lack of consistency between the created didactic object and the scientific object of knowledge which precipitated it.

The adaptive transformation of knowledge that takes place in a museum exhibition engineering context, *museographic transposition*, was first studied by Simonneaux and Jacobi (1997) who conceived of the process as the transposition of an object of knowledge contained in scientific literature and other sources to an object of knowledge contained in the exhibition (Figure 2.1 A). This conception was expanded by Gouvêa de Sousa et al. (2002) to encompass three *moments of transformation* of knowledge: preparation, execution, and the visit to the exhibition. Preparation corresponds to the transition between scientific source knowledge and the strategy to put it on exhibition. The second moment, execution, marks the installation of that knowledge into space – the physical implementation of the exhibition. The third moment, the visit, is marked by the arrival of the visitor to the completed exhibition (Gouvêa de Sousa et al., 2002) (Figure 2.1 B).

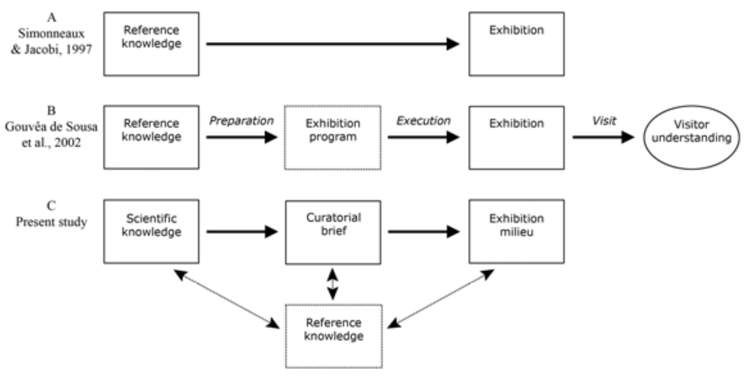

Figure 2.1. The model of museographic transposition as conceptualised by Simonneaux & Jacobi (1997), Gouvêa de Sousa et al. (2002), and in the present study.

Neither Gouvêa de Sousa et al. (2002) nor Simonneaux and Jacobi (1997) conceive explicitly of an intermediate phase between that of the scientific source knowledge and that of the exhibition, although Gouvêa de Sousa et al. (2002) imply the presence of such an intermediate stage by considering preparation and execution as two discrete moments. Indeed, in practice, exhibition engineering usually entails the formulation of a document or collection of documents, the curatorial brief (Nicks, 2002, p. 356), which spans the boundary between the context within which the scientific knowledge evolves and exists and the context within which a physical installation, namely the exhibition, is developed and implemented. The creation of such a document serves not only to extract a body of knowledge from the scientific field and reduce it to a content according to the exhibition objectives (Gouvêa de Sousa et al., 2002) but also to provide a guiding purpose (Nicks, 2002, p. 356) which informs the further creative work that is required during the implementation stage (Miles, 1988, p. 43). The brief thus provides a means of translation between a scientific context and an exhibition context. In the present study, museographic transposition is conceptualised with a three-stage framework including the contexts of the scientific source knowledge, the curatorial brief, and the exhibition milieu (Figure 2.1 C).

The model of museographic transposition offers a structure for the analysis of the development and implementation of content in an exhibition, but does not in itself provide a theoretical context for this analysis. Simonneaux & Jacobi (1997) used the model to carry out a linguistic analysis of the transposition of exhibition texts (Figure 2.1 A), while Gouvêa de Sousa et al. (2002) used it to frame a semiotic exhibition analysis (Figure 2.1 B). In both cases, the scientific source knowledge comprised the baseline against which the transposed version of the content was compared; hence the starting point of the transposition framework was in both instances designated as the *reference knowledge* (Figure 2.1 A and B). In the present study, the notion of museographic transposition is used to structure an epistemological analysis in which the changes following the deconstruction and reconstruction of a biological object of knowledge are mapped and analysed. Each step of the transposition is analysed in terms of the preceding steps as well as the current context; the reference knowledge may accordingly be thought of as an independent structure which encompasses not only the scientific knowledge in question, but also the context-related museographic permutations of it.

Museographic Form

The term museographic transposition has wider implications than just offering a model of the transformation of knowledge in an exhibition engineering context. While the modality of knowledge is the same in the scientific context and in the curatorial brief, namely text, the modality of the knowledge undergoes a change as it is transposed into the three-dimensional installation of the exhibition milieu. The museographics of a subject accordingly deals with the material representation of a subject in a museum setting, i.e. the manner in which the subject is exhibited or its museographic form. Science museum exhibitions present scientific content, but inherent in the presentation is an indication of how the content is to be understood (Davallon, 1999, p. 7) and a comprehensive study of the knowledge present in the museum exhibition–the end product of museographic transposition–must consequently include an investigation of the museographic form in which that knowledge is presented. The present study employs the analytical framework regarding immersive exhibitions which was elaborated by Belaën (2003) on the basis of work by Montpetit (1996), and which is outlined in the following.

Immersion is a specialised exhibition practice in museums, defined by the creation of an illusion of time and place through the reconstruction of key characteristics of a reference world and by integrating the visitor in this reconstructed world (Bitgood, 1990). The successful reconstitution of the reference world relies on the presentation of the exhibition as a coherent whole with all the exhibited objects supporting the representation, the integration of the visitor as a component of the exhibit, and the consequent dramatisation of matter and message (Belaën, 2003) (Table 2.1).

Logic of representation of the reference world

Belaën (2003) distinguishes three logics of representation: exogenous logic, endogenous logic, and a combination of the two. An immersive exhibition that is based on an exogenous logic represents a reference world which is real or fictional. The intent is to reconstitute this reference world as authentically as possible, and the rules or logic of this representation thus originate outside (exogenously to) the exhibition, in the existing reference world (Montpetit, 1996). An example of an immersive exhibit which represents a reference world according to an exogenous logic could be a walk-through tropical African rain forest with authentic animal and plant specimens or exact replicas of them. Here, the exhibition engineers are not free to interpret the subject matter, but must closely reconstitute the reference world.

If an immersive exhibit refers to a world that does not exist nor has existed, its mode of representation then follows an endogenous logic

(Montpetit, 1996). The world represented in the immersive exhibit is created ad hoc to serve the needs of the exhibition objectives, and follows only the rules and logic which it itself generates (which are endogenous to it). An example of an exhibit which is based on an endogenous logic could be a virtual reality exhibit which creates a world for the user to explore according to the exhibition engineers' predefined rules. Here, the exhibition engineers have complete discretion over the creation of the represented world.

Finally, an immersive exhibition which employs a combination of exogenous and endogenous logics is an exhibition that utilises interpretation. If the reference world is not a human-scale realm, or if the significant experiences of the reference world are abstract, the exhibition engineers must rely on a metaphorical or analogical principle in order to represent that reference world (Montpetit, 1996). An example of an immersive exhibit based on a combination of logics could be a walk-through exhibit of a scale model of the human digestive tract. The morphology of such an exhibit would be based on the exogenous logic of an existing reference world (the human digestive tract) interpreted by exhibition engineers to create an ad hoc analogical representation according to an endogenous logic.

Integration of the visitor

Physical space is not just the background to human activity and experience, but an intrinsic aspect of it (Hillier & Tzortzi, 2006), and the spatial aspect of immersion exhibitions is thus central to the integration of the visitor. The integration of the visitor is due not only to their physical presence in the exhibit, but also to the implications of their body in the installation. These implications include the perceptual experiences the visitor has during the visit and the role which is implicitly assigned to them in the proposed enactment. For this reason, if the exhibition does not invite the visitor to interact, the installation may be perceived as decoration and may not assume the full meaning necessary for the comprehension of the exhibition's message (Belaën, 2003).

The integration of the visitor may be based on a variety of techniques which offer more or less complete immersion. At one end of this range are exhibitions which simply reconstitute an authentic setting. Beyond creating an ambience, such exhibitions do not attempt to assign the visitor a role. An example of this level of visitor integration could be the aforementioned reconstruction of an African rainforest, open for visitor perusal and percolation.

Role-play is an intermediate form of visitor integration where the visitor is specifically assigned a role or character to play in an enactment. Belaën (2003) mentions as an example of such role-play the exhibition *Titanic: the Artifact Exhibition*, where visitors are given a replica of a White Star Line ticket bearing the name and history of an authentic passenger on the *Titanic*.

Finally, truly interactive exhibitions (rather than merely reactive exhibitions) allow the visitors to interact with and modify their environment in real time and thus offer a high level of visitor integration. An example could be the experience provided by a virtual reality walk on the bottom of the ocean, where events unfold according to the decisions acted out by the participant.

Dramatisation of subject matter

Immersion exhibitions operate according to a principle of dramatisation, where the subject of the exhibition is apprehended by the visitor in terms of time and space (Belaën, 2003). The goal of any dramatisation is to make the audience perceive a narrative by displaying the actions of some *characters* in conflict. The characters' actions are organized in a *plot*, and the plot moves in a *direction* (Damiano, Lombardo, & Pizzo, 2005). Accordingly, the degree to which the subject of an immersive exhibition may be dramatised depends on the degree to which the museum visitor understands and accepts their role as the main character, the degree to which the conflicts of that character are made clear to them, the degree to which the surroundings allow them to act on that conflict, and the degree to which they are able to make sense of these actions in terms of a direction. Some types of immersive exhibitions depend strongly upon this principle of dramatisation (for example, a virtual reality experience), while others rely less on it (for example, a reconstituted African rain forest).

In sum, the analysis of the museographic transposition presented in the following sections will consider an object of knowledge and its moments of transformation between the scientific context, the curatorial brief, and the exhibition milieu. Further, the analysis will account for the museographic form of the knowledge in the exhibition milieu, specifically the components of an immersion exhibit: logic of representation, integration of visitor, and dramatisation of subject matter (Table 2.1).

Table 2.1. Characteristics of an immersion exhibit and their respective subcategories. The subcategories of logic of representation are mutually exclusive; the subcategories of integrating the visitor represent a range; both are from Belaën (2003). The subcategories of dramatisation of subject matter are interdependent components from Damiano et al. (2005).

Characteristics of an immersion exhibit	**Subcategories or components**
Logic of representation of the reference world	• Exogenous • Endogenous • Combination of exogenous and endogenous
Integration of visitor	• Ambience • Role-play • Real time modification of environment
Dramatisation of subject matter	• Visitor accepts the role of a character • Visitor understands the conflicts of character • Exhibit allows visitor to act on conflicts • Visitor makes sense of actions in terms of direction of plot

2.3 Empirical Setting, Data, and Method of Analysis

Setting

The case used to exemplify this theoretical framework was part of the exhibition *Xtreme Expedition* which opened in 2007 at the Danish science centre Experimentarium in Copenhagen. *Xtreme Expedition* was the result of collaboration between three institutions: Experimentarium, the Royal Belgian Institute of Natural Sciences (RBINS) in Belgium, and Naturalis in the Netherlands. The general theme of *Xtreme Expedition* was adaptations to extreme environmental conditions on Earth and it featured five clusters featuring heat, cold, aridity, low oxygen, and darkness, respectively. The attention here was to the engineering of a single immersive exhibit, *Cave Expedition*, within the cluster on darkness. The stated objective of *Xtreme Expedition* was to enable visitors to "find out how animals, microbes and plants are adapted to survive under stressful conditions" (Executive Committee, 2005b, p. 4), and extrapolating the objective to the exhibit level, the goal of *Cave Expedition* may be expressed as enabling the visitor to find out how the cave beetle is adapted to its environment of permanently dark caves.

Materials

The object of knowledge *the adaptations of the blind cave beetle to its environment of permanently dark caves* was studied in the three contexts: the scientific discourse, the curatorial brief, and the exhibition milieu, respectively. For the context of the scientific discourse, scientific journals and text books on cave fauna and carabid beetles in general and darkness-adapted beetles in particular were examined. Furthermore, the curator of beetles at the Natural History Museum of Denmark was consulted.

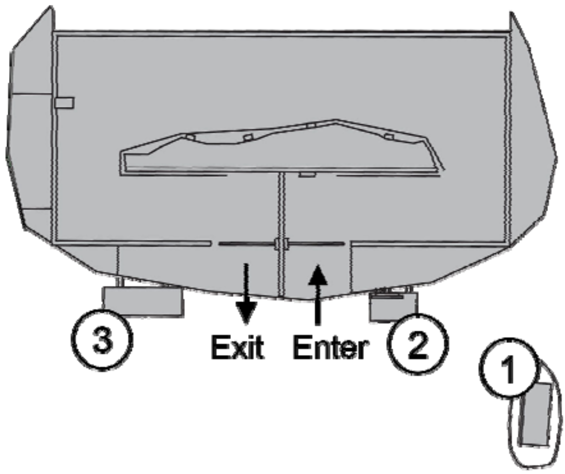

Figure 2.2. Cross section of the exhibition unit *Cave Expedition*. The unit consisted of three text panels with the labels: (1) “Extra long legs”, (2) “Cave expedition”, and (3) “Check your score”, as well as an artificial cave through which a passageway ran. The passageway was completely darkened and had a guide rope on the left side. On the left wall six animal models were mounted at a height of about 1 m. The entire cave structure was about 3 m deep by 8 m long by 3 m high.

The curatorial brief consisted of the document *Xtremes: storyline for an exhibition about adaptations to extreme environmental conditions on Earth*, the purpose of which was to present the conceptual framework of the exhibition and translate it into exhibition design (Executive Committee, 2005b). A preliminary document *Xtremes: final content analysis* (Executive Committee, 2005a) also created by exhibition engineering staff, was included in the study. This document did not consider the museography of the exhibition theme, but dealt exclusively with the scientific content. The latter document was annotated, and the references contained therein were included in the scientific literature examined.

Finally, the exhibition milieu studied was the immersive exhibition unit *Cave Expedition* which consisted of three panels and an artificial cave (Figure 2.2). The cave consisted of a darkened scented passageway with nine animal models: four lizards, three spiders, and two frogs mounted on the wall. The models were to scale, i.e. 5-15 cm long. Panel 1, located approximately 2 m to the right of the entrance to the cave, carried a short text about the blind cave beetle, an illustration of five carabid beetles sequenced according to increasing degree of adaptation to living underground (Figure 2.3), and a preserved specimen of *Aphaenops cerberus*, a blind cave beetle, with a distribution map. Panel 2 was located at the entrance to the artificial cave and carried text instructions to the visitors about how to interact with the exhibition unit. Panel 3 was located immediately outside the exit of the cave and carried text instructions to the visitors about how to use the adjacent score board. This score board carried replicas of the animal models and sources of scents found inside the cave, each equipped with a button which fed back to a single digital display.

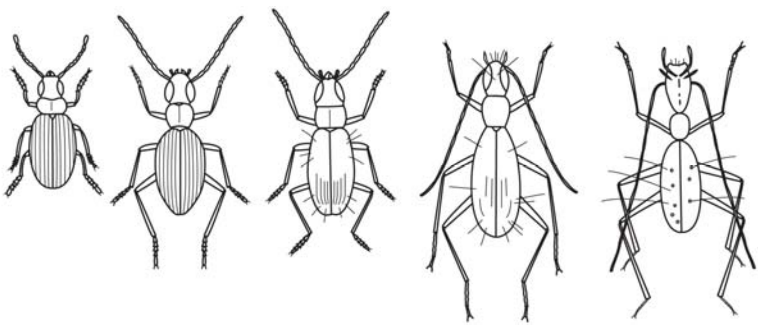

Figure 2.3 Illustration used in panel 1 in *Cave Expedition*. The illustration was accompanied by the caption: "Carabid beetles with different degrees of adaptation to their life under ground. Left: Beetles that live above ground. Right: Beetles that live under ground". © 2007 by RBINS, Experimentarium, and Naturalis. Reprinted with permission.

Informants

The study of the tangible components of the museographic transposition – the scientific literature, the curatorial brief, and the exhibition unit – was informed by open-ended interviews with four selected exhibition engineers involved in the exhibition development. The curatorial brief and the preliminary document mentioned in the preceding section were used in the interviews as conceptual milestones in the transposition process; these documents were used by the interviewer as evidence of the status of the transposition at different stages and as prompts to the exhibition engineers' memories of past events, helping them to avoid post hoc rationalisations of their past actions.

Two of the interviewed exhibition engineers were employed at Experimentarium (in the following they are designated as EE1 and EE2); two were employed at RBINS (in the following designated as EE3 and EE4). The exhibition engineer responsible for Naturalis' contribution to the exhibition was no longer employed there; thus there were no informants from the Netherlands. Three exhibition engineers were interviewed separately, and one, EE4, was interviewed in the presence of EE3. The interviews lasted for one to two hours and were audio recorded and later transcribed. The interviews at Experimentarium took place in November, 2007, where the first half-hour of the interviews at Experimentarium took place at the exhibit itself. The interviews at RBINS took place in April, 2008; the exhibit had not yet been moved to RBINS at this time, so the interviews took place in an office.

Procedure

In order to map the changes in the structure of the object of knowledge *the adaptations of the blind cave beetle to its environment of permanently dark caves* through the phases of museographic transposition, it was necessary to understand the context and modality of the knowledge present in each stage of the transposition. For example, the knowledge contained in the scientific discourse was in a written form and readily defined, whereas the knowledge contained in the exhibition milieu was embodied in text panels, objects, and other three-dimensional installations and was accordingly defined partly through inference.

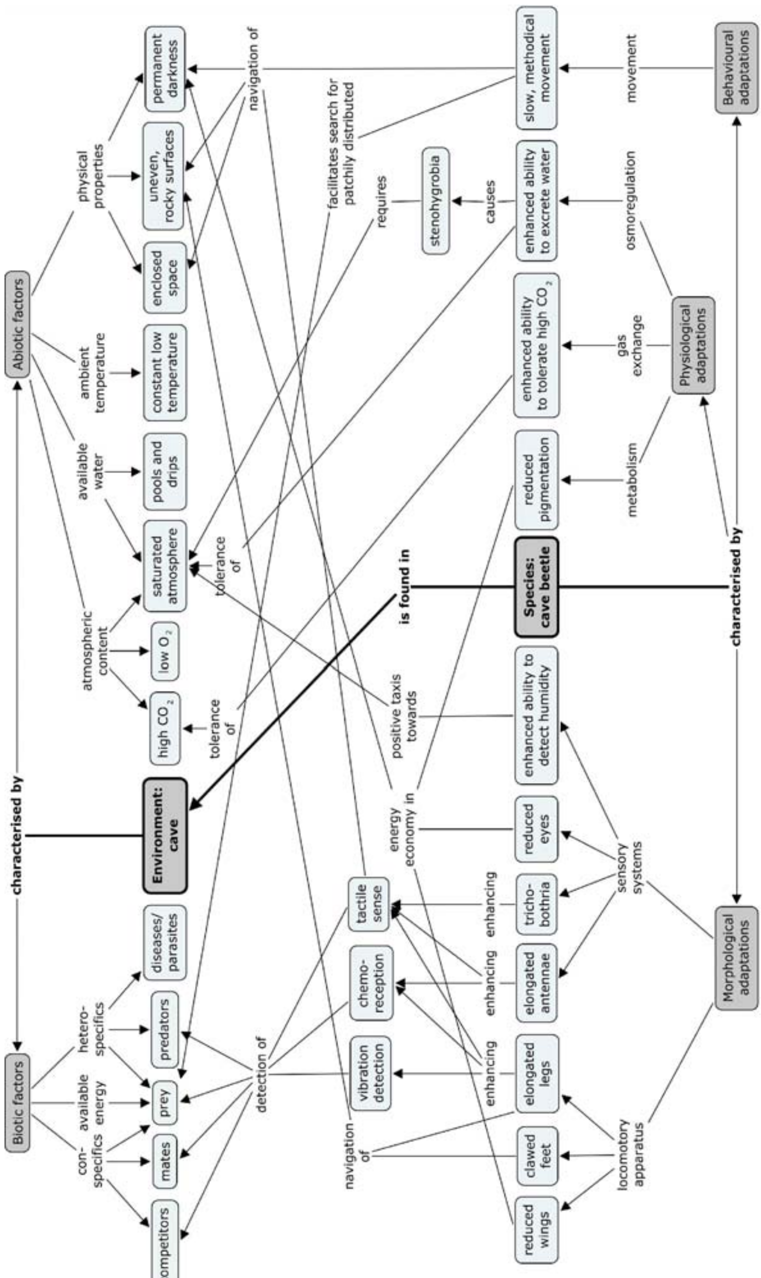
Biotic factors
characterised by
Abiotic factors
con-specifics
available energy
hetero-specifics
competitors
mates
prey
predators
diseases/ parasites
Environment: cave
high CO2
low O2
atmospheric content
saturated atmosphere
available water
pools and drips
ambient temperature
constant low temperature
enclosed space
uneven, rocky surfaces
physical properties
permanent darkness
navigation of
detection of
vibration detection
chemo-reception
tactile sense
tolerance of
positive taxis towards
energy economy in
is found in
facilitates search for patchily distributed
requires
stenohygrobia
causes
enhancing
reduced wings
clawed feet
elongated legs
elongated antennae
tricho-bothria
reduced eyes
enhanced ability to detect humidity
Species: cave beetle
reduced pigmentation
enhanced ability to tolerate high CO2
enhanced ability to excrete water
slow, methodical movement
locomotory apparatus
sensory systems
metabolism
gas exchange
osmoregulation
movement
Morphological adaptations
Physiological adaptations
Behavioural adaptations

Figure 2.4 Structure of the object of knowledge *the adaptations of the blind cave beetle to its environment of permanently dark caves* in the scientific context. The cave environment and its biotic and abiotic characteristics are shown at the top of the diagram, and the cave beetle and its morphological, physiological, and behavioural traits are shown at the bottom of the diagram. The relationships between the beetle's traits and the environmental factors are shown with connecting lines.

Knowledge in the scientific context.

The scientific study of animal adaptations entails an analysis of the environment of the species in question and an examination of the morphological, physiological, and behavioural traits of that species which may improve its ability to interact with its environment and thus may be categorised as adaptive (cf. Culver, 1982). From the perspective of the scientific discourse, the theme of animal adaptations accordingly spans several domains of knowledge (e.g. biology, chemistry, geophysics) as well as several subdomains (e.g. ecology, physiology, behaviour). Furthermore, animal adaptations are in a sense immaterial because they consist of both a structure and a function and consequently only manifest themselves in interaction with the environment. These characteristics make the theme of an animal's adaptations to its environment difficult to describe within a general epistemological model of biological knowledge. Here, a concept map is used to structure the object of knowledge *the adaptations of the blind cave beetle to its environment of permanently dark caves* in the scientific context.

Concept maps graphically organise and represent knowledge by connecting single knowledge units, or concepts, with one another using linking words or phrases (Novak & Cañas, 2008). Such links may connect concepts located in different domains of knowledge and are thus able to capture the relationship between, for example, a given feature of the environment and the corresponding adaptive trait of an animal. Furthermore, concept maps may include several domains of knowledge and can thus encompass objects of knowledge that span multiple disciplines.

On the basis of a survey of scientific journal articles and textbooks, a text was constructed describing the blind cave beetle's adaptations to its environment of permanently dark caves. This text was reviewed for scientific accuracy by the curator of beetles at the Natural History Museum of Denmark and finally summarised in the form of a concept map (Figure 2.4) hereafter designated as the scientific knowledge.

Knowledge in the curatorial brief context

The curatorial brief included a summary of the scientific content and a brief description of the proposed exhibit on the blind cave beetle and its adaptations to darkness (Table 2.2). The exhibit was described in the text as consisting of two subunits, a specimen-based display of three beetle species and an experience-based subunit comprising an orientation route for visitors. The text summarising the scientific content and describing the proposed exhibit subunits was analysed in terms of the concepts defined in the scientific knowledge as exemplified in the following excerpt from the curatorial brief:

Beetles that live in caves generally have longer legs and antennae
Cave beetle (organism) — *Cave (environment)* — *Elongated legs* — *Elongated antennae*

than closely related species that live above the ground. The legs and antennae
Elongated legs — *Elongated antennae*

are used for orientation by touch. (Excecutive Committee, 2005b, p. 28)
Tactile sense

The presence of other concepts in the curatorial brief had to be inferred. Consider the description of the experience-based subunit as an "orientation route in the dark for visitors". The objective of this orientation route was to give the visitor the experience of being a cave beetle by putting the visitor in the place of the animal (EE1). Accordingly, it was inferred that visitors would experience transient loss of vision when entering the darkened orientation route, and that this transient sightlessness was an analogy to the cave beetle's adaptation of having reduced eyes. The concept of "reduced eyes" was thus included in the concept map of the knowledge present in the curatorial brief (Figure 2.5).

Knowledge in the exhibition milieu

The exhibition milieu of the *Cave Expedition* exhibit consisted of text, illustrations, models, scent, a walk-through artificial cave, an interactive score board, and a specimen. As in the case of the curatorial brief, the reference knowledge was used as the basis with which to map the elements of knowledge which were present in the exhibition context. An example of this analysis is offered by the illustration on Panel 1 of the exhibition unit (Figure 2.3). Discernable from the comparison of the five carabid beetles are the following characteristics of cave beetles: elongated legs, elongated antennae, trichobothria (the presence of sensory hairs), clawed feet, and in one case, reduced eyes. These concepts were therefore included in the concept map of the exhibition milieu.

Table 2.2. Excerpt from the curatorial brief (Executive Committee, 2005b, p. 28) describing the scientific content and proposed exhibition unit on the blind cave beetle and its adaptations to darkness.

Scientific content	**Description of proposed exhibition unit**
Cave beetle (*Duvalius stankovitchi*) Beetles that live in caves generally have longer legs and antennae than closely related species that live above the ground. The legs and antennae are used for orientation by touch (compare with a blind man's walking stick).	Orientation route in the dark for visitors, using a stick for orientation.
Three coleopteran species of the Trechinae group in the genus *Duvalius*, from different habitats, have different body size and antennae size. The *Duvalius procerus* species live in the alpine zone. They have eyes and a massive body with short legs and antennae. The species *Duvalius subterraneus* lives under stones buried in woods. It has reduced eyes, a longer body and longer antennae than the former species. The species *Duvalius stankovitchi* lives in caves. It is totally blind, depigmentated, with a longer body and antennae, and more pubescences ("hairs") than the former two species.	Specimen of *Duvalius procerus*, *Duvalius subterraneus*, *Duvalius stankovitchi*. NB They are small: 5-7 mm.

Several elements of knowledge were present only implicitly as features of the immersion experience, and consequently only became tangible through interpretation of the immersive exhibit form. For example, the presence of models of lizards, frogs, and spiders inside the artificial cave may be construed in a number of ways, but only through the understanding of the exhibit as an immersive experience where the visitor takes on the role of the cave beetle, do the animal models assume their intended meaning: that of cave beetle heterospecifics, and more specifically, that of cave beetle predators (EE1). The presence of these animal models was thus interpreted as the concept of heterospecific predators and included in the concept map of the exhibition milieu.

2.4 Results

The First Moment of Transformation

The purpose of the curatorial brief was to extract a body of knowledge regarding *the adaptations of the blind cave beetle to its environment of permanently dark caves* from the scientific field and reduce it to a content from the viewpoint of the exhibition objective: to enable visitors to "find out how animals, microbes and plants are adapted to survive under stressful conditions" (Executive Committee, 2005b, p. 5). The transposition of the object of knowledge to the curatorial brief context involved a division of the knowledge into proposals for two subunits: a proposal for a specimen-based subunit and a proposal for an experience-based subunit (Table 2.2). The transposition entailed a reduction in the complexity of the object of knowledge: of the 28 concepts that formed the structure of the knowledge in the preceding step, the scientific context, 9 were present in the curatorial brief context.

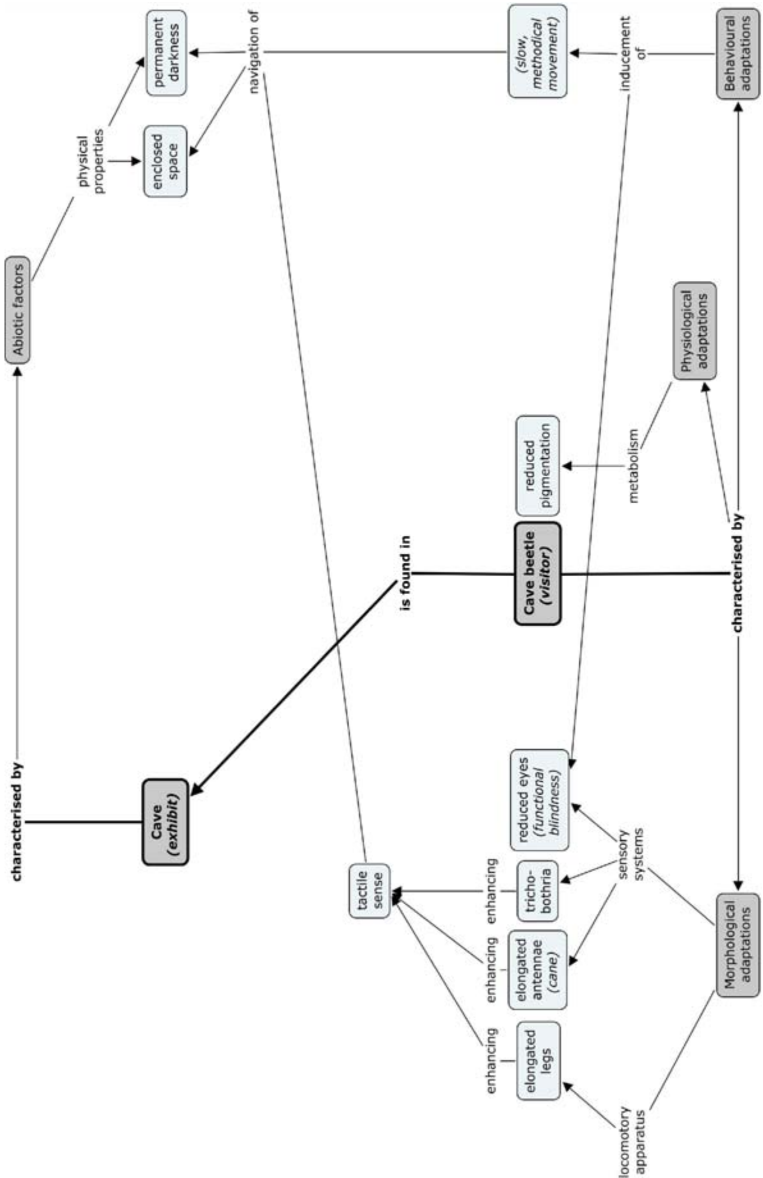
characterised by
Abiotic factors
physical properties
enclosed space
permanent darkness
navigation of
Cave (exhibit)
is found in
Cave beetle (visitor)
characterised by
(slow, methodical movement)
inducement of
Behavioural adaptations
Physiological adaptations
metabolism
reduced pigmentation
Morphological adaptations
sensory systems
locomotory apparatus
reduced eyes (functional blindness)
tricho-bothria
elongated antennae (cane)
elongated legs
enhancing
enhancing
enhancing
tactile sense

Figure 2.5. Structure of the object of knowledge *the adaptations of the blind cave beetle to its environment of permanently dark caves* in the curatorial brief. Concepts which are directly mentioned in the curatorial brief text are printed in roman, while concepts whose presence in the curatorial brief was inferred are italicised and in parentheses. Some concepts are present in both forms, e.g. elongated antennae are present both as text but also as the inferred analogy of the visitor using a blind person's cane.

The specimen-based subunit was considered by the exhibition engineers to be a concession to the museal tradition of exhibiting specimens (EE3). The partners finally included the specimen-based subunit in the curatorial brief due to the perceived illustrative value of the specimens: "because what the cave beetle does with its long antennae and its long legs – that's what the humans do in the cave exhibition: finding their way" (EE3). The specimen-based subunit thus provided the background knowledge for the visitor to subsequently play the role of the beetle in the experience-based subunit (EE1). The proposal for the specimen-based subunit included the display of three beetles, namely *Duvalius procerus* which lives above ground, *D. subterraneus* which lives under stones, and *D. stankovitchi* which is a blind cave beetle and lives in permanently dark caves. Discernable from the comparison of these three species were four concepts, namely those of the cave beetle as being blind (having reduced eyes), being depigmentated, having elongated antennae, and having more sensory hairs (trichobothria) than its above-ground counterparts.

The main objective of the experience-based subunit of *Cave Expedition* was to give the visitor the experience of being a cave beetle by putting the visitor in the place of the animal (EE1) and "activating [in the visitor] the senses which darkness-adapted animals rely on and navigate by" (EE2). The transposition of the object of knowledge *the adaptations of the blind cave beetle to its environment of permanently dark caves* towards this goal was accordingly centred on the beetle's elongated legs and antennae, which provide it with excellent chemoreception and mechanoreception abilities. The curatorial brief proposed the construction of an orientation route in the dark (the cave) through which the visitor (the beetle) could navigate with a blind person's cane (elongated antennae). The cane may be thought of as a temporary morphological adaptation in the visitor providing tactile experiences, whereas the idea of chemoreception is not mentioned further in the curatorial brief.

The proposed subunit indirectly induces in the visitor another cave beetle sensory feature, namely that of reduced eyes. The visitor, of course, does not experience the morphological adaptation of reduced eyes, but the sightlessness that is brought about by the darkness of the proposed visitor orientation route can be described as a temporary behavioural analogue to the cave beetle's permanent blindness. The darkness also induces slow, systematic movement in the visitor, who without the use of vision is forced to feel their way through the cave.

In summary, of the concepts present in the scientific context, a total of nine were transposed to the curatorial brief, namely those of a cave as an enclosed, darkened space and the blind cave beetle as being depigmentated and as having sensory hairs, elongated legs and antennae which enhance its tactile sense, and which, together with the slow methodical movement induced by the surroundings, enhance its ability to navigate its environment (Figure 2.5).

The Second Moment of Transformation

The curatorial brief provided the exhibition engineers with content and purpose, leaving room for the creative reconstruction of the object of knowledge *the adaptations of the blind cave beetle to its environment of permanently dark caves* in the transposition from the curatorial brief context to the exhibition milieu. This creative reconstruction is evidenced by an increase in the complexity of the object of knowledge: of the nine concepts that structured the object of knowledge *the adaptations of the blind cave beetle to its environment of permanently dark caves* in the curatorial brief, eight were transposed into the exhibition milieu and an additional six concepts were added.

The number of specimens in the specimen-based subunit was reduced from the three proposed in the curatorial brief to just one actually displayed specimen, *Aphaenops cerberus*. RBINS staff, who were responsible for the specimens exhibited in *Xtreme Expedition*, were unable to locate three comparable beetle specimens that could be displayed for the duration of the exhibition, and the substitution of the planned three specimens with the one specimen and the illustration of five beetles (Figure 2.3) was thus a case of “small details disturbing the beautiful plans - a well-known phenomenon in exhibition preparation!” (EE3).

In spite of this constraint, the specimen-based subunit included the concepts of the cave beetle having the following morphological adaptations: clawed feet, elongated legs and antennae, trichobothria, and reduced eyes. The elongated legs and antennae enhance the animal’s chemoreceptive abilities, and the legs, antennae and sensory hairs enhance its tactile sense. These enhancements enable the beetle to detect its prey and to navigate its environment, which is permanently dark. The specimen subunit thus includes nine concepts, three of which (elongated antennae, trichobothria, and reduced eyes) can be traced from the curatorial brief and six of which (clawed feet, elongated legs, enhanced tactile sense and chemoreception, prey, and darkness) originate in the scientific context (Figure 2.6)

The experience-based subunit is founded on an immersion principle, where an illusion of time and place is created through the reconstruction of key characteristics of the cave beetle's life history and habitat; and through the integration of the visitor into this reconstructed world. The reconstructed world is based on an interpretation where the reference world, the cave beetle's habitat, is represented as a scale model. The experience-based subunit accordingly relies on a principle of analogy to mediate its message, namely the analogies of the exhibit being the cave beetle habitat, the visitor being the cave beetle and the visitor's experiences being those of the cave beetle. It is based on an exogenous logic, i.e. a reference world that actually exists (the cave beetle's life history and habitat) combined with an endogenous logic, i.e. a world that is created in conjunction with the exhibition (the analogical representation of the reference world).

Representation of the reference world: The artificial cave

The exhibition milieu representing the cave beetle habitat consists of an expansion of the curatorial brief's concept of an enclosed, darkened passageway with the concepts of uneven, rocklike surfaces and the presence of heterospecific predators (animal models) and a source of scent. The curatorial brief described the physical structure of the experience-based subunit simply as a darkened orientation route. Yet, the completed subunit has irregular, rock-like surfaces that somewhat reflect the physical properties of the cave beetle's natural cave environment as described in the scientific context. Did the concept of the cave interior in fact originate in the scientific context? Howarth (1983) describes the morphology of the cave beetle habitat as an "interconnected network of spaces […] which range from over 1 mm to about 20 mm in width". The 5 mm cave beetle thus experiences variations in the rock structure of its cave habitat ranging from 20% to 400% of its own body length. A model of the cave beetle habitat scaled up to human size would thus consist of spaces ranging in width from 35 to 700 cm. In fact, the width of the passageway of the experience-based subunit varies on a much smaller scale, with a difference of less than 30 cm between the widest and narrowest points, corresponding more realistically to the characteristics of a man-made tunnel through rock.

The animal models (four lizards, three spiders, and two frogs) in the passageway of the artificial cave were explained differently by the exhibition engineers from Experimentarium and RBINS, respectively. The models were perceived by one Experimentarium exhibition engineer as a natural choice of heterospecific species in that they reflected what could be found in natural caves (EE2). The other Experimentarium exhibition engineer elaborated “These are the types of animals you’d find in caves. These are animals that would prey on the beetles [in the wild]” but goes on to say:

> It’s also a practical consideration: which animal [models] were available at the toy store and how durable were they. […] And [the visitors] must to be able to feel the difference between them. Basically, this exhibition unit is an exercise in feeling and remembering (EE1).

One RBINS exhibition engineer agreed with this viewpoint, stating that the animal models were chosen because they were easy for the visitors to identify by touch, but questioned the idea of the chosen species as being representative of cave beetle predators or heterospecifics (EE3). This exhibition engineer went on to clarify that the dependence on the sun of herpetiles such as lizards and frogs precludes them from inhabiting permanently dark caves, but that there do exist darkness-adapted spiders that prey on cave beetles.

Integration of the visitor: The role of the cave beetle

The stated intent of the experience-based subunit was to put the visitor in the place of the cave beetle, physically placing the visitor in the artificial cave and producing by way of analogy an experience for the visitor of the cave beetle’s adaptations and its resulting experience of its surroundings. The visitor is introduced to the role of being the cave beetle by the text on Panel 2 (Figure 2.2) which reads “Enter the cave. Use your hands and nose to search for animals and scents along the cave wall”. This text refers back to the text on Panel 1 (Figure 2.2) of the specimen-based subunit, which reads “The blind cave beetle feels, smells, and tastes its way through the dark. [...]”. The analogies are thus presented between the tactile sense of the visitor and the beetle, and between the chemoreceptive sense of the visitor and the beetle (Figure 2.6).

The idea of providing the visitors with canes for navigating the darkened passageway as an analogy to the cave beetle’s morphological adaptation of elongated limbs was not realised in the experience-based subunit. One exhibition engineer explained that visitors’ effective use of canes in the darkness would require both some practice and some physical space, and that due to constraints on both of these commodities it was decided to abandon the idea (EE3). Thus, the recruitment of the visitors' tactile sense is mapped as a behavioural rather than a morphological adaptation (Figure 2.6).

The concept of chemoreception is not mentioned in the curatorial brief, and even though chemoreception is a crucial sensory channel for insects (Kershaw, 1988, p. 143), the re-entrance of the concept of chemoreception via the presence of scents in the exhibition milieu is not explicitly derived from the scientific knowledge. Instead, chemoreception or the sense of smell is consistently mentioned by the exhibition engineers as being just one of several sensory channels available to humans in the dark (EE3, EE2), referring to capacities of the visitor rather than of the beetle. When asked for the reason the scents were included in the exhibition subunit, one exhibition engineer stated "I believe that the more senses we can make people employ, the wider we can open the door to their minds" (EE1).

Dramatisation of the subject matter: The cave beetle's experiences

The experience-based subunit operates according to a principle of dramatisation. The main character of the drama is that of the cave beetle, which role the visitor is induced into playing. The visitor is thus both audience and participant in the narrative. The conflict of the main character is that of inhabiting the cave environment, and the character's actions: navigating the dark cave environment, locating and successfully identifying the animal models (which represent cave beetle predators) and identifying scents (which represent cave beetle sources of food) accordingly comprise the plot of the narrative. The plot moves in the direction of the cave beetle's orientation in and navigation of its habitat, which for the visitor corresponds to a successful circuit of the cave environment. The visitor enters the artificial cave through a clearly marked entrance; this entrance is situated immediately next to the clearly marked exit. The physical beginning and end of the walk-through tunnel thus also mark the beginning and end of the narrative, and consequently provide the visitor with additional navigational and narrative direction.

On entering the cave, the visitor, is rendered functionally sightless (reduced eyes) by the darkness of the artificial cave, and must accordingly slowly and methodically navigate the darkened passageway using his/her tactile sense. The spatial layout of the artificial cave–that of a tunnel–effectively dictates the direction of movement towards the exit, and the presence of a scent induces the visitor to use his/her sense of smell during the circuit of the cave.

In total, the exhibition milieu includes five (darkness, enclosed space, tactile sense, reduced eyes, and slow methodical movement) of the seven concepts present in the curatorial brief and three (predators, chemoreception, and uneven, rocky surfaces) which were present in the scientific knowledge (Figure 2.6).

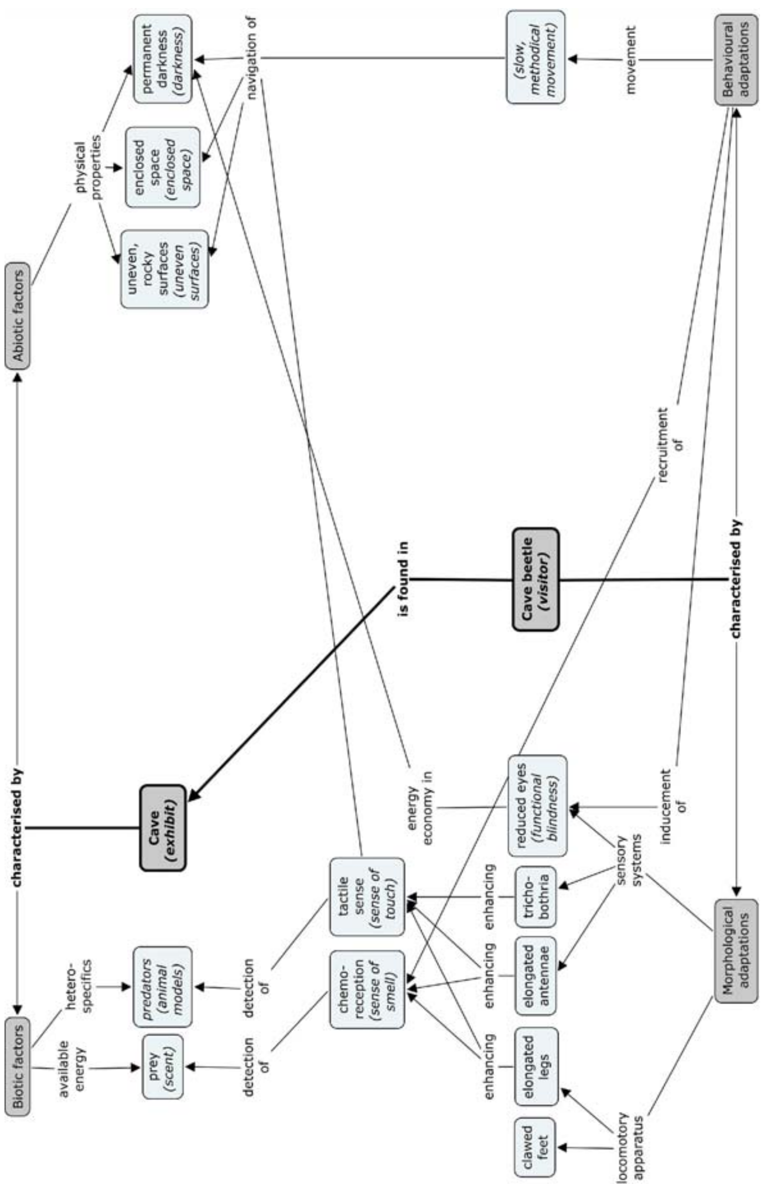
Biotic factors
characterised by
Abiotic factors
physical properties
uneven, rocky surfaces (uneven surfaces)
enclosed space (enclosed space)
permanent darkness (darkness)
navigation of
(slow, methodical movement)
movement
Behavioural adaptations
recruitment of
characterised by
Cave beetle (visitor)
is found in
Cave (exhibit)
available energy
prey (scent)
hetero-specifics
predators (animal models)
detection of
detection of
chemo-reception (sense of smell)
tactile sense (sense of touch)
energy economy in
reduced eyes (functional blindness)
inducement of
sensory systems
enhancing
enhancing
enhancing
tricho-bothria
elongated antennae
elongated legs
clawed feet
locomotory apparatus
Morphological adaptations

Figure 2.6. Structure of the object of knowledge *the adaptations of the blind cave beetle to its environment of permanently dark caves* in the exhibition milieu. As in Figure 2.5, concepts which are explicitly present are printed in roman, while concepts which are implicitly present, such as the darkness-induced functional blindness in the visitor, are italicised and in parentheses.

2.5 Synthesis of Descriptive Model

In the following, the results will be synthesised into a descriptive model that accounts for the two moments of transformation as well as the status of the object of knowledge in each of the three transposition contexts: the scientific context, the curatorial brief, and the exhibition milieu.

The creation of the curatorial brief marks the intersection between the scientific source knowledge and the particulars of the museographic form. Each element of knowledge that figures in the curatorial brief ideally serves the dual role of representing an aspect of the scientific knowledge and constituting a part of the support for the intended visitor experience. It is therefore not surprising that the creation of the curatorial brief involves a reduction of the elements of scientific knowledge, as not all elements of knowledge are equally suited to serving this dual role. From the vantage point of the scientific context, the process towards the curatorial brief may be seen as an epistemological development, while from a museographic perspective, the process may be seen as a museum-pedagogical development which considers the non-content-related particulars of the exhibit form–here, the component parts of an immersion exhibit.

Once developed, the curatorial brief serves as a focus for the second moment of transformation: the execution of the exhibition milieu. The creative interpretation by the exhibition engineers of each of the elements in the curatorial brief combines to form the exhibition milieu, a three-dimensional installation the purpose of which is to provide the visitor with an intended experience.

According to this model of exhibition engineering, the *integrity* of the exhibition milieu–the degree to which the implemented exhibit forms a coherent whole–is a function of the consistency of the museographic transposition of its component parts. Ideally, each of these component parts should grow from the intersection between a specific element of scientific knowledge and a specific element of the museographic form as illustrated in the model (Figure 2.7). Where a component is not consistently supported by both scientific knowledge and museographic form, the component in question runs the risk of compromising the integrity of the exhibition milieu.

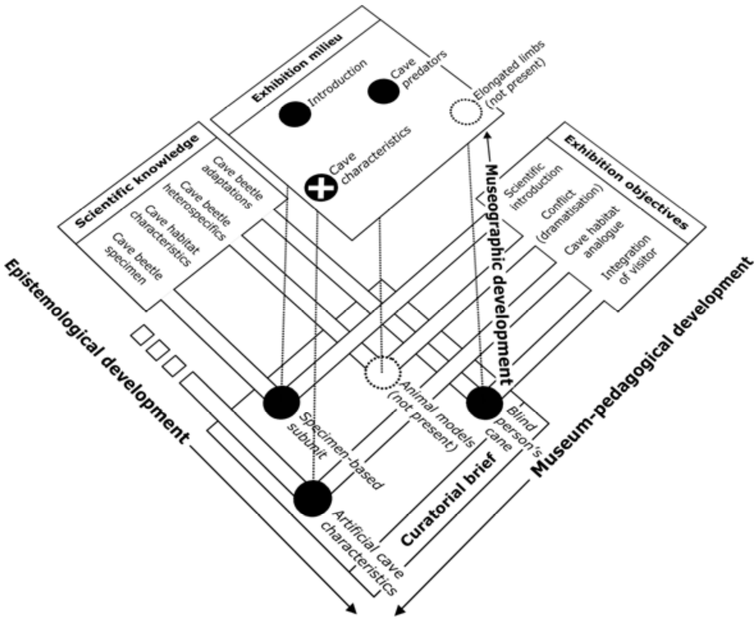

Figure 2.7. Descriptive model of museographic transposition. Simultaneous processes of epistemological and museum-pedagogical development create elements of knowledge in the curatorial brief (black circles). For example, the intersection between the scientific knowledge of cave beetle adaptations such as elongated limbs and the immersion exhibit objective of integrating the visitor is exemplified by the curatorial brief notion of letting the visitor use a blind person's cane to navigate the exhibit. Elements of knowledge in the curatorial brief are then implemented by exhibition engineers to form the exhibition milieu in a process of execution. In the mentioned example, the notion of the blind person's cane as an analogy to elongated limbs is not carried through to the exhibition milieu (dotted circle). The exhibition milieu also features elements of knowledge that are not present in the curatorial brief, for example the animal models as cave beetle heterospecifics. Finally, some elements of knowledge in the curatorial brief are the result of museum-pedagogical but not epistemological development, for example the physical characteristics of the cave beetle's habitat (black circle with white cross). This element serves the exhibition objective of creating a cave analogy for the visitor; yet this cave analogy is not rooted in scientific knowledge about the cave beetle's habitat.

Our attention may now be directed back towards the research question, namely: what is the nature of the constraints and opportunities which govern the putting-into-exhibition of a specific object of knowledge? According to the presented model, the main constraint on the process of exhibiting an object of knowledge is reconciling the pertinent elements of the scientific knowledge with the particulars of the museographic form. In other words, the chosen exhibit type or genre has real constraints as to how a scientific object of knowledge can be transposed into a didactic object. But conversely, in a more positive view, the museographic form may also be seen as the lens through which a scientific object of knowledge can be viewed in order to achieve a consistent transposition of it. In this sense, the choice of museographic form offers the exhibition engineers genuine (and perhaps new) opportunities as to which aspects of an object of scientific knowledge they wish to emphasise, although choosing this emphasis requires a thorough understanding of the specificities of the chosen museographic form and their implications. In sum, the first moment of transformation in museographic transposition is governed by a dialectic relationship between scientific knowledge and museographic form. According to the model, the second moment of transformation or execution is influenced by more practical considerations. The execution phase, being one step removed from the context of the scientific knowledge, is marked by a relaxation of epistemological vigilance which allows for the introduction of concepts originating from outside the transposition process. This relaxation of epistemological vigilance, then, may undermine the integrity of the exhibit in spite of the fact that the introduction of these concepts signifies an attempt to create exactly that: a coherent exhibit. In sum, the second moment of transformation is under less rigid epistemological control and thus subject to external influences such as the alternative scientific conceptions of exhibition engineers.

2.6 Discussion

The museographic transposition that took place in the development of the exhibit *Cave Exhibition* was shaped by constraints and opportunities related to the particulars of the scientific knowledge, the particulars of the museographic form, and external influences. The following sections first discuss the limitations of this study and its findings, then provide select examples of components of *Cave Expedition* that have been transposed with varying degrees of consistency, the resulting contributions of these component parts to the integrity of the exhibition milieu, and finally, some perspectives on the implications of the findings.

Limitations of this Study

The analysis of museographic transposition was based on tangible sources, such as documents and the exhibit itself as well as intangible sources, namely the four exhibition engineers' recollections of the process of exhibit development. Using the exhibition engineers' recollections as evidence of the transposition process rather than studying the process in real time raises some issues of validity, simply because the exhibition engineers may have had difficulty remembering in detail the content of their past discussions and negotiations. As a consequence, the exhibition engineers may have provided the interviewer with accounts that reflected their post hoc rationalisations of the exhibit development process rather than reconstructing the events that actually took place. Using the exhibit planning documents as a point of departure for the interview questions was one way of fixing some of the actual events in time and place; another was physically situating the interviews at the exhibit itself, as was the case in Experimentarium. Ideally, a study of museographic transposition would follow the discussions and negotiations of exhibition engineers in situ (e.g. Macdonald, 2002); however, the advantage of acquiring such data should be weighed against the relatively long period of time in which the process of full-time museum exhibition planning and implementation takes place (20 months in the case reported in Macdonald, 2002).

Example 1: The Display of Specimens

The three collaborators Naturalis, RBINS, and Experimentarium had different approaches to exhibition engineering, deeply rooted in the characteristics of their respective institutions. The difference in approaches was acknowledged by the respective exhibition engineers who cited the potential for cross-fertilisation as the reason the collaboration had been undertaken in the first place (EE1, EE2, EE3), but it was also evident in many of the decisions made during the exhibition engineering process. Naturalis adhered strongly to the scientific content which was to be exhibited and preferred to develop this content extensively prior to any consideration of the exhibition form. In contrast, Experimentarium perceived visitor considerations as the most important criterion in selecting the scientific content to be displayed. RBINS placed itself between these two positions, "understanding the excellent reasons of both" (EE3).

The difference in institutional approaches to exhibition engineering illustrates the use of the model of exhibition engineering (Figure 2.7). When deciding whether to exhibit the cave beetle specimens, the staff of RBINS and Naturalis, adhering to their traditional role of collecting and exhibiting specimens (cf. Doering, 1999), felt it was important to display the animal which was the scientific basis of the exhibition unit (EE4). The notion of displaying the specimen thus serves as an example of an exhibition strategy favoured for its traditional closeness to the scientific context. The science centre staff, on the other hand, felt that due to the beetle's small size and the lack of any inherent interactivity in a specimen display, such a display would be of relatively little interest to visitors (EE3); a point of view which is supported by research (Bitgood, Patterson, & Benefield, 1988; Harvey, Loomis, Bell, & Marino, 1998). Therefore, from the point of view of the science centre, the idea of exhibiting the specimen did not intersect with any visitor-related, i.e. museum-pedagogical purpose.

Dissonance in the agendas of exhibition staff is a common occurrence in exhibition engineering processes within the same institution (Lindauer, 2005), so it is not surprising to find such a dissonance among exhibition staff of different institutional affiliations. However, the present situation was resolved positively with the creation of the specimen-based subunit which fulfils the museums' obligation to exhibit their collections (EE4) while serving as the scientific introduction to the interactive experience (the experience-based subunit), a constellation which the science centre employs extensively (EE2). The specimen display may be seen as a component which marks an intersection between the scientific source knowledge and the exhibition's objectives, and which accordingly contributes to the integrity of the exhibition milieu of *Cave Expedition*.

Example 2: The Creation of a Cave Beetle Habitat Analogue

The museographic transposition of the object of knowledge *the cave beetle's habitat* constituted a combination of the exogenous logic of the existing reference world of the cave beetle's habitat and the endogenous logic of the museum analogue to this reference world. The creation of the cave beetle habitat analogy thus provides another example of how epistemology and museum-pedagogy may coincide, but in practice, it was not always possible for the exhibition engineers to reconcile these two logics. For example, in the first moment of transformation, the reduction of the object of knowledge *the cave environment* into what is basically described as a "darkened passageway" (Executive Committee, 2005b), indicates that the darkness and the enclosed space were the aspects that the exhibition engineers found to be simultaneously the most descriptive of the cave beetle's environment, the most experienceable by human visitors (EE1), and the most unproblematically realisable in terms of exhibition construction (cf. Gilbert & Stocklmayer, 2007). However, the subsequent expansion of the cave concept in the exhibition milieu added aspects to the "darkened passageway" concept which do not reflect cave beetle habitat characteristics found in the scientific context (Figure 2.7). The uneven, rocklike surfaces that characterise the artificial cave arguably reflect a relatively smooth man-made passageway through rock rather than the cracks and voids that comprise the cave beetle's natural habitat, and the animal models added to the artificial cave to signify cave beetle predators seem to reflect, in scale as well as in choice of species, a human's rather than a cave beetle's experience of heterospecific animals associated with caves. Thus, the reconstitution of the cave beetle habitat in the exhibition milieu marks a departure from the endogenous logic of creating a cave beetle habitat analogue, and an implicit refocusing of the exhibit according to the exogenous logic of recreating an existing world. The world recreated is not based on the original reference world, the cave beetle's habitat, but rather on a cave environment which is recognisable as such by humans. This inference is supported by the human perspective evident in statements made by the exhibition engineers when asked to give the experience-based subunit a one-sentence headline, the exhibit was described as "a sensory tunnel" by EE1, "feel your way to the animals in the dark" by EE2, and as "the mysterious cave" by EE3. In addition, the title of the experience-based subunit, *Cave Expedition*, reflects a decidedly human perspective.

The integrity of the exhibition milieu is compromised by this shift of the visitor perspective. In the intersection between the scientific knowledge of the characteristics of the cave beetle's habitat and the museum-pedagogical notion of creating an analogue to that habitat, the scientific knowledge of the characteristics of the cave beetle's habitat is replaced with out-of-context ideas of what characterises a cave environment from a human perspective (Figure 2.7). This refocusing is perhaps not surprising, considering that in order for visitors to recognise and comprehend an immersive exhibit of a reference world recreated according to an exogenous logic, that reference world must be familiar to them (Montpetit, 1996). The inherent difficulty of creating a recognisable experience of a blind cave beetle's natural habitat for a human is perhaps best described by an expert:

> […] the cave environment is so foreign to human experience that it is often difficult to conceptualize the [environmental] parameters as they affect the inhabitants rather than from an anthropocentric point of view (Howarth, 1983, p. 380).

The alignment of the exhibition milieu with a human perspective may consequently be an implicit attempt by the exhibition engineers to create a world which they could be certain visitors would recognise. Furthermore, a pre-existing exhibition unit titled *Sensory Tunnel* located in another part of the science centre had previously proven very popular among visitors and served as inspiration in the creation of the experience-based subunit of *Cave Expedition* (EE1), which may consequently have been endowed with social and psychological characteristics with proven palatability to science centre visitors (cf. Gilbert & Stocklmayer, 2007).

Example 3: The Integration of the Visitor

The intent of the experience-based subunit of *Cave Expedition* is for the visitor to assume the specific role of the cave beetle by the inducement, through analogy, of a number of the cave beetle's adaptations in the visitor. Generally, an analogy describes a first subject, the target, as being equal in some sense to a second subject, the analogue (Duit, 1991). The target may be efficiently described because implicit and explicit attributes from the analogue are used to clarify the description of the target. The successful use of analogy is thus based on the existence of shared attributes between the analogue and the target (Gilbert & Stocklmayer, 2007). In the present case, where the analogue is the human visitor’s experience and the target is the cave beetle’s adaptations and its resulting experience of the surroundings, the analogy depends on an overlap between the attributes of the human visitor’s perceptual capacity and the beetle’s adaptations. While the adaptations of the cave beetle are products of thousands or millions of years of evolution, the analogous adaptations induced in the visitor must necessarily be of a transient nature, lasting for the duration of the interaction with the exhibit. Accordingly, the substantial reduction of the object of knowledge *the cave beetle’s adaptations* that took place in the transposition from the scientific context to the curatorial brief is a testament to both the didactic constraint of the basic biological dissimilarity between humans and cave beetles, and the museographic challenge of meaningfully and effortlessly transposing some of the more complex beetle adaptations. For example, none of the beetle’s physiological adaptations were transposed to the curatorial brief or indeed the exhibition milieu. How does a cave beetle experience having reduced pigmentation and how, indeed, may that experience be meaningfully transposed to a human visitor?

Consequently, the elements of the object of knowledge *the cave beetle’s adaptations* that were transposed to the curatorial brief were elements that were readily inducible as analogous transient behaviours or traits in the human visitor. In other words, they comprised an intersection between the scientific knowledge of the cave beetle's adaptations and the museographic objective of putting the visitor in the place of the beetle (Figure 2.7). Among these elements was the notion of providing the visitor with a blind person's cane as an analogue to the target: the cave beetle's elongated limbs and subsequent increased tactile range. This notion arguably would provide the visitor with the distance between the analogue and the target required in order for the analogy to work. If this *ontological distance* (Ogborn & Martins, 1996) is too small, the analogy will be “too much like a close similarity and fail to excite or interest the imagination” whereas if it is larger, there is analogical work to be carried out by the visitor in terms of “probing the analogy by elaborating certain of its concrete consequences” (Ogborn & Martins, 1996). The subsequent removal, for practical reasons, of the notion of providing the visitor with a blind person’s cane in the exhibition milieu, and consequent dependence on the darkness of the artificial cave to induce an increased use of the visitor's tactile sense, accordingly marks a reduction of the ontological distance between analogue and target–a reduction which may cause the visitor to either remain ignorant of the intended analogy, or indeed to perceive their increased use of tactile sense as another component supporting the perception of the exhibit experience as that of a human, rather than a cave beetle, navigating a cave. On the other hand, the reduction of the ontological distance may also serve to remove an obstacle to visitor understanding, rendering the analogy between visitor's sense of touch and beetle's sense of touch comprehensible for the visitor.

The issue of ontological distance is relevant to several of the elements of the object of knowledge *the cave beetle’s adaptations* that were transposed to the exhibition milieu. For example, does the inducement of temporary blindness in the visitor as an analogue to the target of the cave beetle's reduced eyes provide that analogy, or does it support the human perspective of a dark cave? The question of the appropriate ontological distance is obviously important; however, it may be more meaningfully explored in a study which includes visitors and their interactions and understandings of the exhibit and is thus beyond the scope of the work presented here.

Example 4: Dramatisation of the Subject Matter

The successful dramatisation of *what it is like to be a cave beetle* is dependent on a number of factors; some of which, as discussed in the preceding sections, support the interpretation of a cave beetle in its habitat and some of which seem to support the reconstruction of a human exploring a cave. However, only empirical studies can clarify the manner in which the dramatic conflicts in the environment are acted upon by visitors and what the visitors' resulting understanding of the plot of the drama is. Consider the spider models on the wall of the artificial cave. In order to serve the dual role of representing an aspect of the scientific knowledge (characteristics of the cave beetle's predators) and supporting the intended visitor experience (an analogy of the cave beetle's experience of a predator), the spider models should be about an order of magnitude larger than the visitor, because cave spiders may be up to an order of magnitude larger than their cave beetle prey. This notion gives rise to an interesting question about exhibition design: How would a human visitor in the dark be able to recognise a ten-metre spider model just by touching it? Instead, the use of the to-scale spider models in the artificial cave provides the visitor with instantly recognisable three-dimensional shapes which in themselves may provide dramatic conflict due to the repulsion many people have towards spiders and other "creepy-crawlies", and such a reaction could indeed be said to be a dramatic analogy of the avoidance reaction the cave beetle no doubt has to its predators.

Thus, although the model of exhibition engineering may be used to analyse the integrity of the exhibition milieu from an epistemological and museographic viewpoint, an analysis of the visitor's understanding is the logical next step towards fully evaluating the exhibition unit *Cave Expedition*.

Museographic Transposition vs. Didactic Transposition

A final discussion point which may serve to locate the present study within a larger context is a comparison between the notion of museographic transposition as developed here and the original notion of didactic transposition, i.e., the transposition that takes place in the production of the knowledge taught in a school context. The two notions have many commonalities as their common origin would suggest; however, in the following, key differences between the two will be briefly discussed.

The two moments of transformation.

Both museographic and didactic transposition take place in two moments of transformation. Didactic transposition in the school context takes place first through an *external* transposition regulated and rationalised by the diverse group of professionals and institutions who work with the contents of teaching at a higher level of didactic determination (e.g. ministry of education and other actors at the societal level; cf. Artigue and Winsløw, 2009). The second moment of transformation is an *internal* didactic transposition which takes place within the educational institution–the school–and is regulated at a lower didactic level mainly by the individual teachers and their interpretation of the curriculum. The two moments of transformation in a school context may thus exist in completely separate spheres. In contrast, museographic transposition is characterised by two moments of transformation which are both regulated by roughly the same group of actors within the same institution: exhibition conceptualisers, curators, education staff, etc. The two moments of museographic transformation are accordingly regulated at much the same level of didactic determination and may therefore exert a stronger influence on each other.

However, in the present case, the immersive experience which is at the core of *Cave Expedition*, namely the experience of being a cave beetle, seems only distantly related to the original scientific object of knowledge and to the manner in which entomologists usually relate to that object of knowledge; to very large extent, the creation of the museographic experience was at the discretion of the exhibition engineers. Thus, in processes of museographic transposition, the semiotic transformations of the body of knowledge may play an especially important role and accordingly tend to increase the distance between the bodies of knowledge in the respective scientific and exhibit contexts.

Implications.

The proximity of the two moments of museographic transposition, with regard both to actors and to level of didactic determination, could have the effect of reducing the degree of dogmatisation of the scientific knowledge in the transposition process; a dogmatisation which Develay (1989) found to be characteristic of the didactic transposition of biological knowledge in a school context. Certainly, the unconstrained experiential nature of *Cave Expedition* in particular and perhaps immersion exhibits in general presumably allow the visitor to freely interpret their impressions and decide which are the most personally meaningful. However, Macdonald (2002) found evidence that museum visitors decoded an exhibit cluster as providing relatively dogmatic information even though the exhibit cluster was designed with no such intentions. Taken together, these findings might be cautiously extrapolated to imply that although museographic transposition provides for less dogmatised knowledge than didactic transposition in a school context, visitors may not perceive it as such.

The proximity of the two moments of museographic transposition could also have the effect of minimising the de-contextualisation and subsequent re-contextualisation of scientific knowledge which is characteristic of didactic transposition (Chevallard, 1991). In the case presented here, the biological object of knowledge was never completely separated from its context, i.e. the cave beetle and its physical habitat were present in both the contexts that preceded the exhibition milieu: the scientific knowledge and the curatorial brief. This linkage would arguably provide the exhibition engineers with background knowledge that could guide the second moment of transformation and accordingly improve the integrity of the implemented exhibit. However, the present study demonstrated the strong influence of the exhibition engineers' alternative conceptions and pedagogical considerations in the second moment of transformation; this would indicate that a stronger degree of de-contextualisation and re-contextualisation takes place in museographic transposition than is the case in didactical transposition. Further studies are required to clarify the relationship between museographic transposition and didactic transposition as described by Chevallard (1991); hopefully, the present work may serve as a point of departure for such studies.

2.7 Concluding Remarks

This study offers three main contributions to the field of museum research. First, the study presents and exemplifies an analytical method applicable to the development of new immersion exhibits as well as the post hoc analysis of existing exhibits. Taking its point of departure in the scientific body of knowledge to be transposed and mapping the changes in this body of knowledge as it is transposed to the new contexts and modalities of the curatorial brief and the exhibition milieu, the method enables the systematic tracking of the epistemological and semiotic changes in a body of knowledge in the exhibit development process. This method along with the findings it yielded here may be considered the first-order results of the present study.

The descriptive model of exhibition engineering synthesised from the analysis of museographic transposition is the second contribution of this work. The model constitutes an important step towards systematic studies of the processes and mechanics of exhibition engineering. It emphasises the dialectic relationship between scientific knowledge and museographic form and ultimately, the importance of optimising the fit between object of knowledge to-be-exhibited and exhibit genre. The model constitutes what may be thought of as a second-order result of the present study.

Finally, a third-order contribution of this study to the field of museum research is the foundation that has been laid for a normative model of exhibition engineering. A study is currently under way which investigates visitor interactions with and understanding of the exhibition unit *Cave Expedition* on the basis of the findings presented here. This study will correlate visitor learning outcomes to the design features of the exhibit and to the considerations that drove that design, and use these correlations to expand the descriptive model of exhibition engineering into a prescriptive model for exhibition engineering.

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3 Analysis of the Educational Potential of a Science Museum Learning Environment

Visitors' experience with and understanding of an immersion exhibit

Marianne Foss Mortensen

Abstract. Research pertaining to science museum exhibit design tends to be articulated at a level of generality that makes it difficult to apply in practise. To address this issue, the present study used a design-based research approach to understand the educational potential of a biology exhibit. The exhibit was considered an educational environment which embodied a certain body of biological knowledge (Biological Organization) in a certain exhibit type (Museographic Organization) with the intention of creating certain learning outcomes among visitors. The notion of praxeology was used to model intended and observed visitor outcomes, and the pattern of relationship between the two praxeologies was examined to pinpoint where and how divergences emerged. The implications of these divergences are discussed at the three levels of exhibit enactment, design, and conjecture, and theoretically based suggestions for a design iteration are given. The potential of the design-based research approach for educational exhibit design is argued. **International Journal of Science Education, iFirst, 2010. Reprinted here with permission.**

3.1 Introduction

Barring a few notable exceptions (e.g. Schauble & Bartlett, 1997; Falcão et al., 2004; Guichard, 1995), current research pertaining to the design of informal educational interventions such as science museum exhibits contributes mainly to an accumulation of general recommendations and design guidelines. Examples of such guidelines from the last three decades are the findings that computer-based exhibits engage visitors (Meisner et al., 2007), that partially completed exhibit puzzles are more motivating for children than fully completed or uncompleted puzzles (Henderlong & Paris, 1996), and that visitors are attracted by exhibits that impart a short clear message displayed in a vivid manner (Alt & Shaw, 1984). While these findings are no doubt both reliable and valid, the design principles derived from them are articulated at a level of generality which makes them difficult to refute, and can accordingly inform museum exhibit engineering only superficially (Moscardo, 1996). Further, the general nature of the design principles makes them unable to account for the influence of contexts and the emergent nature of outcomes (Robinson, 1998); yet the phenomena that emerge from the context and its interaction of numerous factors are 'precisely what educational research most needs to account for in order to have application to educational practice' (The Design-Based Research Collective, 2003, p. 6).

The present study takes a design[1]-based research approach to exhibit engineering. In this perspective, the science museum exhibit is considered an embodiment of specific theoretical claims about teaching and learning (The Design-Based Research Collective, 2003); an embodiment which may be refined by investigating and connecting processes of its enactment (the outcomes of visitors' interactions with the exhibit) to aspects of its design and thus back to the conjecture which drives the design (Sandoval, 2004). The embodiment and enactment of these specific theoretical claims are examined as a way to not only improve the designed intervention – the exhibit – but also as a way to pinpoint contextual features that may improve the understanding of the underlying learning processes targeted by the design. Thus, rather than testing *that* the intervention works, the question is *how* it works (Sandoval, 2004).

Aim

The aim of the present study is to investigate the relationship between the design of a museum exhibit and the subsequent visitor interactions with and understandings of that exhibit, using the stated learning objectives for the exhibit as a measure of how well the exhibit performs. The stated learning objective of the exhibit may accordingly be thought of as its theoretical claim about teaching and learning, the exhibit itself as the embodiment of that claim, and the visitor interactions and understandings as the enactment of the claim.

3.2 Theory and Application

The Notion of Praxeology as an Analytical Framework

A praxeology is a general model which links the practical dimensions (the *practice*) and the theoretical dimensions (the *theory*) of any commonly occurring human activity (Barbé et al., 2005). The simplest praxeology (Figure 3.1) consists of a *task* of some type which is perceived by the learner and accomplished using a corresponding *technique*. The *technology* is the learner's rationale or justification for the chosen technique – why does it work, where does its effectiveness come from? – and finally, the *theory* refers to a more abstract set of concepts and arguments arranged into a general discourse which justifies the technology itself (Chevallard, 2007). An example from third-level biology education may serve to illustrate the model (Figure 3.2).

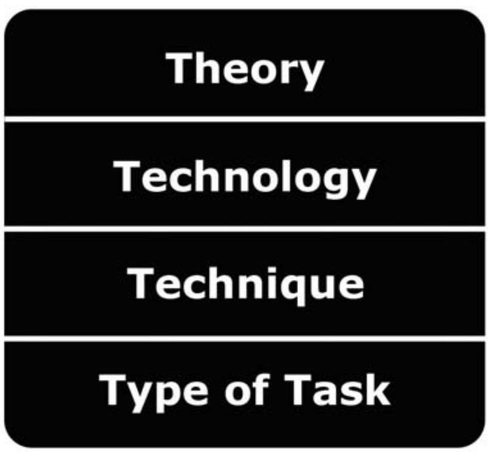

Figure 3.1. A praxeology, consisting of a type of task, a technique, a technology and a theory.

The practice block of a praxeology consists of the task and the technique components, and may be thought of as 'know-how', while the theory block, consisting of the technology and the theory, may be thought of as 'know-why'. Praxeologies may occur in larger systems in which several practice blocks are explained by one theory block; a collection of practice blocks that share the same technology and theory is called a local organization (Chevallard, 1999). Expanding the example of a praxeology provided in Figure 3.2 to a local organization could entail including a second task, for example one that dealt with dihybrid crosses. The technique used to accomplish this second task would be different from the technique used to solve the first, yet can be explained using the same technology (and theory) as the first task.

Any body of knowledge may be thought of as a praxeology or family of praxeologies the acquisition of which corresponds to the mastery of the *practice* and *theory* components of the knowledge. The praxeology model has been used as a framework for the analysis and design of teaching interventions in formal science education settings where its most important contribution has been the identification and remediation of disassociations between the practice and the theory of taught bodies of knowledge; disassociations that originated at the curriculum level and which precluded students from gaining any deeper understanding of the bodies of knowledge in question (e.g. Barquero et al., 2007; Rodríguez et al., 2007). The strength of the notion of praxeology is thus its ability to link the characteristics of taught bodies of knowledge with the characteristics of learnt bodies of knowledge, or, as outlined by Sandoval (2004), to connect processes of the enactment of a teaching intervention to aspects of its design and thus back to the conjecture which drives this design.

In the present study, the notion of praxeology is used in an analysis of the teaching environment that is the museum exhibit. The *intended praxeology* embodied by a museum exhibit is elucidated and compared with the *observed praxeology* of visitors to the exhibit. The emergent patterns of difference between these praxeologies will make possible the assessment and subsequent refinement of the conjecture embodied by the exhibit as a means of supporting a specific educational objective among museum visitors. In other words, the approach will yield theoretically grounded and practically applicable principles for improving the alignment of exhibit conjecture, design, and educational outcomes.

	T	**t**
T	**TT**	**Tt**
t	**Tt**	**tt**

Figure 3.2. An example of a praxeology. A learner is given the following question: ‘if a monohybrid cross was carried out between two pea plants, both of the phenotype ‘tall’ and genotype Tt, what would be the expected ratio of the phenotypes of the resulting offspring?’ The task perceived by the learner in this case could be expressed as: ‘find the ratio of tall plants to short plants in the group of plants produced by crossing a Tt plant with a Tt plant’. The technique with which the learner could do this is by constructing a Punnett square – a diagram to predict the outcome of any breeding experiment – resulting in the present case in the offspring genotype ratio of 1TT : 2Tt : 1tt. The technology, or justification of the use of the Punnett square, is that each of the parent plants produces gametes with just one of the two alleles for each trait. Because the parent plants are both genotype Tt, they can produce gametes containing either the T allele or the t allele. Fertilisation entails the fusion of one maternal gamete with one paternal gamete resulting in one of the four genotypes shown in the Punnett square (TT, Tt, or tt). Because the dominant allele (denoted by the capitalised letter T) is always expressed, the resulting phenotypes of the offspring are, on average, 3 tall pea plants (TT + Tt + Tt) to 1 short pea plant (tt). The theory of the praxeology exemplified here entails a broader understanding of genetics, including the facts that the Mendelian ratio of 3:1 is a theoretical prediction that assumes segregation and independent assortment of alleles, and that there are situations where these assumptions are not met, for example when alleles are co-dominant or when there are interactions between alleles of different genes.

The Exhibit and its Intended Praxeology

The studied exhibit is part of the travelling exhibition 'Xtremes' which opened in October 2007 at Experimentarium, a science centre in Copenhagen, Denmark and in October 2008 at the Royal Belgian Institute of Natural Sciences (RBINS) in Belgium. The general theme of *Xtremes* is animal adaptations to extreme environmental conditions on Earth and it features five clusters: Heat, Cold, Aridity, Low Oxygen, and Darkness, respectively. The attention here is to a single immersive exhibit, 'Cave Expedition', within the cluster about darkness. The exhibit is described in detail in Mortensen (2010).

The design process of *Cave Expedition* integrated a biological body of knowledge with a chosen exhibit style or strategy (Mortensen, 2010). Translated into praxeology terminology, the process deconstructed and reconstructed a biological body of knowledge (or Biological Organization) by means of an exhibit strategy (or Museographic Organization). The Biological Organization embodied by *Cave Expedition* is *the adaptations of the blind cave beetle to its environment of permanently dark caves*, and the means by which this Biological Organization is embodied is the Museographic Organization of an immersion exhibit. Immersion is a specialised exhibit practice in museums, defined by the creation of an illusion of time and place through the reconstruction of key characteristics of a reference world, and by integrating the visitor in this reconstructed world (Bitgood, 1990). The successful reconstitution of the reference world relies on the presentation of the exhibit as a coherent whole, the integration of the visitor as a component of the exhibit, and the consequent dramatisation of matter and message (Belaën, 2003).

In *Cave Expedition*, the integral components of the Museographic Organization are the reconstruction of the cave beetle’s habitat in the form of an artificial, scaled-up cave containing representations of key characteristics of the cave beetle’s habitat; the bestowing of the role of the cave beetle to the visitor through interpretive signage; and finally, the interaction between the visitor in their role as a cave beetle and the reconstructed cave beetle habitat which potentially creates a discourse which dramatises aspects of the cave beetle’s daily struggle for survival (Mortensen, 2010). These key components of the Museographic Organization together represent the Biological Organization, resulting in a *multiply embodied learning ecology* which functions as a whole rather than as a collection of activities or separate factors that operate in isolation from one another (Cobb et al., 2003; Sandoval, 2004). For the purposes of analysis, these activities are defined and operationalised in the praxeology framework in the following.

A praxeology is defined by its component task or tasks. The exhibit Cave Expedition consists of a number of different types of tasks that may be accomplished using different techniques, e.g. interpretive panels to be read, an artificial cave to be navigated, etc. The first observation that may be made is that the intended praxeology of the exhibit encompasses more than one practical block. Further, the intended visitor outcome of the exhibit is to enable the visitor to find out, through their experiences, how the cave beetle is adapted to its environment of permanently dark caves (Executive Committee, 2005). This outcome frames the tasks and techniques embodied by the exhibit, and may thus serve as the unifying technology of the exhibit. The second observation that may be made is accordingly that the intended praxeology of the exhibit is of the type: local organization. The theory component of such a local organization may or may not encompass several local organizations; in the present case, the theory is located at the level of the entire exhibit cluster 'Darkness' and will consequently not be considered further here.

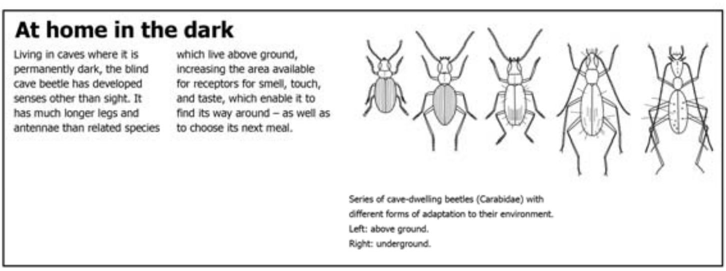

Figure 3.3. Panel 1 in Cave Expedition consisted of an introductory text, an illustration, and a caption in roughly the proportions shown. Beetle illustration © 2007 by RBINS, Experimentarium, and Naturalis. Reprinted with permission.

Table 3.1. The intended praxeology of the exhibit *Cave Expedition*, expressed in terms of tasks, techniques, and technology.

Task	**Embodied by**	**Technique**	**Technology**
Perceive that beetle adaptations are: elongated legs and antennae, reduced eyes, enhanced smell, taste, and touch	Panel 1 text and illustration	Discern variation in beetle features in illustration; read text	
Perceive intended visitor role as cave beetle	Panel 2 text	Identify instructions on panel 2 as pertaining to how to proceed and to cave beetle behaviour	
Perceive exhibit as representation of cave habitat	External and internal cave structure	Recognise characteristics of exhibit as cave-like	Interpret own role to be an analogy of the cave beetle's, interpret own actions to be analogies of those of the cave beetle's, interpret exhibit features to represent characteristics of cave beetle habitat...
Assume role of cave beetle by assuming its adaptations	Internal cave structure and transition from the outside	Switch sensory modalities from primarily vision to touch and smell	

Perceive that cave beetle movement is dictated by cave habitat's physical boundaries	The configuration of the passageway inside the cave	Use touch to assess boundaries, proceed accordingly	...thereby experiencing vicariously and understanding that the cave beetle's habitat is characterised by being dark and enclosed; that the beetle navigates using touch, not vision; that there are other cave-dwelling animals in the cave beetle's habitat and that the cave beetle may discern these by touch.
Perceive that cave beetle heterospecifics co-inhabit the cave habitat	Animal models mounted on internal wall of exhibit	Discern and identify animal models as cave inhabitants by touch	
Perceive that cave beetle habitat may be characterised by odours	Presence of odour in exhibit	React to odour gradient from outside to inside of cave structure	
Assess own ability to survive the daily conditions for a cave beetle	Panel 3 text and scoreboard	Compare visible animal models with memory of models inside cave structure; compare scents with memory of scent inside cave structure	

The tasks embodied by *Cave Expedition* were induced and defined by their role in the Museographic Organization. For example, the first task was embodied by Panel 1 and its text and illustration (Figure 3.3). This panel embodies the visitor task of perceiving that the cave beetle's adaptations include elongated legs, elongated antennae, reduced eyes, and enhanced senses of smell, taste and touch. The technique to accomplish this task is reading the text and discerning the variations in the traits of the depicted beetles. Another task is embodied in Panel 2 and its text, which reads:

> Cave Expedition.
>
> Wait for the light to turn green and go into the cave.
>
> Return to the darkness.
>
> Feel the walls, find the animals, smell the odours.
>
> When you are outside, identify your findings.

Panel 2 embodies the visitor task of perceiving and accepting their intended role as the cave beetle, and this task may be accomplished by reading the text which requests the visitor to enter the cave and *feel* the walls, *find* the animals, and *smell* the odours, at the same time referring to Panel 1 where these behaviours were described as cave beetle characteristics.

A final example of a task embodied by *Cave Expedition* is the external and internal structure of the artificial cave. The artificial cave is constructed from an uneven, grey, rocklike material and has a completely darkened interior; these characteristics embody the visitor task of perceiving the exhibit as a representation of a cave. The technique with which this task may be carried out is the visitor's recognising the characteristics of the artificial cave as 'cave-like'. The complete intended praxeology of *Cave Expedition*, eight tasks and their corresponding techniques and technology, is shown in Table 3.1.

3.3 Data Collection and Analysis

Data were collected from three discrete groups of visitors designated as pilot visitor groups, casual visitors, and respondents, respectively (Table 3.2). The pilot visitor groups were observed and interviewed at

Experimentarium in Copenhagen in August 2008 and the casual visitors and respondents were observed and/or interviewed at RBINS in Brussels in February and March 2009. The layout and content of the exhibits comprising *Xtremes* were identical in the two locations barring a few instances which were unrelated to the cluster *Darkness*. All data were collected in the immediate vicinity of *Cave Expedition*. Interviews were conducted in Danish at Experimentarium and in English at RBINS. Some informants at RBINS responded to the questions or the *think aloud* (explained in the following) in their native language, thus of the 16 respondents, 5 responded entirely or partially in French, and 5 responded entirely or partially in Flemish. The audio recordings of these respondents were transcribed and translated into English by native French and Flemish speakers, respectively. The audio recordings of the informants responding in English or Danish were transcribed (and translated into English in the latter case) by the author. All data was collected during school holidays.

Table 3.2. Details of informants. No informant participated in more than one group.

Participant type	n	Designation	Location	Treatment
Pilot visitor groups	20	P001 – P020	Experimentarium	Observation, interview
Casual visitors	100	C001-C100	Royal Belgian Institute of Natural Science	Observation
Respondents	16	R001 – R016	Royal Belgian Institute of Natural Science	Observation, think aloud, interview

Pilot Study

The basic idea of the design-based research approach is that it responds to emergent features of the educational setting (The Design-Based Research Collective, 2003). In order to gain an initial understanding of this setting (i.e. the visitors' interactions with the exhibit) and what might constitute emergent features, a pilot study was conducted. Family groups, i.e. groups consisting of at least one adult and one to three children, were designated as the target pilot visitor demographic. Visitor groups which fulfilled these requirements were discreetly observed during their approach to the exhibit, and when the second member of the group crossed an imaginary line on the floor, the observer formally started the observation. If they continued past the exhibit, the timing was stopped and the group not included in the study. If they navigated through the exhibit (the criterion for inclusion in the pilot study), they were observed during their interaction with the exhibit. Their behaviour inside the cave was observed via an infra-red closed circuit TV installed for safety purposes and publically viewable outside the exhibit. Their path through the exhibit area was traced on a floor map. Upon their leaving the exhibit, as gauged by the second member of the group crossing an imaginary line on the floor, the observer stopped the time-taking and approached them to request a brief interview. Consenting groups were interviewed, and the entire exchange recorded on a digital recorder. Gender and approximate age of each group member were recorded. A total of 20 groups, designated as P001 through P020, were observed and interviewed.

Interview questions.

The initial interview questions were formulated on the praxeology-based idea that the engagement between the visitor and the exhibit had two aspects: a practical and a theoretical aspect. The practical aspect consisted of visitors' direct interactions and experiences with the exhibit and could be investigated through direct observations and interview questions; the theoretical aspect consisted of visitors' reflections about and explanations of these direct experiences and could be made tangible through interviews. The interview questions were consequently formulated at two levels: a basic level to probe the visitors' direct (and when possible, observed) interactions with the exhibit, and at a higher level to elucidate how these interactions were interpreted. Consider the following example:

1. What is it supposed to be, the exhibit you were just exploring?

A majority of pilot visitor groups answered 'a cave', which led to the second question:

2. What makes it a cave, in your opinion?

Question 1 is a basic-level question intended to focus the visitors' attention on an exhibit feature (the artificial cave); question 2 attempts to discover why the visitors interpret the exhibit feature in question as they do. Question 1 was considered practical-level question; question 2 a theoretical-level question. Another example of a theoretical-level question is the following:

8. What is the point of this exhibit? What are you meant to learn from it or do with it?

Questions of this level were intended to probe how the visitors integrated their exhibit experiences into a coherent whole.

The interview questions underwent two sets of revisions during the 12 days in which the pilot study took place, once after the first five interviews (P001-P005) and again after the next five interviews (P006-P010). These revisions were based on the previous observations and visitor responses and consisted of clarifications of the questions in order to focus more precisely on the visitors' experiences with and subsequent interpretation of the exhibit. For example, question 2 in the above example was formulated after the second revision and accordingly only applied to groups P011-P020.

Outcomes of the pilot study.

The pilot study had three outcomes that shaped the continued investigation: First, the study confirmed that the visitors' interactions with and understandings of *Cave Expedition* could indeed be described using both practical and theoretical aspects. This led to the choice of the praxeology as an analytical tool for the investigation of the exhibit. Second, even though the combination of methods (observations and interviews) guided the refinement of the interview questions towards a better description of the relationship between the practical and theoretical aspects of the exhibit interaction, this relationship was not being fully captured. Specifically, there were practical aspects of the visitor-exhibit interactions that were not observable, and in the short time between their exhibit interaction and the interview, the visitors had already processed and rationalised the experience, making it part of the theoretical aspect of the exhibit visit. In other words, the visitor's memory of the experience was guided by their subsequent rationalisation of it (cf. van Someren et al., 1994, p. 21). Thus the decision was made to include the think aloud method in the further investigation (cf. Tulley & Lucas, 1991) as outlined in the following section. Employing the think aloud method entailed a change in the target informant demographic. The use of family groups in the pilot study had been based on the best case scenario behaviour of such groups (Allen, 2002); however, the think aloud method utilises single informants (van Someren et al., 1994) and thus precluded the study of visitor groups.

Finally, the pilot study revealed that only a very small fraction of the pilot visitor groups (1 group of 20) perceived *Cave Expedition* to be about cave beetles. Based on this finding, it was decided to add two extra questions to the nine questions refined in the pilot study. These two additional questions were of a different nature than the first nine; in the absence of the visitors' own awareness of their role as cave beetles, these two questions would serve to inform them about this intended role and to prompt them to re-interpret on their exhibit experiences. The idea was to probe visitors' own ideas about 'what it is like to be a cave beetle' and to relate these ideas to exhibit design features. The full list of questions is listed in Appendix A.

Experimental Design

The final experimental design consisted of three data collection methods: observations, think aloud recordings, and interviews (Table 3.3). These three methods were chosen to cover the range of visitor educational outcomes from the practical to the theoretical level of the exhibit's intended praxeology. By covering, with an extent of overlap, the entire range of visitor outcomes specified here, the combination of methods also provides a degree of triangulation which has the potential to strengthen the findings.

Table 3.3. The practical and theoretical components of the visitor's interaction with and understanding of *Cave Expedition* and the corresponding experimental method with which the visitor's engagement at that level was assessed.

Praxeology	Observations	Think aloud recordings	Unprompted recall interview	Prompted interpretation interview
Practical level (technique)	✓	✓	✓	
Theoretical level (technology)		✓	✓	✓

Observations.

The visitor observations had the primary goal of determining in which intended techniques visitors engaged in. For example, the task embodied by exhibit Panel 1 may be accomplished by discerning the variation in beetle features in the illustration and reading the text (Figure 3.3). The minimal requirement for this task to be accomplished is for the visitor to approach and view the panel. The corresponding visitor behaviour category is thus labelled ‘View Panel 1’. Another task, embodied by the animal models mounted on the internal cave wall, is accomplished by the technique of the visitor using their sense of touch to discern these models and to identify them as cave inhabitants. This technique may be partially observed using the visitor behavioural category ‘Touch animals’. The procedure yielded seven behavioural categories which formed the basis of the observation study. These behavioural categories, referred to as ‘behaviours’, are summed up in Table 3.4. Two additional visitor behaviours (‘View monitor’ and ‘Watch other visitors’) were included in the visitor observations but not used in the present analysis and not considered further here.

Think aloud method.

The think aloud method consists of asking informants to solve a certain problem while verbalising their thoughts, and was developed to investigate the cognitive processes that take place during problem solving (van Someren et al., 1994). The method requires the construction of coding scheme and a psychological model of the problem-solving to interpret the obtained protocols. In the present case, the method was used to provide qualitative descriptions of an exploration activity. Accordingly, a very simple verbalisation process by the informant was assumed, yielding an objective reflection of informant thought processes (cf. Dufresne-Tassé et al., 2006).

Interviews.

Open-ended interviews were conducted to explore how visitors interpreted their practical interactions with the exhibit (their techniques). The nine interview questions were finalised in the pilot study. In addition to these nine questions, two additional questions were posed to the respondents (Appendix A).

Casual Visitor Study

The casual visitor study consisted of non-intervening observations of visitors who entered a well-defined area bounded on two sides by elements of the exhibit *Cave Expedition*. Any adult visitor entering this area during the observation session was classified as a casual visitor, and alternate female and male subjects were observed: when the first observed casual visitor exited the observation area, the next adult of the opposite sex to enter the area became the second observed casual visitor, etc. The observations were carried out in half-hour sessions during the same weekdays and hours as used in the respondent study (described in the following section). The observations included recording which behaviours occurred and the amount of time spent, if any, inside the artificial cave. A total of 100 casual visitors, designated C001 through C100, were observed.

Table 3.4 Recorded visitor behaviours at *Cave Expedition*.

Behaviour	**Description**
View Panel 1	Visitor stands still facing Panel 1 at distance of 1m or less
View Panel 2	Visitor stands still facing Panel 2 at distance of 1m or less
View infrared monitor	Visitor stands still with lifted head facing monitor
Enter cave	Visitor passes through turnstile
Navigate cave	Visitor proceeds through passage towards exit (observable by CC TV)
Touch animals	Visitor pauses with hands on animal models (observable by CC TV)
View Panel 3	Visitor stands still facing Panel 3 at distance of 1m or less
Interact with Panel 3	Visitor touches animal models, bends to smell scent, or presses buttons on Panel 3
Watch other visitors	Visitor stands still, facing exhibit area

Respondent Study

In the respondent study, single adult visitors unaccompanied by children were recruited when they approached *Cave Expedition*. Consenting visitors were fitted with a lapel microphone connected to a wireless transmitter which fit in their pocket or clipped onto their belt. The audio feed from the microphone was transmitted to a receiver clipped on the interviewer's belt; from here it was fed to a digital Dictaphone also on the interviewer's belt. The audio feed was monitored by the interviewer using earphones plugged into the Dictaphone.

The interviewer showed the respondent the exhibit by outlining the same well-defined area as used in the casual visitor study, and asked the respondent to visit the exhibit as they normally would but at the same time vocalising their thoughts. The introduction was kept brief to minimise the degree to which respondents could form their own interpretations of the intentions of the study (cf. van Someren et al., 1994, p. 43). When the respondent turned towards the exhibit area, the interviewer began the observation. Respondent behaviour, route through the exhibit, and time spent in the artificial cave were recorded. In addition, the interviewer made notes as to the respondent's location and activities as they conducted their narration. When the respondents exited the exhibit area, they were intercepted and asked to sit down for a brief interview. The audio capture and transmission equipment stayed attached to the respondent during the interview; the lapel microphone was sensitive enough to capture the interviewer's voice as well as the respondent's. An open-ended interview was carried out using the questions listed in Appendix A. The interviewer made notes as the interview progressed to inform the subsequent questions. When the interview was concluded, the visitor was thanked and given the interviewer's contact information in case questions arose. The respondent's gender and approximate age were noted. A total of 45 visitors were asked to participate; of these 29 declined and 16 accepted. The most often stated reasons for declining was that the visitor in question didn't have time to participate, or that they didn't understand English. The sample (n = 16) was deemed representative of adult visitors on the basis of two findings: 1) the nature of the responses given to the interview questions by respondents was relatively constant from respondent to respondent throughout the data collection period, and 2) a comparison of the observed behaviours of the casual visitors and of the respondents showed no significant differences, i.e. the frequency of behaviours observed in the respondents did not measurably differ from the frequency of behaviours observed in the casual visitors (nine individual χ^2 tests, 1 d.f., $p > 0.05$ in all cases).

Data Analysis

The transcripts of the think aloud and interviews were pooled for the analysis. In the first reading of the transcripts, the informants' utterances were categorised as either technique or technology and their concurrent behaviour and location noted. In the subsequent reading, the categorisation was confirmed, and emergent patterns within the two categories were noted. Specifically, the visitors' perceptions of the various tasks embodied by the exhibit emerged from this analysis. The data were analysed for both confirming and discrepant situations.

3.4 The Observed Praxeology

The observed praxeology constructed on the basis of respondent data differed in a slight but fundamental manner from the intended praxeology. The following section illustrates how the observed praxeology was created.

The Observed Tasks and Techniques

In the intended praxeology, *Cave Expedition* Panel 1 embodied the task of 'perceiving that cave beetle adaptations include: elongated legs, elongated antennae, reduced eyes, enhanced senses of smell, taste, and touch'. In contrast, only one of the three respondents who carried out the behaviour 'View Panel 1' made reference to these adaptations:

> Here, you… it is something about insects, I think. 'Living in the caves where it is permanently dark, the blind cave beetle has developed its sense other than sight. It has much longer legs and antennae than related to species which live above the ground, increasing the area available for the receptors for smell, touch and taste which enable it to find its way around as well as to choose its next meal'. All right. Explaining, eh, this insect, and uhm, you can also see a picture of it. And where it has lived. (Think aloud, R013)

Another respondent noted simply that the panel content pertained to beetles as illustrated in the following excerpt. The third respondent viewed but did not comment on Panel 1.

> It represents some kind of bugs… beetles, they are. OK, so that explains, I guess, the… yes, OK, the blind cave beetle. OK. Well, that looks not so nice to me because I'm not so interested in bugs, but OK [laughs] (Think aloud, R012).

While R013 read aloud the text on Panel 1, he did not verbally link the text on the cave beetle adaptations of elongated legs and antennae to the illustration of beetles which emphasise these features. Likewise, R012 did not comment on the beetle's characteristics. Accordingly, the observed task embodied by Panel 1 may be stated as: 'Perceive text and illustration to pertain to insects, specifically, beetles'. This task is accomplished by the observed technique of reading (parts of) the text and recognising the illustration as showing beetles.

Panel 2 embodied the task 'perceive intended visitor role as cave beetle' which could be accomplished by the intended technique of identifying the text on the panel as pertaining simultaneously to how to proceed and to cave beetle behaviour. None of the ten respondents who viewed Panel 2 showed evidence of accomplishing this dual task: the text panel elicited think aloud utterances from two of them, and their perception of the text as instructions of a purely practical nature was apparent in these verbalisations:

> First, [I'll] read... it is green then you can enter ... yes? (Think aloud, R006)

> OK, now I am just reading the explanation: how to visit this cave… so I will wait for the green light. […] the purpose is to feel the smell, and what kind of insects that you are finding inside this cave. That's the purpose, I think. And insects living in darkness, probably (Think aloud, R013).

The second respondent also referred to the biological content of Panel 2, inferring that the purpose of the subsequent cave experience is to find various insects and smells in the darkness. However, R013 did not explicitly relate the assignment of finding insects and smells inside the cave to cave beetle behaviour, a disconnect which is echoed by another respondent:

R007:	Where… the kind of, little information [referring to Panel 2] just told when I could and couldn't enter the exhibit, it didn't tell me anything specifically about it being about a cave beetle.

The task perceived by visitors to be embodied by Panel 2 may accordingly be stated conservatively as 'enter exhibit' accomplished by the technique of 'perceive that green light indicates "enter exhibit"'.

Another example of an observed task and technique is the visitors' responses to the internal and external structure of the artificial cave. The intended task embodied by these structures is 'perceive artificial cave as representation of cave beetle habitat'. Although only two respondents referred to the exhibit as a cave during the think aloud, a majority of respondents (11 of 16) stated that the exhibit was a cave when asked 'what is it supposed to be, the exhibit structure you were just visiting?', and when asked to elaborate why they perceived it to be a cave, explanations such as darkness (11 respondents), the rock-like structure (6 respondents), the appearance of the entrance (5 respondents) and the presence of models of animals associated with caves (2 respondents) were given. However, when asked whether the exhibit pertained to any particular animal, none of the respondents named the cave beetle. The following responses are typical:

R002:	Yeah, I think, these animals that live in darkness.
Interviewer:	Any particular animals?
R002:	Just reptiles, insects, I don't know – I haven't seen any… what is it… bats?

R005:	About the animals that live in the dark, I imagine.

R010: No, just different animals… Different animals that are living in the dark and… yeah… oh, and living under the ground.

In sum, while all respondents approached and entered the artificial cave and a majority stated that they perceived it to be a cave, none of them made reference to the cave beetle. Some respondents showed evidence of interpreting the cave from a human perspective as illustrated by the following excerpt:

R012: It's also this, uhm, door maybe [refers to exhibit entrance] because sometimes you can see in the cartoons, the kind of, you know things that they made while people – at the times when they lived in the caves they made these kind of doors, so…

The observed task that may be elucidated from the data is accordingly 'perceive exhibit (from a human perspective) as representation of cave', and this was accomplished by the respondents using the technique of 'recognise internal and external characteristics of exhibit as cave-like'.

The examples shown above establish a pattern that permeated the remaining five observed tasks and techniques. While the visitors in the majority of cases responded to the exhibit tasks in accordance with the intended techniques, their fundamental perception of the tasks was from a human perspective rather than from the perspective of the cave beetle; a perception which had consequences for the nature of the technologies constructed by the respondents.

The Observed Technology

The rationales formed by the respondents as a response to their experiences with *Cave Expedition* ranged from a characterising their interactions with the exhibit from a purely human perspective, over the intermediate position of characterising their experiences from a human point of view and drawing parallels to animals, and finally to interpreting the exhibit as being a more or less static display about animals. In all cases where animals were mentioned, the respondents were referring to either the animals depicted in the animal models in the cave (lizards, spiders, frogs), a non-specified collection of dark-adapted animals, e.g. 'Different animals that are living in the dark and… yeah… oh, and living under the ground' (Interview, R010), or a combination of these two groups.

Examples of a purely human perspective taken in rationalising the exhibit experience are the following answers to the interview question 'What is this exhibit about? What are you meant to learn from it, or experience?':

R002:	This experience just shows you other senses that you can rely on when you are in a different situation, just… I think that's the goal of… I think that's it.
R008:	That you don't need your sight. That you can find your way by feeling and touching things.

Six respondents took this perspective, explaining their experiences from a purely human point of view. Two respondents also took a human perspective, but in addition compared these experiences to those of dark-adapted animals when posed the above interview question:

R004:	Maybe how we still function even if we don't see. And that's [what] the animals have done: adapted themselves, and we still… we could do it also.

Four respondents went further, and directly interpreted their experiences in the exhibit as analogies of those of dark-adapted animals:

R006:	Oh, I think it's interesting, it's… 'cause it… it immerses us… we are like in the real… [environment]. And here, you have some sensation of the way, the animals live.

R007:	Uhm, to experience what it would be like to be an animal that lived in a cave. So, it would be an animal that had adapted probably to become blind… and then using just its other senses.
Interviewer:	OK? But no particular animal springs to mind?
R007:	Uh… no.

R012:	Well, I guess the experience, it's about to show you the real conditions – or at least close to real – in which those animals live in the darkness. And maybe, if you think about it, afterwards you realise that they have some senses that are much more developed than ours, because they probably could use smell or… I don't know, whatever, to find their way.

Finally, four respondents perceived the exhibit as pertaining only to animals, with no explicit link between the animals and their own experiences:

R010:	That they are living in the dark. The animals are living in the dark…

R013:	I think that it is just to have a feeling how the… to feel the animals. I don't know, I… it didn't give me so much actually. I think it will give the children more, actually. Since you have this touching and smelling thing. I think it is to underline that these animals are… that they live in darkness.

There were no discernable differences in the behaviour patterns of the visitors whose rationales fell into these different groupings. In other words, although the techniques were relatively constant from visitor to visitor throughout the sample, their technologies fell into two main categories: an exhibit-rationalised-as-experience category (twelve respondents), and a smaller exhibit-rationalised-as-static-display category (four respondents). The former technology may be conservatively described as: 'Interpret own actions to be those of human in a cave, interpret exhibit features to represent characteristics of a cave; thereby experiencing that caves are characterised by being dark and rocky, that navigation is based on touch, not vision, and that caves are inhabited by certain animals.' In some cases an additional reflection was detected, namely: 'Extrapolate own experiences in cave to those of animals inhabiting caves'. The exhibit-rationalised-as-static-display technology may be described more simply as: 'Understand that certain animal species inhabit dark environments such as caves'. The observed tasks, techniques, and technology are summed up in Table 3.5. For reasons discussed in the following, only the exhibit-rationalised-as-experience technology is included in Table 3.5.

3.5 Comparing the Intended and the Observed Praxeologies

Comparing the theoretically derived intended praxeology with the empirically derived observed praxeology reveals subtle differences at the *task* level that lead to a substantial divergence at the technology level, namely the respondents' failure to perceive their intended roles as cave beetles. At a first glance, it would seem that the failure of most respondents to view the exhibit's Panel 1, i.e. accomplish task 1, is at the root of the divergence. Three out of 16 respondents viewed Panel 1 (a percentage which does not significantly differ from that of the casual visitors), but these three visitors did not as a result view their subsequent experiences as those of a cave beetle, nor did they perceive the exhibit to pertain to cave beetles. Apparently, the divergence between intended and observed praxeologies had a more pervasive origin.

In fact, *Cave Expedition* was perceived to embody a human perspective rather than a cave beetle perspective in almost every aspect, not just in the perceived lack of information to this effect cited by five respondents (task 1 and 2 embodied by Panels 1 and 2). Another often cited reason was the configuration of the passageway inside the cave (five respondents) which was found to be too short, too broad, and not convoluted enough to reflect the respondents' ideas of a cave beetle's habitat. These perceived shortcomings may accordingly have obstructed the intended accomplishment of task 5 (perceive that cave beetle movement is dictated by cave habitat's physical boundaries) and substituted instead a human perception. In addition, the presence of a guide rope inside the passageway (mentioned by two respondents) and the ambient light which, while dim, was discernable (mentioned by two respondents), may have hindered the visitors' assumption of the adaptations of the cave beetle (task 4) and contributed instead to the perception of the exhibit as a cave in human terms.

The scaling of the exhibit was mentioned by four respondents as a reason they were not aware of their intended roles as cave beetles. Specifically, two respondents indicated that the scale of the animal models on the cave wall reflected a human perspective rather than a cave beetle:

R009: Yes, because a human is bigger than a beetle, so eh… the animals, the spider has to be bigger than us.

Accordingly, while a majority (7 of 12) of the respondents who discovered the animal models on the exhibit wall perceived them to be indicative of a cave habitat thus using the intended technique, the scaling of the animal models reinforced the human perspective and thus obscured the intended task embodied by the animal models (task 6: perceive that cave beetle heterospecifics co-inhabit the cave habitat).

Table 3.5. The observed praxeology of the exhibit *Cave Expedition*, expressed in terms of tasks, techniques, and technology.

Task	Embodied by	Technique	Technology
Perceive text and illustration to pertain to insects, specifically, beetles	Panel 1 text and illustration	Read (parts of) text; recognise the illustration as showing beetles	
Enter exhibit	Panel 2 text	Identify instructions on panel 2 as how to enter exhibit	Interpret own actions to be those of human in a cave, interpret exhibit features to represent characteristics of a cave; thereby experiencing that caves are characterised by being dark and rocky, that navigation is based mainly on touch, not vision, and that caves are inhabited by certain animals.
Perceive exhibit as representation of cave habitat	External and internal cave structure	Recognise characteristics of exhibit as cave-like	
Assume role of human exploring cave	The internal cave structure and the transition from the outside	Switch sensory modalities from primarily vision to touch	

Perceive that movement is dictated by cave's physical boundaries	The configuration of the passageway inside the cave structure	Use touch to assess boundaries, proceed accordingly	In some cases, additionally: Extrapolate own experiences in cave to those of animals inhabiting darkness/caves.
Perceive that certain animals inhabit caves	Animal models mounted on internal wall of exhibit	Discern and identify animal models as cave inhabitants by touch	
Assess own perceptual capabilities in the dark	Panel 3 text and scoreboard	Compare visible animal models with memory of models inside cave structure	

Note: the odour feature of the exhibit was out of order during the data collection; the odour-related *task* and *technique* have accordingly been omitted.

Finally, five respondents answered the question of why they didn't assume the role of a cave beetle in the exhibit by pointing out that the vast differences between cave beetles and humans would make any assumption of such a role difficult or impossible:

> R012: The idea of feeling like an insect is very strange to me [laughs], so I think that they would have to put significantly more effort into that to really make me imagine that I feel like a cave beetle in this cave [laughs].

> R016: Because we are deeply human inside, actually. It's hard and difficult to think differently… because we are used to being human.

As exemplified in the above, the establishment of a human perspective by the visitor to the exhibit is substantially, though unintentionally, supported by the exhibit's component parts and thus by the exhibit as a whole. In the following, the implications of this particular configuration of Biological Organization, Museographic Organization, and subsequent learning outcome are discussed with a view to elucidating patterns that may be generalised to a larger class of exhibit learning environments.

3.6 Discussion

The aim of the present study was to study the embodiment of a body of knowledge as a means of supporting a certain learning outcome by connecting processes of its enactment to aspects of its design and thus back to the conjecture which drives the design. Specifically, the study deals with the claim that embodying the Biological Organization of *the adaptations of the blind cave beetle to its environment of permanently dark caves* with the Museographic Organization of an immersion exhibit can support the visitor learning outcome of experiencing how the cave beetle is adapted to its environment of permanently dark caves. After a brief discussion of some methodological issues, the main findings of the study regarding exhibit enactment, design, and conjecture will be discussed and their implications presented.

Methodological Issues

Studying visitor behaviour and vocalisations in a museum setting is logistically difficult due to variables such as the acoustics of the space, the ambient noise level, the movement and activity of the subject, and the various dynamics of other visitors (Allen, 2002). In the present study, the decision to observe single adult visitors primarily facilitated the chosen data collection method, but also served to control some of the variables. First, by fixing the audio capture equipment to the single subject being observed, the subject was never out of range of the microphone, a problem which would have been especially pertinent due to the walk-through nature of *Cave Expedition* if an attempt had been made to record group conversations. Second, the think aloud vocalisations of single adult visitors arguably included less of the fragmented and ambiguous discourse characteristic of groups of visitors (Allen, 2002) and could thus be coded more reliably.

The main limitation of investigating single adult visitors' interactions with and understandings of a museum exhibit is the issue of generalising the results to groups of visitors. Many studies emphasise the social nature of museum visits and the collaborative learning that takes place during such visits (e.g. Allen, 2002), an aspect of the museum visit that is absent from the analysis of the present study. On the other hand, the single adult is an existing museum visitor demographic (e.g. McManus, 1989) and thus also merits study. A potentially fruitful perspective could be to consider the observed praxeology of the single visitor as a baseline or first-order description of the exhibit's learning potential against which learning outcomes of group visits could be gauged. This would contribute to the understanding of exactly how the group dynamic influences the learning potential of an exhibit, and would be an interesting topic for a follow-up study.

Exhibit Enactment

Although the intended learning outcome was not fully achieved by any of the respondents, it was partially achieved by a majority while a minority perceived the exhibit as a static display. This fundamental division corresponds well with two of the families of visitor reactions to immersion exhibits found by Belaën (2003), namely *resonance* and *distance*. In the resonance group, the visitors willingly surrendered themselves to the premise of the exhibit, immersing themselves in the representation and adopting the role assigned to them. These characteristics apply, as well, to the exhibit-rationalised-as-experience group who adopted the role assigned to them to the extent that they perceived it.

Likewise, the exhibit-rationalised-as-static-display respondents found in the present study may be characterised by those features that describe Belaën’s distance category: these visitors figuratively, and sometimes literally, refuse to enter the immersion exhibit, deeming the staging disproportionate to the exhibited content. This distance-taking is caused by a gap between the visitors’ expectations and the premise of the exhibition, but especially by the fact that these visitors do not grasp the meaning of the setting-in-space. The existence of this taxonomy of visitor reactions supports Belaën’s (2003) conclusion: that the Museographic Organization of immersion exhibits requires a certain ability in the visitor to decipher the language of the form, and that if the visitor does not have this ability, they are confused by the exhibit’s premise.

Because immersion exhibits require a certain suspension of reality to function as intended (Belaën, 2005; Bitgood, 1990), the critical distance shown by the respondents in the exhibit-rationalised-as-static-display group could be indicative of their failure or disinclination to use their imagination. Dufresne-Tassé et al. (2006) defined the term as ‘psychological functioning where the intervention of the imagination can be observed’ (author’s translation) and found imagination to have a powerful motivating nature in museum exhibits, ‘anchor[ing] the world of meaning created around the [exhibited] object within the visitor's experience and knowledge. It is a powerful agent of ownership of what is acquired in the exhibition’ (Dufresne-Tassé et al., 2006, p. 172, author's translation). Dufresne-Tassé et al. estimated that 30-40% of museum visitors use their imagination little or not at all during their visit, and argue that ‘given the importance of an intense use of the imagination for a successful visit, it would be appropriate to intervene through the development of (…) exhibitions promoting its employment’ (Dufresne-Tassé et al., 2006, p. 173, author's translation). The four recommendations made by these researchers to that end will be discussed in the following section on exhibit design.

If a reluctance to use their imagination was the reason that the respondents in the exhibit-rationalised-as-static-display group were not able to develop the intended technology, this was not the case with the respondents in the exhibit-rationalised-as-experience group. As shown in the preceding, the failure of these respondents to achieve the intended outcome was due to their perceptions of what, exactly, *Cave Expedition* as a whole was a representation of. When museum visitors are faced by an exhibit, they decide on the phenomenon or experience to be modelled in accordance with their own interpretive abilities (Falcão et al., 2004); lacking the means to decipher the exhibit as intended, they 'unconsciously apply the codes that apply to the deciphering of objects in the world familiar to them' (Bourdieu, 1969, p. 170, cited in Montpetit, 1996, p. 89, author's translation). Considering that the cave beetle environment represented by *Cave Expedition* is a world scarcely recognisable by humans (Howarth, 1983), it is not surprising that visitors substitute it with a familiar, *human* version of a cave environment. Moreover, as discussed in Mortensen (2010), the exhibit engineers themselves may have implicitly attempted to create a recognisable and thus anthropocentric world for visitors in order to ensure their comprehension. The implications of these coding and decoding issues for exhibit design will be discussed in the following section.

Exhibit Design

Two concerns with implications for exhibit design arose from the discussion of exhibit enactment, namely the rejection of the immersive premise of *Cave Expedition*'s Museographic Organization by some respondents, and the unintended deciphering of the exhibit by other respondents. In the following sections, the three fundamental principles of immersion exhibits: the presentation of the exhibit as a coherent whole, the integration of the visitor, and the consequent dramatisation of matter and message (Belaën, 2003) will frame the discussion of the design implications of these visitor issues.

The presentation of the exhibit as a coherent whole.

As a scale version of a cave beetle habitat, *Cave Expedition* relies on a combination of two logics of representation: an exogenous logic, where the characteristics of the existing reference world of the cave beetle's habitat give rise to the characteristics of the exhibit; and an endogenous logic, where this reference world is reconstituted on a human scale (Mortensen, 2010). Exhibits of this type run an increased risk of excluding those visitors who cannot decipher the form, as was indeed the case here with the respondents who rationalised *Cave Expedition* as a static display. Such exhibits accordingly require mediation that can assist the 'first degree' perception of the exhibit (Belaën, 2005). This suggestion converges with the first recommendation of Dufresne-Tassé et al. (2006): introduce the exhibit so that visitors can easily use their imagination to establish a first link between what the exhibit offers and their own experience or knowledge. In other words, the metaphor employed in the exhibit should be made explicit – in the present case, the nature of the exhibit as an animal habitat should be clarified and the scaling made obvious in a manner which links to the visitors' prior knowledge.

The respondents who rationalised the exhibit as an experience appeared to have no trouble with the first degree perception of the exhibit as an immersive cave environment, albeit from a human perspective. The human perspective incorporated into the exhibit design was found to originate in the exhibit development, at a point where processes of physically implementing the exhibit took over from processes of developing the biological content (Mortensen, 2010). This phase of development may be particularly vulnerable to a lessening of epistemological vigilance due to technical issues, costs, or the desire to employ exhibit styles that have proven popular. When this is the case, the further development of the exhibit tends to ignore the scientific discourse in favour of visual and spatial logic (Gouvêa de Sousa et al., 2002), and as a consequence, visitors' conceptions of the exhibit's content may reflect those of the exhibit engineers rather than those of scientists (Van-Praët, 1989). In the present case, the relaxation of epistemological vigilance in the exhibit design process had direct consequences for visitor outcomes; consequences that meant that the intended visitor learning outcome was not achieved.

On one hand, it is understandable that exhibit engineers, when dealing with the reconstruction of an environment which is difficult for humans to conceive of, take recourse in reconstructing a related environment which most visitors presumably are able to decipher. On the other hand, it could be argued that it is the finest challenge of exhibit engineers to not shy away from difficult subject matter, but to embrace it. Indeed, Dufresne-Tassé et al. (2006) emphasise the importance of designing an exhibit in ways that are novel to the visitor in order to engage their curiosity; this recommendation tends to encourage a pushing of the museographic boundaries towards new innovative forms. The challenge here is accordingly to not only re-create the cave beetle's environment in an immersive exhibit with fidelity towards the original, but to do so in a way which communicates precisely and coherently what is on display.

The integration of the visitor.

Cave Expedition did not succeed in integrating the visitors as intended. Although in some cases the exhibit did promote a sense of an authentic cave setting and ambience among the visitors and thus achieved a low level of visitor integration (cf. Belaën, 2003), it failed to do so in other cases where it was perceived merely as a decoration or backdrop for the content on display. What are the design implications of these shortcomings?

The point raised by some visitors that human beings and cave beetles are vastly different organisms with little or no commonality seems to provide at least a partial explanation for why the visitors did not perceive and step into their intended roles as cave beetles. However, role-play in formal science education contexts includes students successfully playing the roles of red blood cells or electrons (Aubusson et al., 1997); entities that arguably have less in common with human beings than cave beetles do. The reason visitors do not comprehend their intended role probably originates elsewhere, namely in the insufficiency of the cues intended to provide them with this information and the means to implement it.

A basic design strategy to achieve a successful integration of the visitor in the exhibit could be to redirect the initial interest of the visitor from the exhibit's content to its participatory form (Belaën, 2005). Once the experiential nature of the interaction-to-come has been unequivocally established, the visitor should be given tools to implement their role. Aubusson et al. (1997) discuss the requirements for the successful implementation of role-playing in a classroom context: 1) introduce the target concept, 2) cue students' memory to the analogy, 3) identify the relevant features of the analogy, 4) map the similarities between the analogy and the target (science subject matter), 5) indicate where the analogy breaks down, and 6) draw conclusions about the target concept. Applying these requirements to an immersion exhibit context yields the following recommendations: 1) introduce the visitor to their intended role, 2) cue the visitor to the situation they are about to experience, 3) identify the relevant features of the immersive exhibit in terms of the visitor's role, 4) map the similarities between the visitor's experience and the scientific content, 5) indicate where the analogy breaks down, and 6) draw conclusions about the target concept. It could be argued that *Cave Expedition* already fulfils some of these requirements, but in a manner too subtle for the visitors to detect. A systematic and concrete embodiment of some or all of the suggestions would presumably assist the visitor in assuming the intended cave beetle role. One example of identifying the relevant features of the immersive cave environment in terms of the visitor in their role of the cave beetle could entail making the visitor aware that the cave beetle lives in complete darkness, and that the visitor must navigate the darkened cave exhibit using mainly their sense of touch – just like the cave beetle.

The dramatisation of matter and message.

In addition to the museum visitor understanding and taking on their role as the main character, the degree to which the subject matter of an immersive exhibition is dramatised depends on the degree to which the conflicts of that character are made clear to them, the degree to which the surroundings allow them to act on that conflict, and the degree to which they are able to make sense of these actions in terms of a direction (cf. Damiano et al., 2005). In the present case, visitors did not interpret the conflicts (e.g. the presence of predators in the form of the animal models in the cave) of their character as intended and consequently were not able to act on those conflicts and make sense of these actions to create a narrative about the cave beetle in the intended way. What are the design implications of these shortcomings?

In media such as film or literature, narratives are conceived of as entire dramatic structures comprised by a beginning, middle, and end. However, when the narrative is not fixed but rather emergent through a user's interactions with a three-dimensional environment, incorporating drama at each moment of the narrative may be a better way to create engagement (Macfadyen et al., 2008); a finding which coincides with Allen's (2004) recommendation that museum exhibits be motivating at every intermediate step of the visitor's experience, not just at the culmination. The immersion exhibit should accordingly act as an imaginative space which creates a desire to discover a new world, and which can be used constructively by visitors to explore this world (Dufresne-Tassé et al., 2006). To this end, Dufresne-Tassé et al. emphasise the importance of conducting a thorough formal contextualisation of the exhibit topic in the development phase in order to give the topic sufficient depth. In *Cave Expedition*, a possible design implication of the findings mentioned above could be for the exhibit to reflect the complexity of the body of knowledge in question (the cave beetle's daily struggle for survival in its habitat) rather than a series of anticipated trajectories of inquiry represented by a sequence of stations, as is perhaps the case now. The idea would be that the visitor, when they entered the exhibit, would not merely be thrown into darkness (which is one aspect of cave beetle reality) but be thrown into the entire complexity of the cave beetle habitat. Such an exhibit would form a framework sufficiently strong, dense, and consistent that the visitor's imagination could be constructively supported to clarify the content matter in ways that are meaningful to them (Dufresne-Tassé et al., 2006), which would especially address the issue of the visitors who perceived *Cave Expedition* as a static display.

Exhibit Conjecture

In retrospect, it is not surprising that the reasons for differences between intended and observed visitor outcomes should be sought at the level of the exhibit rather than at the level of its component parts: the Museological Organization of *Cave Expedition* embodies a human perspective of a cave environment, and the visitors' accommodation of this perspective, while unintended, substantiates the premise that the exhibit constitutes a learning ecology which is perceived as a whole (cf. Cobb et al., 2003). This observation in turn emphasises the importance of making a well-informed choice of exhibit type (or Museographic Organization) when a subject has been decided upon in the exhibit planning phase. As there is no exclusive museographic form for specific themes, although some subjects have characteristics that are more or less suitable to a particular exhibit type (Gouvêa de Sousa et al., 2002), matching the Biological (or other) Organization and the corresponding learning goals to the Museographic Organization becomes an all-important undertaking if exhibit engineers are serious about achieving educational objectives.

In this light, the conjecture that embodying the Biological Organization of *the adaptations of the blind cave beetle to its environment of permanently dark caves* with the Museographic Organization of an immersion exhibit can support the visitor learning outcome of experiencing how the cave beetle is adapted to its environment of permanently dark caves seems to be a reasonable one. Although the stated goal of the exhibit – the intended praxeology – was not achieved by the museum visitors, it was partially achieved by a majority of respondents. Immersion exhibits are vehicles of experience, and although the experiences of the visitors observed here were shown to diverge from the intended experience, the exhibit showed clear potential in the direction of creating the intended experience.

3.7 Concluding Remarks

The present study examined in detail how an immersion exhibit works, i.e. how it mediates its message to museum visitors. The notion of praxeology allowed the study to pinpoint not only how and why divergences between intended and observed learning outcomes occurred, but at which level of the Museographic Organization they originated. As a consequence, the exhibit characteristics at the origin of the divergences could be examined, and theoretical suggestions for remedial design formulated. It is beyond the scope of this paper to construct a theoretical model for the design of immersion exhibits; however, some generalisable suggestions were given, i.e.: An immersion exhibit which employs a metaphorical representation of a reference world requires the metaphor to be apparent to the visitor without sacrificing scientific rigour. The participatory nature of the immersion exhibit should also be made explicit; role-play guidelines may be useful in this regard. Finally, it is important to conduct a thorough contextualisation of the exhibit's scientific content in the development phase in order to achieve a sufficiently strong and consistent framework which can successfully support the interactive visitor-exhibit dramatisation of the subject matter.

These rather general suggestions assume their full meaning when implemented with a concrete scientific content. It is clear, though, that exhibit design may benefit from an approach that considers both practical and theoretical aspects such as the praxeology-based approach exemplified here. A follow-up study is currently under way which uses the notion of praxeology to synthesise a coherent and broadly applicable theoretical framework to guide the didactical design of immersion exhibits.

3.8 Notes

1. The term design is used in this paper to indicate the pedagogical and didactical engineering of an educational intervention such as an exhibit.

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3.10 Appendix

The Questions Developed in the Pilot Study

1. What is it supposed to be, the exhibit you were just exploring? (practical level)
2. What makes it a [answer from 1]? (theoretical level)
3. Did you notice anything (else) when you entered? (practical level)
4. How did you find your way, inside? (practical level)
5. What was inside/what did you find, inside? (practical level)
6. (If ”animals” then) Why do you think those particular animals were there? (theoretical level)
7. Did you use your other senses, inside? (practical level)
8. What is the point of this exhibit? What are you meant to learn from it or do with it? (theoretical level)
9. Is this exhibit about any particular animal? (theoretical level)

The Additional Questions

1. This exhibit is about the blind cave beetle and its adaptations to its habitat. If you imagine yourself in the role of the cave beetle, or if you think about your experience in the exhibit in terms of being a cave beetle, what does this exhibit tell you about cave beetles?
    a. How do they find their way in the dark?
    b. What are their most important senses?
    c. What is their environment like?
    d. What other animals might they encounter in their environment?
2. Why did you not feel that you were a cave beetle in this exhibit? What aspects of this exhibit could be changed to make you, the visitor, feel like a cave beetle?

4 A Normative Model for Science Exhibit Design

Marianne Foss Mortensen

Abstract. Current informal education research literature is beset by three issues: The lack of a convincing definition of the characteristics of informal education settings, the high level of generality of inquiries into informal education, and the focus on informal learning to the exclusion of informal teaching. Here, I consider the museum exhibit to be the primary medium for museum education, and I take a design-based research approach to exhibit engineering as a way to characterise the education environment, specify my inquiry, and focus on the connection between teaching and learning. I construct a theoretical model of exhibit engineering based on a retrospective analysis of the design and enactment of an exhibit with biological content, and I inform the construction of this model with current research findings from science education literature in general and museum research literature in particular. I then exemplify the use of the model by describing a theoretical design iteration of the studied exhibit. Finally, I discuss the model of exhibit engineering in terms of its contributions on three levels: Domain theory, design framework, and design methodology.

4.1 Introduction

Numerous studies have sought to characterise informal science education settings such as science centres and museums [1] and in doing so to determine how, exactly, they differ from formal settings in terms of the science learning that occurs there. This undertaking is justified by the increased realisation of the role of science learning in out-of-school contexts (Editorial, 2010) and the need to understand how such science learning can be harnessed. The argument is that informal science education has the potential to influence the recruitment of students to the natural sciences, the overall quality of science education at the primary, secondary, and even tertiary level, and the creation of a scientifically literate citizenry. However, three issues emerge from the research: First, the lack of a convincing definition of the characteristics of informal education settings; second, the very general nature of the inquiries into the education that takes place there; and third, the focus on informal science *learning* to the exclusion of informal science *teaching*.

The problems regarding the first issue are reflected in the struggle to find consensus on a term that can describe the field of research. Free-choice learning (Falk & Dierking, 2000), informal learning (Wellington, 1990), or extra-mural learning (Bagge, 2003); none of these terms adequately and exclusively distinguish museum learning from other types of learning. Even though free-choice learning may characterise some museum visits, it does not as a rule occur during all museum visits. In addition, free-choice learning may also (and hopefully does) occur in formal education settings. At the other end of the spectrum, defining learning by whether it takes place inside or outside the school walls seems to be a more pragmatic than informative distinction, at least in terms of understanding the characteristics of that learning. Perhaps a more fruitful perspective would be to consider science learning as science learning no matter how or where it occurs. Hence, I view the museum setting as a rich variation of other, more formalised science education arenas rather than as distinct from them (Hsi et al., 2004).

The second issue is the very general nature of the inquiries into science education in museums. For example, the research finding that it is important to structure the scientific content of an exhibition in order to make it educationally coherent for visitors (Miles, 1986) may be corroborated by later studies (cf. Falk, 1997), and thus considered valid. But it is formulated at such a high level of generality that it is difficult to apply concretely in the development of educational environments. I do not mean to suggest that studies such as those cited here are useless; indeed, they have provided the research community with valuable insights on the overarching features of museums and exhibitions. But I do suggest that it is time to take a more fine-grained look at the design of museum exhibitions than has typically been the case.

The third issue to emerge from the research on science education in museum settings is the focus on the learning of museum visitors to the exclusion of the teaching that takes place in museums.

Quantitatively, the most important medium for educational activity in museums is the exhibition. In addition, the properties of the exhibition are the only aspects of the museum visit that are under the museum's control; the actions and reflections of the visitors are certainly not! Accordingly, I view museum "teaching" to be mediated by the exhibition, and I argue the importance of understanding the relationship between museum teaching and museum learning as a means (perhaps the only means) to influencing and improving the educational impact of the museum.

To address these three issues, I present an account of a design-based research approach to museum exhibit engineering. Design-based research targets learning in context. This means that rather than artificially decomposing the educational system under investigation into a number of factors that fail to capture pertinent properties of the system as a whole, this approach accounts for the "ecology" of the entire system (Schauble, Leinhardt, & Martin, 1997). Differences between learning in in-school and out-of-school contexts (if they exist) are thus rendered irrelevant.

Design-based research is a fine-grained approach to educational design. This means that it is able to capture content-specific aspects of teaching and learning that more general approaches cannot. It reflects the growing realisation within the science education research community that general approaches to education such as constructivism (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003) or developments at the national curriculum level (Lijnse, 2000) fail to target or account for what goes on in terms of the content-specific teaching-learning processes that constitute science education.

Finally, design-based research seeks to establish a very tight relationship between the design of a teaching intervention and the learning outcomes it precipitates with the ultimate goal of improving this relationship. The design-based research approach is accordingly a useful framework for understanding the specifics of any teaching intervention and to make qualified and testable hypotheses about how it can be developed in a constructive way.

Aim

In this paper I develop and present a theoretical model for the design and analysis of museum exhibits. The model establishes a relationship between epistemology, learning, and teaching in a form that applies to immersion exhibits on animal adaptations within the discipline of biology. It is developed using research findings derived from the case described in the following as well as from the research literature on museums in particular and science teaching and learning in general. The aim is to construct a normative model for exhibit design which is content- and context-specific and has certain, more generalisable aspects.

Paradigm

As mentioned in the preceding, the overarching paradigm of this account is design-based research, an approach that studies learning in context through the systematic design and study of instructional strategies and tools (The Design-Based Research Collective [DBRC], 2003). The purpose of design-based research is to develop so-called 'humble' theory which targets domain-specific teaching-learning processes (Cobb et al., 2003). Such theory is developed through iterative cycles of design, enactment, analysis, and redesign (DBRC, 2003).

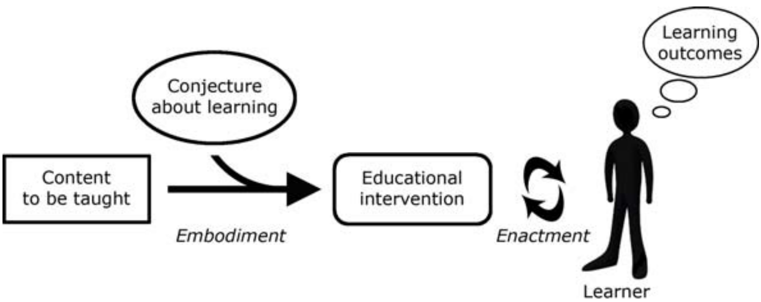

Figure 4.1 The design-based research approach embodies a conjecture about learning within an educational intervention (any teaching intervention, e.g. a lesson series). The enactment of the intervention (e.g. the teaching of the lesson series) precipitates certain learning outcomes in the learners. Studying this system of conjecture – embodiment – educational intervention – enactment – learning outcomes can serve as a means to improve the design of the intervention, but it can also generate theoretical insights about the original conjecture.

Sandoval (2004) suggests that the fundamental claim of design-based research is that it embodies testable conjectures about learning within the design of educational interventions (Figure 4.1). I use the term 'educational intervention' to mean any situation which has been designed with a didactic [2] intent, i.e., which reflects the intent of someone to teach something to someone (Chevallard, 2009). For example, in a classroom setting, an educational intervention could be a lesson series conducted by a biology teacher with the intent of teaching mammal phylogeny to her students. In a museum setting, an educational intervention could be an exhibit designed by exhibit engineers with the intent of teaching photosynthesis to visitors. In the latter case, the exhibit functions as a teacher by proxy, but the design still reflects the intent of somebody (the exhibit engineers) to teach something (photosynthesis) to somebody (the visitors).

Studying educational interventions by studying the conjectures embodied within them and the learning outcomes they cause can uncover content- and context-specific aspects of the intervention that affect learning. This uncovering, in turn, may help improve the designed intervention, but it also has the potential to improve the conjecture that drives the design (Sandoval, 2004). In the section entitled "Case", I shall explain in detail how Sandoval's framework is mobilised in relation to the museum exhibit used as a case here.

Procedure

The point of departure for this account is the museum exhibit *Cave Expedition*, which is indeed an example of an educational intervention in the sense defined in the preceding. The exhibit accordingly may be seen as a testable embodiment of a conjecture about learning. What is then this conjecture? How is it embodied? And how is the embodiment tested?

In the first section of this account, I draw on studies [3] reported earlier regarding the design (Mortensen, 2010c) and enactment (Mortensen, 2010a) of the exhibit in order to define the system under investigation and some issues related to it. By *design*, I refer to the ways in which the didactic intent is embodied in both content and form of the exhibit. By *enactment*, I refer to the implementation of the exhibit, i.e. the meeting between exhibit and visitors and the resulting outcomes.

The second section of this account analyses the findings from the design and enactment studies of the exhibit *Cave Expedition* with a view to constructing, step by step, a prescriptive model for exhibit design. Specifically, this section relates the exhibit's design to the learning outcomes it precipitates in order to create a hypothesis (i.e. the model) about how to refine the design. The model systematises the exhibit design process in a way that addresses the observed shortcomings of *Cave Expedition*. The synthesis of this model is additionally informed by pertinent empirical findings and theoretical notions from the museum research literature and general science education literature; these are developed and presented in due course.

Finally, the third section of this account illustrates the use of the constructed model in a theoretical re-design of the exhibit *Cave Expedition*. This section demonstrates how documented shortcomings of the existing exhibit can be remedied using the constructed model. In addition, it exemplifies how a careful and systematic application of the model is able to generate completely new ideas for exhibit design. The section ends with a discussion of the generalisability of the model.

4.2 Case

The case discussed here was part of the exhibition *Xtreme Expedition* which opened in 2007 at the science centre Experimentarium in Copenhagen, Denmark. The exhibition was the result of collaboration between three institutions: Experimentarium, the Royal Belgian Institute of Natural Sciences (RBINS) in Belgium, and Naturalis in the Netherlands. The general theme of *Xtreme Expedition* was adaptations to extreme environmental conditions on Earth and it featured clusters on heat, cold, aridity, low oxygen, and darkness. I analyse a single immersive exhibit, *Cave Expedition*, within the cluster about darkness. *Cave Expedition* focused on the adaptations of the blind cave beetle to its environment of permanently dark caves (the particulars of the exhibit form and biological content will be further explained in due course). The exhibit consisted of an artificial cave structure with a built-in passageway. The passageway was about 12 m long, completely darkened, and had a guide rope on the left side. On the left wall nine life-size animal models (lizards, spiders, and frogs) were mounted at varying heights. A source of scent was present inside the cave. The entire structure was about 3 m deep by 8 m long by 3 m high. Outside the cave, there was an introductory text panel with illustrations of cave beetles and their closest relatives, and a preserved cave beetle specimen. Next to the cave entrance, a text panel was placed bearing instructions about how to interact with the exhibit. Finally, at the exit of the cave, an interactive panel was placed bearing animal models (some of which were replicas of the models inside the cave), two sources of scent, and a score board where visitors could check their findings.

The Conjecture

In order to determine the original conjecture about learning that drove the design of *Cave Expedition*, I analysed the planning document (Executive Committee, 2005) that guided the construction of the exhibit. In the following, this document is designated as the *curatorial brief*. The conjecture about learning was not explicitly stated in the curatorial brief, but can be inferred from the following, more overarching principles:

> We will use the stress factors as a primary focus to make an exhibition that is full of experience and attractive exploration exhibits. In that way we will serve our target groups in the best possible way. […] Visitors will experience several stress factors (within safe limits, of course) that plants and animals have to tolerate in order to survive in hot deserts, at high mountains, in the deep sea and in other extreme habitats (Executive Committee, 2005, p. 4).
>
> The visitors will find out how animals, microbes and plants are adapted to survive under stressful conditions (Executive Committee, 2005, p. 5).

These principles are articulated at a rather general level, and emphasise mainly the importance of experience as the vehicle of visitor knowledge construction in the exhibition *Xtreme Expedition*. The principles were interpreted by the exhibit engineers in the concrete design of *Cave Expedition* (as well as the design of other exhibits in *Xtreme Expedition*). The interpretative process is evident from the preliminary description of the cave beetle exhibit as an "orientation route in the dark for visitors, using a stick for orientation" (Executive Committee, 2005), as well as from the following statements made by the exhibit engineers about the development of the exhibit:

> The idea was to use the animal's situation as a point of departure – to create a situation such as the animal would experience it (Exhibit Engineer 1 [EE1]).
>
> We wanted to […] try to activate some of the senses [in the visitor] that the animals living in the dark – that

> they are dependent on and navigate by. […] We wanted to put the visitor in the place of the animal (EE2).
>
> Interviewer: Was it the intention that the visitor would have a more affective or a more scientific outcome?
>
> EE2: It's a combination… hopefully. You learn more when you experience more. So really, the point was to play on the affective, because "ooh, it's dark!" and "it's exciting!" and so on. In this way, [we wanted to] incorporate some learning and engender an interest in the more concrete scientific aspects.

From these statements I extrapolate the following conjecture about learning embodied in this particular intervention: An immersive exhibit environment which puts the visitor in the place of the cave beetle will give the visitor an experience of how the cave beetle is adapted to survive in the extreme environment of permanently dark caves. Through this experience, the visitor can construct cognitive, affective, and kinaesthetic knowledge about the specific adaptations of the cave beetle. I argue that this theoretical conjecture, which addresses both the content and the form of the teaching intervention, is the claim that the exhibit engineers implicitly embody in their exhibit design.

The Embodiment Process

What was the process by which the theoretical conjecture was embodied in the physical installation that is *Cave Expedition*? Before outlining how the exhibit engineers proceeded to embody the conjecture in an educational intervention, I summarise the particulars of the relevant biological content and the chosen exhibit form.

Biological content

In the case of *Cave Expedition*, the biological content in question was the adaptations of the cave beetle to its environment of permanently dark caves (in the following designated as the *biological organization*). The cave beetle's environment consists of subterranean rocks which form labyrinthine networks of interconnected spaces ranging from 1 mm to about 20 mm in width (Howarth, 1983). The deep cave zone, which is the habitat of obligate cave-dwellers such as the cave beetle, comprises the areas furthest from the cave entrance, where the conditions are relatively constant

(Howarth, 1980). This environment is completely and permanently dark, with a constant low temperature, a constant high humidity (Dethier & Hubart, 2005), and a higher CO_2 and lower O_2 concentration than atmospheric air. The cave surfaces are irregular and continuously wet, and pools and drips of water may occur (Howarth, 1983).

The food sources of the cave environment include organic material transported in by water and gravity, as well as organisms that migrate or fall into the caves (Howarth, 1993). Food sources originating inside the cave include the eggs, larvae, and adults of other cave-dwelling species, as well as bacteria, fungi, and slime moulds. Cave beetles are predators and prey on smaller invertebrates such as springtails, annelids and mites as well as their larvae and eggs. Cave beetles themselves may be preyed upon by other larger arthropods such as millipedes, spiders, and larger beetles (A. Solodovnikov, pers. comm., April 10, 2008).

Animal adaptations are features that improve an animal's ability to interact with its environment (Wharton, 2002). The most striking morphological adaptations of cave beetles are the loss of eyes, reduced pigmentation, and the loss of wings (Crowson, 1981; Dethier & Hubart, 2005; Howarth, 1983). These characteristics may be explained in terms of energy economy. Cave beetles are also characterised by having very long legs and antennae with specially developed chemical and tactile receptors (Crowson, 1981). The legs carry vibration receptors which may be useful for detecting prey (A. Solodovnikov, pers. comm., May 16, 2008). The beetle's tactile sense is further enhanced by the presence of very long sensory hairs on the body (Howarth, 1993; Crowson, 1981).

The ability to navigate is very important in the cave environment, and the slow, methodical movement of cave insects may be an adaptation to negotiating the complex three-dimensional dark cave habitat (Howarth, 1983). Finally, cave insects have a number of physiological adaptations, including tolerance to high humidity and high CO_2 concentration, probably by having a low metabolism compared to their terrestrial counterparts (Howarth, 1983).

Exhibit form

In the case of *Cave Expedition*, the chosen exhibit form was an immersion exhibit. Immersion is a museographic [4] genre which integrates the visitor in a three-dimensional representation of a reference world, creating the illusion of a certain time and place

(Bitgood, 1990). The success of an immersion exhibit relies on three main principles: The presentation of the reference world as a coherent whole, the integration of the visitor as a component of the exhibit, and the consequent dramatisation of matter and message (Belaën, 2003). This particular constellation of principles is specific to the pedagogy of the immersion exhibit, and is designated as its *museographic organization* in the following.

Immersion exhibits may be classified by their relationship with the reference world. This relationship may range from a basic analogy of resemblance to a more symbolic or indicative association (Belaën, 2003). Exhibits of the first type usually have a straightforward, one-to-one physical resemblance to their reference world, while exhibits of the second type create a setting which does not correspond to any real environment, but rather to a logic generated by the exhibit itself. Immersion exhibits may also combine the two logics, resulting in settings that refer to real environments, but without reproducing them in an authentic way. This is often the case when the knowledge to be exhibited is not associated with a representable human-scale realm, or the significant experiences of the reference world are abstract (see Mortensen, 2010b for examples).

Another variable related to the museographic organization of an immersion exhibit is the degree to which the visitor is integrated into the exhibit (Belaën, 2003). At one end of the scale, the exhibit may provide a setting and an ambience which merely require the visitors to play the role of themselves. A stronger degree of integration is indicated by exhibits that give the visitor a certain character to play, and at the far end of the scale, we find settings that allow visitors to interact by making real time modifications to their surroundings (see Mortensen, 2010b for examples).

Museographic transposition

The embodiment of the theoretical conjecture into a physical installation has been described as *museographic transposition*: A systematic deconstruction and reconstruction of the biological organization in order to express it according to the specifics of the museographic organization (Mortensen, 2010c). This transposition process consisted of two distinct phases of transformation.

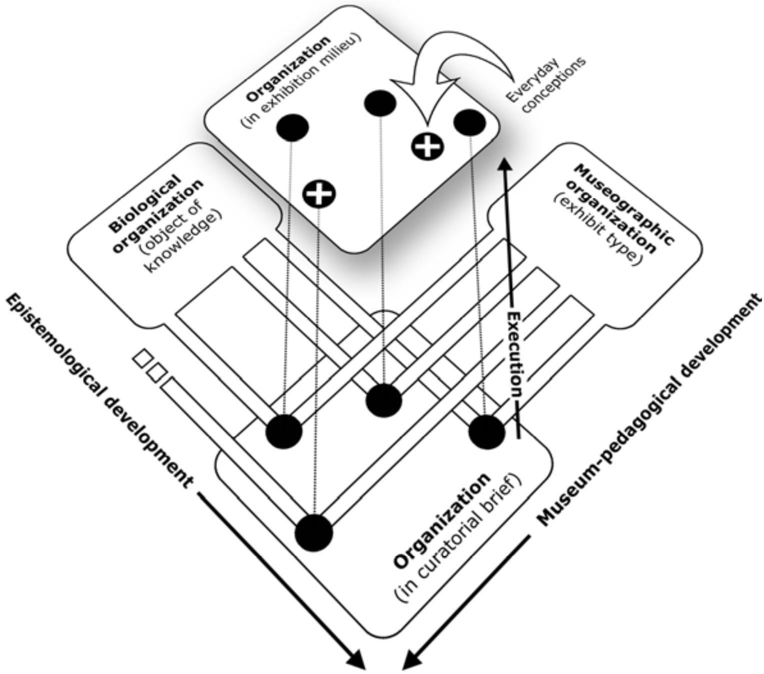

Figure 4.2. The process of museographic transposition consisted of two phases. The point of departure was an object of knowledge-to-be-taught (biological organization) and a chosen exhibit type (museographic organization). The first phase of transposition consisted of the simultaneous epistemological and museum-pedagogical developments that created an organization of knowledge (black circles) at their intersection. This organization of knowledge was present in the curatorial brief, an exhibition planning document. The second phase of transposition consisted of the execution of this organization into the physical, three-dimensional installation of the exhibit *Cave Expedition*. Inconsistencies in the exhibition milieu (indicated by white crosses) could be attributed to either the fundamental non-intersection between the biological and the museographic organizations or the inclusion of the developers' everyday conceptions. Adapted from Mortensen (2010c).

The first phase of transformation was characterised by simultaneous processes of epistemological and museum-pedagogical development. In the epistemological development, biological concepts were selected and re-phrased in terms of the knowledge at the centre of the intended learning outcome. In the process of museum-pedagogical development, the content-specific learning objectives were related to the specifics of the chosen immersive exhibit type. Together, these processes co-determined the expression of the organization in the curatorial brief (Figure 4.2).

Consider the following example: In the biological organization, the cave beetle environment is described as interconnected subterranean rock spaces which are completely and permanently dark. How was this organization deconstructed and reconstructed in terms of an immersion exhibit? The reference world is obviously not associated with a human-scale realm. Accordingly, the exhibit engineers combined features of the reference world (darkness, enclosed space) with the logic of creating a scaled-up three-dimensional setting for humans to enter. This resulted in the description, in the curatorial brief, of the exhibit as a darkened passageway for visitors to navigate.

In this fashion, the organization in the curatorial brief was co-determined by the respective biological and museographic organizations (Figure 4.2).

The second phase of transformation or *execution* (Gouvêa de Sousa et al., 2002) consisted of the physical implementation of the exhibit in space. This step involved an obvious modality change: The organization in the curatorial brief consisted of text while the organization in the exhibition milieu was of course a three-dimensional installation. The physical implementation of the exhibit also involved creative interpretation by the exhibit engineers (Miles, 1988, p. 43). For example, the darkened passageway described in the curatorial brief was expanded into a cave structure in the physical exhibit with a rocklike uneven surface both inside and out, even though this was not specified in the curatorial brief.

The development of *Cave Expedition* was not completely unproblematic. According to the analysis, the integrity of the completed exhibit suffered from inconsistencies that originated in the transposition process (Mortensen, 2010c). These inconsistencies were due to instances where elements present in the organization in the exhibition milieu were not supported by the premises of both biological and museographic organizations. For example, as mentioned in the preceding, *Cave Expedition* recreated a darkened cave environment which the visitor could enter in the role of the beetle. At a glance, this was consistent with the premise of the museographic organization. However, further study revealed that the created cave environment was inconsistent with the biological organization mainly because its physical qualities reflected a human-scale perspective of a man-made cave rather than a scaled-up rendering of a cave beetle's perspective on its environment. This type of inconsistency originated in a lack of reconciliation between the two determining organizations at the basis of the transposition process: The premise of the museographic organization was not reconciled with the premise of the biological organization.

Another type of exhibit inconsistency was observed which could be attributed to the practicalities of the day-to-day functioning of the museum or the so-called "everyday conceptions" of the exhibit engineers. For example, *Cave Expedition* included a number of animal models (frogs, lizards, and spiders) the purpose of which was to represent examples of predators that might prey on the cave beetles in the wild. However, the chosen species were not cave beetle heterospecifics although they *did* represent animals commonly known to prey on insects. The presence of these models may thus have played a role in compromising the exhibit's coherence or *integrity* (Mortensen, 2010c). This type of inconsistency originated in a relaxation of *epistemological vigilance* (cf. Brousseau, 2002, p. 39) in the transposition process.

To sum up: The theoretical conjecture regarding learning that drove the design of *Cave Expedition* addressed both the content to be learned (biological organization) and the didactic form (museographic organisation). The theoretical conjecture was embodied in a two-step process (museographic transposition). The first step involved a merge of the biological organization and the museographic organization to form the organization in the curatorial brief. The second step involved the implementation of the organization in the curatorial brief into the physical, three-dimensional exhibit that was the organization in the exhibition milieu. Two types of issues were identified which affected the consistency of the museographic transposition process: Instances of non-reconciliation between biological organization and museographic organization in the first phase of transformation, and instances of relaxation of epistemological vigilance in the second phase of transformation.

The Embodied Conjecture

A designed educational intervention such as a museum exhibit is characterised by being a material embodiment of a theoretical conjecture. According to Sandoval (2004), embodied conjectures predict outcomes from their use at two levels: *Immediate outcomes*, which are described as observable patterns of behaviour; and *intervention outcomes*, which are learning-related effects. In the case of *Cave Expedition*, the predicted outcomes of visitors' interactions with the exhibit were modelled using the notion of *praxeology* developed by Chevallard (e.g. 2005) within the framework of the Anthropological Theory of Didactics.

Briefly, a praxeology is a general model of human activity which links the practical dimensions (the *practice*) and the theoretical dimensions (the *theory*) of the activity (Barbé, Bosch, Espinoza, & Gascón, 2005). A learner constructs a praxeology by carrying out certain practical tasks using certain techniques. The rationale or explanation constructed by the learner for carrying out those activities comprises the theoretical block of the praxeology. In the case of a museum exhibit, we may think of the task or tasks as being embodied in the exhibit design. The intention is for the visitor to perceive these tasks and apply certain techniques to accomplish them, and in doing so gradually constructing a rationale. The praxeology thus constructed or "lived" by the visitor may be thought of as a certain body of knowledge, generated and acquired through the exhibit interaction. In the praxeology perspective, then, the mastery of a body of knowledge corresponds to the comprehension of the practical tasks involved in generating this knowledge and the ability to carry them out as well as a grasp of the unifying theoretical rationale for the practical activities (for a more comprehensive explanation, see Mortensen, 2010a).

In *Cave Expedition*, the predicted outcomes of visitors' interactions with the exhibit were modelled in a so-called *intended* praxeology. The elucidation of this praxeology proceeded from the assumption that the intended outcome of visitors' interactions with the exhibit was to give the visitor an experience of how the cave beetle is adapted to survive in its extreme habitat of permanent darkness and through this experience to construct cognitive, affective, and kinaesthetic knowledge about the specific adaptations of the cave beetle. This intended outcome was differentiated into a practical level and a theoretical level. The practical level consisted of those first order perceptions of the exhibit's premise and first-order interactions with it that the visitor was intended to have, and thus corresponds to what Feher (1990) designates as the *experience* and *exploration* levels of an exhibit interaction. The theoretical level consisted of the rationalisation of this experience that the visitor was intended to construct, and thus corresponds to Feher's *explanation* level.

For example, an important intended achievement in *Cave Expedition* was for the visitor to perceive that cave beetle movement is dictated by the physical boundaries of its environment. At the practical level, this task was staged by the totally dark passageway with its uneven, rock-like surfaces. The intended practical interaction between the visitor and the exhibit was accordingly the successful navigation of the dark cave passageway by the visitor. The accomplishment of this practical task was intended to support the creation of the visitors' interpretation of their own actions at the theoretical level: "A cave beetle's movements are restricted by the boundaries imposed by its cave habitat".

To sum up: In the analysis of the exhibit *Cave Expedition*, the embodiment of the learning conjecture was modelled in terms of a praxeology which described several different types of tasks at the practical level which, when accomplished by visitors, could contribute to precipitate the intended learning outcome at the theoretical level (Mortensen, 2010a). Note that at I am still referring to the activities and interpretations the exhibit was intended to precipitate; actual visitors were not yet included at this point of the analysis.

The Enactment of the Embodied Conjecture

The enactment or testing of the conjecture refers to the implementation of the designed educational intervention–in the present case, what happened when museum visitors encountered the exhibit *Cave Expedition*. The actual outcomes of visitors' interactions with *Cave Expedition* were modelled in what is referred to as the *observed* praxeology. To construct this observed praxeology, a variety of methods were used to capture the practical and theoretical levels of the visitors' exhibit interactions. For example, in order to ascertain whether the visitors accomplished the various practical tasks staged by the exhibit, it was in many cases enough to observe them and make notes of their behaviour. Supplementary data was provided by equipping respondents with a lapel microphone which fed a digital recorder, and asking them to 'think aloud' during their exhibit visit. In order to capture the theoretical component, i.e. visitors' rationalisations or interpretations of their exhibit interactions, open-ended interviews were carried out immediately after the exhibit interaction. Due to a high degree of consistency in the responses of the observed visitors to *Cave Expedition*, a single observed praxeology was constructed that unified and described their actions and reflections (Mortensen, 2010a).

The observed praxeology was found to be consistent with the intended praxeology at the practical level, but diverged from the intended praxeology at the theoretical level. In other words, although the visitors were doing what they were supposed to be doing in terms of practical activities, they were not interpreting these actions in the intended way. This unintended decoding of the exhibit experience was traceable to the two main issues in the exhibit design process, namely instances of non-reconciliation between the biological organization and the museographic organization in the first phase of transformation as well as instances of relaxation of epistemological vigilance in the second phase of transformation (Mortensen, 2010a).

4.3 Constructing the Model

In the following sections, the findings presented in the preceding inform a step-by-step construction of a normative model for exhibit engineering. My starting point for this construction process is the shortcoming of the exhibit in producing the intended learning outcome. I address this shortcoming by tracing the museographic transposition process back to the starting point: The biological organization. Then, I consider the implications of the museographic organization, and make a suggestion about how to conceptualise the merge between museographic and biological organizations in a coherent way. I point out some epistemological considerations that should be made in regard to this merge. Finally, I address the process of implementing the exhibit in space.

The Biological Organization

The central finding in the analysis of the design and enactment of *Cave Expedition* was the divergence of intended and observed learning outcomes. More specifically, even though the visitors enacted the practical activities intended by the exhibit engineers, they did not construct the intended interpretation of these activities. This finding is not exceptional in research on exhibit-based learning (cf. Anderson, Lucas, Ginns, & Dierking, 2000; Borun, Massey, & Lutter, 1993; Falcão et al., 2004). Considered in terms of praxeology, it constitutes a case of learners who, when lacking sufficient support for the construction of an intended theoretical component of a praxeology, construct an alternative theoretical block based on their own conceptions and experiences (Figure 4.3) (Yves Chevallard, pers. comm., 11-02-10). The problem then arises to recast the process of exhibit design in a way that can guide and account for the creation of a strongly structured support for visitors' theory construction.

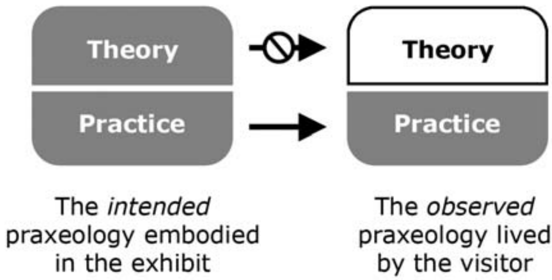

Figure 4.3. The observed praxeology of the museum visitor was consistent with the intended praxeology at the practical level, but not at the theoretical level. A weak or insufficient embodiment of the theory component in the exhibit caused visitors to construct their own interpretations.

The introduction of the notion of praxeology has two implications that contribute to a model of exhibit design. First, praxeology is a precise way to describe the causal connection between, on one hand, the tasks presented by the exhibit and the visitor's resulting actions, and on the other, the visitor's interpretation or rationalisation of these actions. The introduction of the notion of praxeology is a means to associate the embodiment of a teaching intervention with its learning outcomes in a coherent way.

The second implication of using the notion of praxeology is related to the nature of the praxeology as an *answer to a question* (Chevallard, 2005). If we think of the intended praxeology embodied by the exhibit *Cave Expedition* we may observe that it represents an answer to the question "how is the blind cave beetle adapted to its environment of permanently dark caves?" And here is the crux of the matter: This question bears a close epistemological relationship with the original question that produced the knowledge, namely the research question asked by an entomologist in a scientific research context: "How is the blind cave beetle adapted to its environment of permanently dark caves?" The implication of the notion of praxeology for designing teaching interventions is thus that the original (research) context that produced an object of knowledge may serve as a model for the design of a teaching intervention that aims to generate or re-produce the same object of knowledge in learners (Brousseau, 2002).

Thus I argue that the notion of praxeology can serve as a model to describe the milieu, actions, and reflections that produced a body of knowledge in the original research context, and that this praxeology also creates a reference for the conditions required for a learner to re-produce that knowledge in an educational context (see Barbé et al., 2005 for an example). This idea is not new to the exhibition research community. Indeed, as Lewis argues:

> One good way of coming to grips with almost any teaching problem whatever is to ask oneself 'How could a motivated person come to know about this particular subject matter?' (Lewis, 1980, p. 154).

If we interpret the term "motivated person" to its ultimate conclusion, we find that the contextual actions and reflections of the original motivated person, namely the researcher who first generated a particular body of knowledge, could provide a template of sorts for the didactical design of an exhibit featuring that knowledge. More recently, Schauble stated:

> It is time to dethrone objects from their traditional, privileged place as the center of attention in the museum. Instead, exhibit designers and visitors alike are being asked to shift their vision from the object qua object toward the practices that imbue these objects with meaning in disciplinary communities (Schauble, 2002, p. 235).

And Bain and Ellenbogen concur:

> Considering the ways practitioners situate and use objects in their work prompts us to reconsider ways we might help learners use objects [in] their learning (Bain & Ellenbogen, 2002, p. 153).

Of course, the idea is not to recreate the researcher's laboratory in the exhibition and expect the visitor to repeat the achievements of the researcher; merely reconstructing the physical setting of the researcher's experience does not guarantee that learners will recreate the "inside" of that experience (Bain & Ellenbogen, 2002). Additionally, the concepts developed by researchers in their quest for understanding do not always map exactly onto the design parameters in the practical terms in which activities for museum visitors must be planned (cf. Layton, Jenkins, Macgill, & Davey, 1993, p. 129). Accordingly, the challenge becomes to use the researcher's praxeology as a *template* to construct a potential learner's praxeology that can then be embodied in an exhibit design. The introduction of the notion of praxeology is thus a means to relate a given object of knowledge produced by a scientific practice to an object of knowledge embodied in an educational exhibit.

To return to the construction of a prescriptive model of exhibit engineering, I therefore conceive of the biological organization in the scientific context as a praxeology which consists of the researcher's actions and reflections in the pursuit of the answer to a research question (Figure 4.4). The first phase of museographic transposition then becomes critical in deconstructing and reconstructing this biological organization in terms of the museographic organization in order to create a new *tentative* praxeology in the curatorial brief with strongly supported practical and theoretical components. These practical and theoretical components take their points of departure in the biological organization of the scientific practice, but because their expression in the curatorial brief is co-determined by the museographic organization, they must be expressed in the terms that this organization specifies.

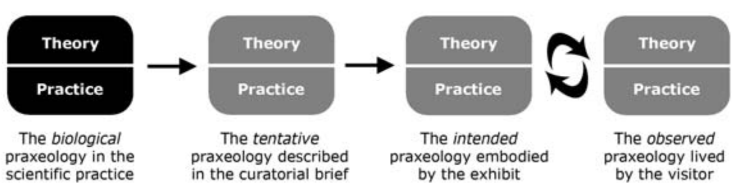

Figure 4.4. A first step towards a prescriptive model of exhibit engineering, using praxeology as the basic unit. The biological organization in the scientific practice is used as a template for constructing an intended learner's praxeology embodied by the exhibit. Please note that at this point of the synthesis the tentative model does not situate the museographic organization.

The First Phase of Museographic Transposition

The creation of the curatorial brief via the first phase of museographic transposition is an important step in exhibit engineering. The brief provides the basis of control in the development process, translating the generalities of the museum's exhibition policy and the chosen biological content into the specifications appropriate for the work at hand (Miles, 1988).

I first turn my attention to the process of epistemological development that takes place in the creation of the curatorial brief. This process ideally involves an analysis of the biological organization-to-be-taught with a view to identifying the pertinent concepts. The process may be designated as *framing*, namely the "selection of [scientific] concepts and the formulation and representation of those concepts in terms of the problems that constitute the core of the desired learning" (Ruthven, Laborde, Leach, & Tiberghien, 2009, p. 331). Here, the term "problem" refers to the practical activities as the core of the desired learning as well as the theoretical rationales for them. In other words, what should be framed in this process are the key tasks in the biological organization and the interpretations that they engender.

Due to its content-specific nature, it is difficult to generalise about how the framing process should take place. However, in the design of any teaching intervention, it is essential to be aware of, and address, the existing conceptions of learners (Clément, 2000). Preconceptions can constitute potential obstacles to the intended learning outcomes (Borun et al., 1993), but may also take the form of *anchors* (Clement, Brown, & Zietsman, 1989) which are commonly held conceptions that do not conflict with what is to be learned, but on the contrary may serve as bridgeheads for the construction of new knowledge. Clearly, for a museum exhibit to be educationally appropriate, the framing of its content should include a thorough analysis of visitors' preconceptions about the content in question (Borun et al., 1993; Schauble & Bartlett, 1997). In the final section of this paper ("Exemplifying the model"), I illustrate how an understanding of learner preconceptions contributes to the process of framing.

Concurrently with the process of framing, a process of museum-pedagogical development goes on. This process ideally involves a review of the pedagogical ends and means of the chosen exhibit type, i.e. of the museographic organization, in terms of the content-to-be-taught. We may consider this a process of *staging*, namely the arrangement of content-specific learning objectives in relation to a teaching intervention which incorporates problem situations capable of stimulating the intended learning (cf. Ruthven et al., 2009). The nature of these "problem situations" is of course determined by the chosen museographic organization. In the section "Exemplifying the model", I demonstrate the process of staging with a specific example.

Clearly, clarifying the pedagogical means and ends of the chosen exhibit type is important to the successful staging of content. Much exhibit engineering takes place without due consideration of the dialectic between the scientific knowledge and the museographic organization (cf. Gouvêa de Sousa et al., 2002). Such cases may result in exhibits that sacrifice visual and spatial logic for the logic of the scientific discourse or vice versa, ultimately causing suboptimal or unintended learning outcomes. A thorough understanding of the specificity of a given museographic organization and its implications for what types of practical and theoretical activities can be realised among visitors thus seems to be an important prerequisite to choosing the optimal exhibit form for a certain object of knowledge-to-be-taught (cf. Afonso & Gilbert, 2007). In a larger perspective, research that systematically maps and classifies the pedagogical specificities of the main extant exhibit forms would be of great service to the museum community.

The Second Phase of Museographic Transposition

The second phase of transformation, or execution, marks the physical implementation of the organization from the curatorial brief into the three-dimensional exhibition milieu. At this point, the curatorial brief should provide the framework under which the exhibit must be developed, but nevertheless leave scope for creative work during the implementation (Miles, 1988). While this scope is a necessary condition for exhibit engineers to exercise due creative license, it also entails certain risks. For example, in the development of *Cave Expedition*, the execution phase was marked by a relaxation of epistemological vigilance which resulted in the *pathological substitution* (cf. Chevallard, 1991) of certain exhibit elements (e.g. the animal models as representations of cave beetle predators as described in the section "Case"). How, then, can the execution process be conceptualised in a way that leaves room for creative development while adhering to the museographic and biological premises of the organization in the curatorial brief? Or more generally, what conditions are needed to create an environment in which the visitor can carry out a biology-related activity which creates or re-creates the intended organization?

According to the Anthropological Theory of Didactics, the process by which a learner appropriates or re-creates a scientific organization takes place in a *didactic process* which is conceptualised in six moments. The first moment is the first encounter, in which the learner meets the scientific organization, typically through one of the tasks that constitute it. The second moment is the exploration of such tasks, usually through practical techniques that are developed ad hoc by the learner in order to accomplish the perceived tasks. The third is the emergence of a rationale or interpretation of the practical activities, i.e. the constitution of a theoretical environment relative to the tasks and techniques. The fourth moment involves the subsequent improvement and mastery of the techniques developed by the learner. In the fifth moment the learner identifies the scientific organization. This step is linked to the sixth evaluation moment in which the learner examines the value of what has been done (Chevallard, 1999; see Barbé et al., 2005 for a translation). These moments are not defined in a chronological or linear sense, but rather as different dimensions of the scientific activity (García, Gascón, Higueras, & Bosch, 2006).

Hence, I hypothesise that conceptualising the execution phase as the work of mobilising the organization in the curatorial brief *via the framework of the didactic process* into the three-dimensional organization in the exhibition milieu can promote epistemological vigilance and contribute to the creation of more coherent and well-integrated exhibits. By encouraging exhibit engineers to think about the physical implementation of the exhibit in terms of praxeology and providing them with the means to operationalise the organization in the curatorial brief in terms of visitors' stepwise interactions and interpretations, the risk of "short-circuits" in the implementation of the exhibit is minimised.

To sum up, I have now constructed a model of exhibit engineering that addresses the biological content as well as the processes of framing, staging, and execution that are necessary in order to create a physical exhibit (Figure 4.5). The main points of this model are:

- The biological content is conceived in terms of praxeology throughout the transposition process
- The first phase of museographic transposition consists of simultaneous processes of framing and staging.
    - Framing entails, among other things, addressing the preconceptions of the target audience.

  - Staging entails, among other things, addressing the premise of the chosen exhibit type.

- The product of framing and staging is the *tentative* praxeology described in the curatorial brief.
- The second phase of museographic transposition is the execution, which entails mobilising the tentative praxeology via the six moments of the didactic process.
- The product of execution is the *intended* praxeology which is embodied in the physical exhibit.

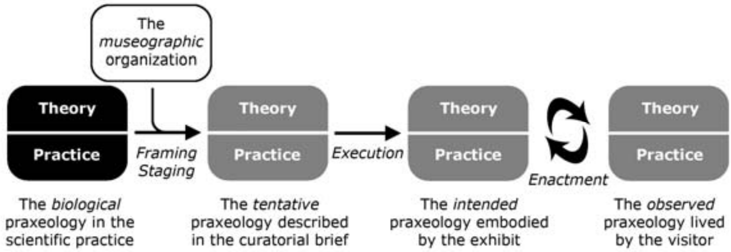

Figure 4.5. A prescriptive model of exhibit engineering. Simultaneous processes of staging and framing co-determine the tentative praxeology in the curatorial brief. This tentative praxeology undergoes a process of execution to embody the intended praxeology in the physical installation of the exhibit. Finally, visitors to the exhibit create or "live" a praxeology. The terms framing, staging, and execution carry special meaning and are explained in the text.

Even though the model is expressed in general terms, it was developed on the basis of the case study of the design and enactment of a single exhibit, *Cave Expedition*, and specifically addresses the issues that emerged from that study. In the following section, I demonstrate the use of the model in a theoretical re-design of *Cave Expedition* is a means to illustrate how those issues are addressed before discussing the model in broader terms.

4.4 Exemplifying the Model

The following narrative is a local theoretical design iteration of *Cave Expedition*. It is local in the sense that it proceeds from the biological content, exhibit form, and intended learning outcome previously decided upon. The thesis presented in the following is not an attempt to second-guess or criticise the creators of what was indisputably a successful exhibit [5], but rather to use the case as a point of departure to illustrate how the model can inform the didactical decisions made in exhibit engineering. For reasons of brevity, I choose two of the activities from the biological organization to illustrate the transposition process rather than presenting an exhaustive redesign. I select these activities to demonstrate how applying the model can increase epistemological vigilance and further a coherent exhibit milieu by helping to avoid commonly occurring problems in exhibit engineering. The theoretically re-designed exhibit is referred to as *Cave Expedition II*.

The Biological Organization

If a biologist were to approach the problem of "what are the adaptations of the blind cave beetle to its environment of permanently dark caves", that biologist would (at least, implicitly) proceed from the theoretical definitions of the terms environment and adaptation. The literature offers the following definitions: An animal's environment is the sum total of the external influences acting on it (Lawrence, 1989, p. 163); animal adaptations are features brought about by natural selection that improve an animal's ability to interact with its environment (Wharton, 2002). In terms of praxeology, these definitions thus form the theoretical rationale for the types of practical activities that must be carried out in order to answer the question. An example of how a biological organization in the scientific practice might be constituted in accordance with these definitions is shown in Figure 4.6.

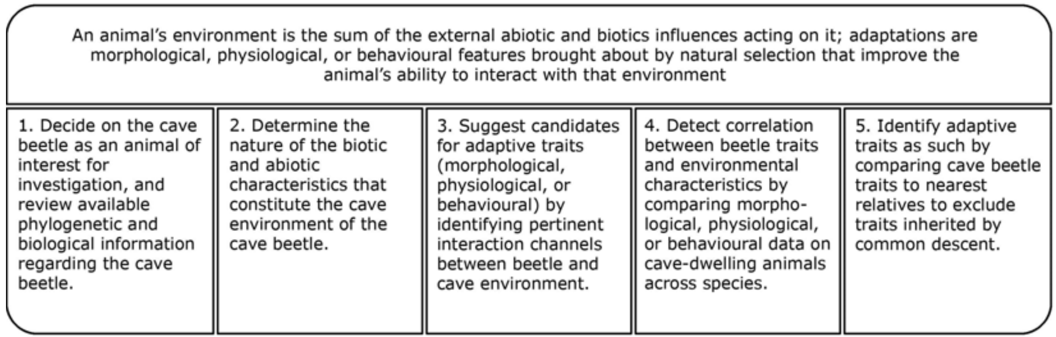

Figure 4.6 The biological organization in the scientific practice. This organization may be seen as the biologist's praxeology with which they answer the research question: How is the blind cave beetle adapted to its environment of permanently dark caves? The lower row represents the practical block with a series of tasks to be carried out (1-5); these tasks are rationalised by the theoretical block of the praxeology, the upper row.

The First Phase of Museographic Transposition: Framing and Staging

The first activity in the biological organization requires the researcher to familiarise themselves with the animal of interest, the cave beetle (Activity 1, Figure 4.6). This task may seem superfluous; indeed, what biologist is not already familiar with the phylogenetic and biological details of the species they are studying? On the other hand, if the scientific praxeology is to be used as a template for didactic design, that praxeology must include all of the practical activities that are necessitated by the theoretical rationale, even though they may seem superfluous to the expert.

For the museum visitor, the activity of familiarising oneself with a particular content, in case the properties of the cave beetle, in preparation for an exhibit interaction is certainly not trivial. The framing of this activity should take its point of departure in common visitor knowledge about insects in general. Children (and presumably adults [6]) have a number of conceptions about insects that could be utilised as anchors in the design of an exhibit on cave beetles and their adaptations, for example: The conception of a typical insect as being small, beetle-like, and crawling, having antennae and multiple legs, and eating other insects and plant material (Barrow, 2002; Braund, 1998; Shephardson, 2002). None of these conceptions are at odds with the established scientific knowledge about cave beetles, and they may thus be used as bridgeheads for further activity and knowledge construction. Accordingly, the activity for the visitor could be framed as a mobilisation of what is already known about insect biology with particular attention to the traits which exhibit special adaptations among cave beetles (i.e. antennae, legs, eyes, etc.)

Staging this activity entails considering the chosen museographic organisation. The premise of *Cave Expedition II* is that the visitor should step into the role of the cave beetle; accordingly, the activity should result in the visitor not only mobilising what they know about insects, but also mapping this knowledge onto themselves by analogy. This could entail, for example, cueing the visitor to the sensory capabilities they have in common with cave beetles: The senses of hearing, touch, smell, air movement detection and vibration detection.

Another important point in the staging process is to address the issue of scaling. The cave beetle is about 5 mm long and thus within the macroscopic category that older children (14-15 year-olds) use as a reference point for size relationships. In the same study, younger children had difficulty relating objects of this size to known references (Tretter, Jones, Andre, Negishi, & Minogue, 2006). Hence, to accommodate both younger and older children, the staging of the relationship between the size of the visitor and the size of the cave beetle could be accomplished by incorporating so-called significant size landmarks on which the visitor can anchor the relative size difference between themselves and the cave beetle to. Once this relationship is established, the next step could be providing the visitor with a kinaesthetic experience (cf. Tretter et al., 2006) of being shrunk to the size of the beetle.

The staging and framing suggestions I make here are not exhaustive, but they do illustrate how an activity from the biological praxeology in the scientific practice can be deconstructed and reconstructed in terms of a tentative activity in the curatorial brief. As recommended by Nicks (2002), this tentative activity helps define the content and the purpose of the exhibit-to-be-implemented, yet leaves room for creative work in the following execution phase of museographic transposition (Figure 4.5). The activity also has the benefit of being structured around a theoretical rationale: That of preparing the visitor to experience the environment of a cave beetle on cave beetle terms. This is because the museographic transposition of activities, rather than concepts, ensures the transposition of the rationale for those activities–or at least of elements of this rationale. This illustrates the strong link between the practical and theoretical levels of a praxeology can provide the basis for epistemological vigilance in the museographic transposition process.

Consider now another activity from the biologist's praxeology, namely the task of determining which abiotic and biotic characteristics constitute the cave beetle's environment (Activity 2, Figure 4.6). The corresponding activity from a museum visitor's point of view could be to explore and examine a representation of the cave beetle's environment to discover what kinds of living and nonliving things characterise this environment. The framing of this task from the visitor viewpoint may be informed by knowledge of visitor preconceptions. For example, from about the age of eight, the notion of ecological niche begins to appear in children's ideas about insects (Shephardson, 2002). Elementary-school-aged children tend to think about what organisms eat in a unidirectional way, i.e. what an animal eats but not what eats the animal (Leach, Driver, Scott, & Wood-Robinson, 1996), and several studies confirm that this is the case when children think about insects as well (Barrow, 2002; Shephardson, 2002; Strommen, 1995). Accordingly, it could be an important point in the framing process to emphasise the roles of both predators and prey as biotic influences on the cave beetle.

How can this activity be staged? The premise of the museographic organization of an immersion exhibit posits that the visitor should be put into the role of the cave beetle; accordingly, the visitor should experience and explore the biotic and abiotic influences on the cave beetle from the cave beetle's viewpoint. This means constructing an immersive cave exhibit for the visitor to enter, complete with representations of the biotic and abiotic characteristics in question. Using the example mentioned in the preceding, predators and prey should be represented in a way that is meaningful to a human playing the role of a beetle. Meaningful, that is, not just as being present and "discoverable", but as having obvious and different roles to play in the representation.

This means that some aspects of the reference world (e.g. darkness or trickling water) can be more or less directly transposed to the exhibit setting, while others (e.g. cave beetle predators) should be scaled to the correct relative size. For example, predators such as spiders are an important biotic influence shaping the cave beetle's environment. Cave spiders may be up to one order of magnitude larger than the cave beetle; thus, consistently scaled up, cave spider models should be about one order of magnitude larger than the visitor.

Another preconception that should be addressed has to do with the abiotic characteristics of the cave beetle habitat. Several studies have found that children tend to think about insects as living on (Barrow, 2002) or in the ground (Shephardson, 2002; Strommen, 1995); none of the children in the studies cited here specifically mentioned caves as potential insect habitats. This means that the framing of the task of discovering the living and nonliving things that act on the cave beetle should emphasise the physical setting of the task: The cave environment. This again means that the staging of the task, namely placing the visitor within the cave beetle's environment, should be designed to ensure that the visitor has no doubts about the nature of the environment in which they are being placed.

How does the tentative visitor activity of exploring the immersive cave environment contribute to the rationale of the tentative praxeology? The idea is, of course, for the visitor to experience not only which biotic and abiotic characteristics that influence the beetle, but also how they influence the beetle. This "how" is an important element in the construction of the intended interpretation of the experience.

The development of tentative visitor activities and rationales illustrated in the preceding demonstrates how the tentative praxeology in the curatorial brief (Figure 4.7) may evolve according to the prescriptive model of exhibit engineering. The process exemplifies the nature of the staging and framing processes as concomitant and reciprocal. Concomitant because the framing of the biological organization must consider how it is staged and vice versa; reciprocal because the framing determines the staging and vice versa. In the following, I proceed to demonstrate how the discussed elements from the tentative praxeology may be executed using the didactic process.

The Second Phase of Museographic Transposition: Execution

The second phase of transposition, or execution, consists of the physical implementation into space of the exhibit outlined in the curatorial brief; a process which entails a creative embodiment or concretisation of the tentative praxeology into an intended praxeology, using the didactic process as a guideline (Figure 4.6). The first moment in the didactic process is the first encounter. In a formal learning setting, this encounter happens when the teacher presents the learner with a concrete task. However, interactive exhibits are designed to be stand-alone teaching devices that must convey their message without the benefit of a human mediator (Feher, 1990). Therefore, presenting the museum visitor with a first encounter needs further consideration.

The first encounter between a visitor and an immersive exhibit is crucial in establishing the experiential nature of the interaction-to-come. In *Cave Expedition II*, the rather metaphorical nature of the intended visitor experience, that of exploring a cave environment in the role of the cave beetle, induces the need for an intermediary mediation which can aid the visitor's first degree perception of the exhibit by shifting their interest from the exhibit's content to its experiential form (Belaën, 2005).

Interpret own role to be an analogy of the cave beetle's; interpret own actions to be those of cave beetle. Interpret resulting kinaesthetic, affective, and cognitive experiences as representative of the cave beetle's daily experiences.				
1. Step into cave beetle role by mapping beetle traits onto own body, and by experiencing scaling or "shrinking" effect.	2. Grasp nature of exhibit as scaled-up cave environment; grasp nature of exhibit features (e.g. scale models of predators) in the context of the cave beetle.	3.	4.	n.

Figure 4.7 The tentative praxeology in the curatorial brief. For reasons of brevity, only two of the activities (1 and 2) from the biological organization in the scientific practice (Figure 4.6) have been transposed and included here. The tentative praxeology may be seen as an outline of which activities the exhibit must promote among museum visitors in order to support the visitor's construction of a praxeology that can answer the question: How is the blind cave beetle adapted to its environment of permanently dark caves? The lower row represents the practical block with a series of practical activities to be carried out (1-n); these tasks are rationalised by the theoretical block of the praxeology, the upper row.

Here, the notion of *immediate apprehendability* may be usefully employed, i.e. the quality of an exhibit such that visitors who encounter it for the first time will understand its purpose, scope, and properties immediately and without conscious effort (Allen, 2004). In this context, Dufresne-Tassé, Marin, Sauvé and Banna (2006) recommend that the exhibit topic be clearly introduced so that visitors can easily establish a first link between what the exhibit offers them and their own bank of experience or knowledge. I suggest that the title of *Cave Expedition II* be formulated along the lines of “Become a cave beetle” or “Can you last a day as a cave beetle?” The chosen title could be boldly displayed at the entrance to the exhibit area in order to unequivocally establish the nature of the experience-to-come. In addition, the visible features of the exhibit area should reflect an appropriate ambience (e.g. through lighting or floor covering) in order to cue the visitor to the fact that they are entering an immersive space (Jones & Wageman, 2000). For example, the entrance to the cave could be shaped as an irregular crevice between scaled-up rocks in order to represent the subterranean cracks and crevices that comprise the cave beetle’s environment.

Further, because insects, and especially beetles, are universally recognised by their morphology, and because insects are universally perceived as being small, a strategically placed 1:350 scaled-up model of a cave beetle on the outside wall of the cave exhibit would help the visitor to effortlessly perceive the nature of the *Cave Expedition II* as a scale model. Anecdotal evidence [7] from two Danish exhibits featuring scaled-up arthropod models suggest that visitors effortlessly and immediately grasp the scaling of the models. In sum, the first encounter of the visitor with the exhibit and its praxeology is conceived, here, to take place as the visitor approaches the exhibit (Figure 4.8).

This brings us to consider the second moment in the didactic process, namely the exploration of the encountered tasks. The first task for the visitor to engage in should be Activity 1 from the tentative praxeology in the curatorial brief, namely the activity that places the visitor into the role of the cave beetle. This activity should be first because it provides the visitors with the decryption key for the interpretation of the following experiences (cf. Belaën, 2005). It is important that this activity (as well as the following ones) is sufficiently motivating in itself that the visitor makes the choice of continuing to invest time in the exhibit (Allen, 2004). An example of an exhibit component which could achieve this is a “shrinking booth” which the visitor could step into. Faced with a touch screen depicting a human and a cave beetle, the visitor could start a shrinking program that scales the image of the beetle up and the image of the human down until they are the same size. The screen could then indicate the beetle's antennae, legs, and lacking eyes, and prompt the visitor to indicate which of the features of the image of the human were analogous to these beetle traits. The "shrinking booth" could then deposit the visitor in front of the entrance to the cave.

The above description is just one suggestion as to how the first activity of the curatorial brief could be executed. One could imagine many other activities that could serve this purpose; indeed, in a real exhibit development case, the expertise and experience of exhibit engineers would vastly enrich the execution process. However, the described activity does have the advantage of addressing common preconceptions about insects to provide the visitor with a size landmark (the image of a human next to a cave beetle) and a virtual shrinking experience, as well as mapping beetle traits onto a human figure, as outlined in the curatorial brief.

The exhibit activity following this "shrinking booth" is the visitor's actual exploration of the immersive environment (Activity 2, Figure 4.7). To this end, the title "Can you last a day as a cave beetle?" placed prominently above the entrance to the cave exhibit would have the advantage of providing the visitor with a challenge in terms of the universal daily struggle for life. While visitors may not be aware of the cave beetle's role as both predator/consumer and prey, children are able to reason based on perceivable features of a phenomenon (Driver, 1985). Equipping the cave exhibit with correctly scaled, easily discernable models of both food items (e.g. cricket eggs) and predators (e.g. cave spiders) could scaffold a visitor's line of inquiry by precipitating reflections on the different roles of these objects in the cave beetle's daily life.

In addition to including aspects of cave beetle life that can be discerned by touch, other aspects could be included which both support the message and reinforce the cave ambience. For example, there is evidence to suggest that the sound of trickling or dripping water supports the feeling of being in a cave among museum visitors (Bitgood, 1990); a soundtrack of dripping water inside *Cave Expedition II* would thus contribute both to the immersive effect and the integrity of the exhibit (as the cave beetle environment is characterised by pools and drips of water).

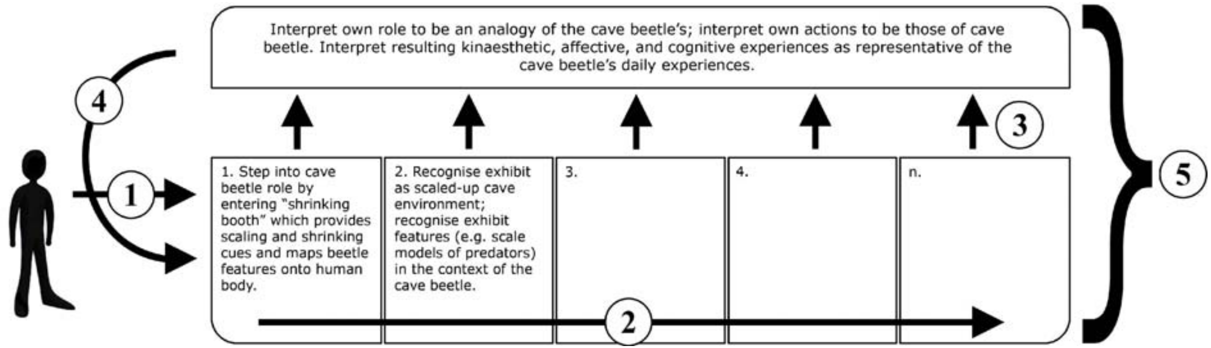

Figure 4.8 The intended praxeology in the exhibition milieu. The arrows indicate the moments in the didactical process, namely the process by which a learner participates in and constructs a praxeology. Moment 1 is the first encounter with the exhibit, moment 2 is the exploration of the practical activities posed by the exhibit, and moment 3 is the emergence of an interpretation of the practical activities. Moment 4 involves a re-engagement with the exhibit and leads to the improvement of the techniques used to engage with the various activities, and in moment 5, the visitor grasps exactly what the biological organization at stake is. In moment 6, the visitor evaluates the praxeology and relates it to other, known praxeologies. In a museum context, this would correspond to comparing the exhibit in question to other exhibits; as the present paper addresses single exhibit design, moment 6 is thus not shown here.

I have only briefly described the execution of two of the activities from the tentative praxeology, but clearly an actual execution of *Cave Expedition II* would require the museographic transposition of the full complement of activities from the biological organization. Indeed, the second moment in the didactic process, the exploration of the encountered tasks, involves this full complement of immersive activities (Figure 4.8).

Consider now the third moment in the didactic process, which is the emergence of an interpretation of the practical activities carried out by the learner. This phase corresponds to the constitution of what Feher (1990) designates as the *explanation*, namely the visitor's construction of a theoretical explanation for the phenomena they experience. In order to create supports for this construction of theory, it may be useful to review the theoretical rationales for the practical tasks in the scientific practice and the curatorial brief. For example, why does the biologist examine the environment of the cave beetle (Activity 2, Figure 4.6)? Because they wish to determine the biotic and abiotic influences on the cave beetle. Which activity in the tentative praxeology does this correspond to? It corresponds to the visitor's exploration of the cave in the role of the cave beetle (Activity 2, Figure 4.7). And finally, does the physical execution of this activity–the exhibit–provide the visitor with the means to interpret what are the most important living and nonliving features of the cave beetle's environment? If the exhibit is successful, the answer is yes: The visitor is able to generate an explanation or interpretation of their practical activities which is in accordance with the stated learning goals of *Cave Expedition II* (Figure 4.8).

Complete mastery of a praxeology requires the learner to continue the didactic process with the fourth, fifth and sixth moments. In other words, this would require the visitor to re-engage with *Cave Expedition II* (Figure 4.8). Studies suggest that visitors rarely return to an exhibit they have already engaged with (Bitgood, Patterson, & Benefield, 1988); indeed, in the observation of 100 casual visitors to *Cave Expedition* (reported in Mortensen, 2010a), only 8 visitors re-engaged with the exhibit after having left it. This could imply that the physical design of an exhibit should address visitors who will interact with it only once. In other words, it should be possible for visitors to achieve or construct the basics of the intended praxeology by engaging with the exhibit just once. Nevertheless, for those visitors who do engage with the exhibit repeatedly, it could be prudent to at least consider the fourth and fifth moment of the didactic process: The improvement of the techniques the visitor employs to interact with the exhibit and the subsequent understanding of the biological organization at stake. Adding an extra layer of detail to the exhibit could be a way to allow the visitor to refine the techniques they have already acquired, or to develop new ones. Providing the visitor with a detailed post hoc explanation for their activities (e.g. a text panel or an interactive screen) could also serve to support a complete acquisition of the intended praxeology.

Finally, in the sixth moment of the didactical process, the visitor evaluates the acquired praxeology. This moment may be located at a higher level of knowledge abstraction than that provided by the individual exhibit. In other words, evaluating the acquired praxeology may entail comparing it to other, related praxeologies and assessing their commonalities and differences. In a museum context, such related praxeologies could be understood as the praxeologies embodied by other exhibits with different contents but unified by a common theme. Hence, designing an exhibit to address the didactical process entails considering the immediate environment of that exhibit and the exhibits located here.

The preceding account has illustrated how the model of exhibit engineering can be applied to an object of biological knowledge and guide the museographic transposition of this knowledge into a physical exhibit. I have made no attempt to address the various influences on exhibit design which are unrelated to the didactic development; in this sense, the account does not correspond to the process of creating exhibits. However, it does address the issues of how to deconstruct and reconstruct knowledge in a way that maintains epistemological vigilance and ensures the development of a coherent teaching milieu. In the following, I offer a reflection on the implications of the model, both as a product of a design-based research approach, and as a theoretical tool in its own right.

4.5 Discussion

Design-based research is a mode of educational inquiry that can yield outcomes at two levels. First, it can provide the means to create and refine an educational intervention, and second, it can provide theoretical insights about the conjecture behind the intervention (Sandoval, 2004). In this paper, I have generated both kinds of outcome. That is, I see the emergence of specific ideas for a design iteration of *Cave Expedition* (described in the section “Exemplifying the model”) as the former type of outcome and the model of exhibit engineering as a development of the latter type. Although the focus of much design-based research has been on the former type of outcome due to the requirements of science education practitioners (e.g. DBRC, 2003), Ruthven et al. (2009) point out that the efficiency and coherence of such refinements depend on the quality of the original intervention and the clarity of the intentions expressed in this intervention. Hence, as these authors argue, the development of theoretical tools that can relate the epistemological and cognitive properties of a given object of knowledge to the intentions embodied in the design of an educational intervention that intends to teach that knowledge is a necessary and important outcome of design-based research. In accordance with this emphasis, I consider the model of exhibit engineering to be the most important outcome of the present work, and I focus the following discussion on what kinds of theoretical insights it may represent.

Edelson (2002) distinguishes between three kinds of theoretical insights derived from design-based work, namely: *Domain theory*, *design frameworks*, and *design methodologies*. Domain theory results from the problem analysis or initial characterisation of the goals and needs an intervention is intended to address, and is not a theory about design per se, but rather, a descriptive theory about the desired outcome of an educational intervention. A design framework is prescriptive, on the other hand, and targets the product of the design process in terms of the necessary qualities and properties this product must have in order to achieve a certain set of goals. Finally, a design methodology is a prescriptive set of guidelines for the process of design, including the process for achieving a certain class of designed intervention, the forms of expertise required, and the roles to be played by the various people involved in the process (Edelson, 2002). The three types of theoretical insights and their application to the model of exhibit engineering are discussed in the following.

Domain Theory within the Model of Exhibit Engineering

In this paper, the development of the model of exhibit engineering took its starting point in the notion of praxeology. Praxeology was incorporated into the model to address the problem of discrepancy between intended and observed outcomes of *Cave Expedition*, and it thus corresponds to what Edelson (2002) designates as domain theory. In this perspective, the main contribution of the notion of praxeology is probably its role of sensitising exhibit engineers to critical issues regarding the outcomes of the design undertaking, rather than its ability to define a particular course of action (cf. Ruthven et al., 2009).

How widely can the notion of praxeology be generalised? The central idea of praxeology, namely that neither practice nor theory can meaningfully exist in the absence of the other when learners construct science knowledge, is becoming widespread in science education research. For example, Lijnse and Klaassen (2004, p. 539) emphasise the importance of science learners being able to see *the point* of what they are doing at any time during the process of teaching and learning. And although we in the museum research community have tended to lag somewhat behind our colleagues in the formal science education research community (Schauble & Bartlett, 1997), the realisation that practice and theory go hand in hand in the process of knowledge construction is also reflected in studies here. For example, Feher's work (1990) cited in the preceding advocates an approach that addresses both the actions and reflections of museum visitors, and Falcão et al. (2004) explicitly model the intended learning outcomes of exhibit interactions in terms of practical actions and theoretical realisations. Thus, it seems there is a need for a coherent and systematic means of expressing or characterising desired visitor learning outcomes and the trajectories that can lead to them in exhibit design research. I suggest that the notion of praxeology constitute this means.

A Design Framework within the Model of Exhibit Engineering

A design framework is a prescriptive, generalised design solution: A description of the characteristics that a designed teaching intervention such as an exhibit must have in order to achieve a particular outcome (Edelson, 2002). In this paper, I have argued that the intended praxeology embodied by the exhibit should be modelled on the original researcher's praxeology; i.e. that the exhibit should be constructed in such a way as to create or promote actions and reflections among museum visitors that are transposed versions of the original researcher's actions and reflections. This proposal thus constitutes a theoretical insight at the level of Edelson's design framework.

A few points bear mentioning in this regard. You, the reader may be asking yourself whether the original researcher's praxeology is the only praxeology that can be used as a template for the properties of a museum exhibit which intends to mediate a certain body of knowledge. The answer, of course, is no. One can imagine any number of praxeologies that could serve as templates for creating appropriate conditions for the construction of a certain body of knowledge. However, the original praxeology that created the knowledge in question has the advantage of being a *proven* means to constructing that knowledge; this is necessarily so because without it, we as a society would not be in possession of the knowledge!

In addition, there may be a cultural argument for using the original researcher's praxeology as a template rather than using a praxeology generated ad hoc; as Clément (1991) suggests the process of museographic transposition and its product, the exhibition, should ideally address and account for the dissemination of scientific culture to the public. In this perspective, using the original researcher's praxeology becomes a means to include this culture in the designed intervention and hence an important point of exhibit design rather than just another property.

A Design Methodology within the Model of Exhibit Engineering

Design methodologies are theoretical insights that provide prescriptive guidelines for the process of design (Edelson, 2002). In the present case, the two phases of museographic transposition described by staging and framing, on the one hand, and execution, on the other, constitute the core of the methodology proposed by the model of exhibit engineering. This methodology does indeed, as Edelson prescribe, lay out a sequence of tasks and describe the objectives and processes for each step.

In essence, the design methodology I advocate can be characterised as a didactic approach. Indeed, Clément (2000) emphasises that the problems relevant to the didactics of biology are those specifically focused on the teaching of biology, both in school but also outside the school, e.g. in the media, in families, or at the workplace. I add museums to this list and thus consider biology exhibition development to be a case of biology didactics. Although I wholeheartedly concur that a content-oriented approach is necessary for the development of successful biology exhibits, in a sense this is bad news for exhibit engineers because it means there is no "one-size-fits-all" approach to exhibit design. Rather, the didactic approach posits that every exhibit should be the subject of individual development, with attention to the relationship between the public and the specific object of knowledge, the specifics of the exhibit type, and the corresponding public dissemination of biological culture (Clément, 1991). This may seem a daunting prospect for exhibit engineers. On the other hand, "scientific or technological competency does not automatically bestow museological competency on a person any more than the converse is true" (Clément, 1991, p. 128, author's translation). Hence, it does not seem unreasonable that a didactic model of exhibit engineering should include and account for epistemological, cognitive, and museographic properties of the exhibit-to-be.

Another point bears mentioning: In some ways, the notion and the mechanism of transposing an original researcher's praxeology into another seems unnecessarily challenging. For example, consider the relative difficulty, in the case of *Cave Expedition II* (and predictably in similar instances of creating immersion exhibits), of conceiving of a visitor's praxeology in terms of a different subject (the cave beetle) on the basis of a praxeology formulated in terms of a third subject, the researcher. While this procedure does seem to complicate the process of transposing an object of knowledge, bear in mind that the complication arises mainly from the intention to create an immersive experience from the viewpoint of a different (and in this case, nonhuman) subject than the visitor. The difficulty is therefore a property of creating immersion exhibits, not of using praxeologies as templates, and it is a difficulty the exhibit engineers would have to face however they decided to conceive of the reference knowledge for their design endeavours. Accordingly, although I would argue the utility of the methodology in the design iteration of the immersive exhibit *Cave Expedition*, it may be more obviously applicable to the design of exhibits with other, less complicated museographic premises.

4.6 Concluding Remarks

In this paper, I have developed and argued for the development of a theoretically informed tool for the systematic construction of museum exhibits as educational environments. However, designed educational interventions such as museum exhibits are the products of significant influences beyond theoretical design tools (cf. Ruthven et al., 2009). For example, exhibit engineers must address also the financial realities of creating exhibits as well as visitor factors unrelated to education such as ergonomics and safety. Furthermore, any exhibit design endeavour is influenced–and should be influenced–by exhibit engineers' often tacit knowledge about "good exhibits". These influences cannot be attributed to or addressed by design tools. However, the model of exhibit engineering can provide even experienced exhibit engineers with new content-related or context-related insights that have the potential to systematically improve their design endeavours. As such, it may be seen as a framework which addresses a broader class of phenomena, namely science exhibit engineering, and which is customisable to specific contexts.

4.7 Notes

1. In the remainder of this text, the term “museum” is used broadly to denote any institution, such as natural history museums, science centres, botanical gardens, zoos and aquaria that conduct informal science education activities.

2. The term didactics refers to the science of the diffusion of knowledge, and encompasses both the process of research into this knowledge diffusion and the organised body of knowledge produced by it (Chevallard, 2005).

3. I refer the reader to these publications for details beyond those presented here.

4. *Museographic*: The visual presentation form (-graphic) proper to the museum (museo-), i.e. an adjective pertaining to the exhibit.

5. At RBINS, about 50% of visitors who ventured into the vicinity of *Cave Expedition* interacted with it, which is a respectable percentage for a museum exhibit (cf. Sandifer, 2003).

6. At the time of writing, no research on adults’ conceptions regarding insects and insect characteristics could be located in the literature. Accordingly, the following sections conservatively consider the conceptions of children from the western hemisphere to be representative of those of the general public.

7. The exhibits are located at the National Natural History Museum of Denmark in Copenhagen and GeoCenter Møns Klint on the island of Møn, Denmark. I spoke with exhibit engineers at both locations.

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5 Designing Immersion Exhibits as Border-Crossing Environments

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Abstract. Science museum exhibits embody both content and form, and these aspects are not independent of each other. However, selecting the right form for a given content is not straightforward. Here, I provide an example of how science education theory, specifically the notion of border crossing, can be applied to achieve an understanding of the *immersion exhibit* form. I show how the characteristics of immersion exhibits and visitors to them classify them as microcultures, and examine the implications of this for exhibit design, using a hypothetical immersion exhibit as a case. Finally, I discuss the generalisability of my findings as a paradigm case of applying education theory to exhibit development. **Museum Management and Curatorship 25(3): 323-336, 2010. Reprinted here with permission.**

5.1 Introduction

Science museum exhibits are stand-alone teaching devices that must attract and hold the visitor's attention and convey a message, usually without the benefit of a human mediator (Feher 1990). To this end, exhibits embody and mediate knowledge in various ways, and accordingly may take a wide range of shapes and forms. Several exhibit classification schemes have been developed and presented by researchers in which the used criteria range from being content-related, e.g. the representation form embodied by the exhibit (Falcão et al. 2004, Gilbert & Stocklmayer 2007), to being related to the characteristics of the exhibit medium, e.g. the mode of use by the visitor (Miles 1988). More pragmatic mixed classification schemes have also been used where the mode of use and form of representation are just some of the variables studied (e.g. Boisvert & Slez 1995, Sandifer 2003). However, all of the schemes seek to systematise the variables of the diverse exhibit medium in order to understand the strengths and weaknesses of its various forms in mediating their content to visitors. One key insight that may be drawn from this collective work is that exhibit content and exhibit form are not mutually independent. However, selecting the right medium for a particular content is not a straightforward undertaking, and there are few rules to guide the process (Miles 1994, 1988).

As a consequence, I approach the problem from the opposite direction. Instead of investigating visitor outcomes as a function of certain exhibit forms and contents, I take as given the special form of museum exhibits called *immersion exhibits* and ask the questions: what are the characteristics of this particular form? How can its design be optimised? To this end, I argue that immersion exhibits may be understood as microcultures, based on the notion of culture described by Sewell Jr. (2005) and Belaën's categorisation of visitor reactions to immersion exhibits (2003, 2005). I further argue that the successful apprehension of such microcultures by visitors may be facilitated using the notion of cultural border crossing (cf. Aikenhead 1996, 2001; Phelan et al. 1991). It follows that the theoretical suggestions for the development of immersion exhibits I present are framed in terms of visitor outcomes rather than scientific content, although I do view scientific content as a core element of science exhibit development.

5.2 Immersion Exhibits

The immersion exhibit has its roots in the diorama, which consists of a three-dimensional life-size simulated environment in which models or taxidermied animals are placed in order to depict a scene or an event (Insley 2008) (Figure 5.1). The diorama exhibit is thus based on an analogy where the exhibited objects form an image that resembles a given reference world: the real environment. In contrast to earlier exhibit forms, where collections of objects were displayed according to a system such as taxonomy and thus intellectually accessible only to scholars who understood the system, dioramas attempt to build upon commonly shared and recognisable references to situate the visitors in known and familiar territory (Montpetit 1996).

Once the analogy was adopted into the exhibition medium, its dynamic extended into including the visitor within the display space. This marked the birth of the immersion exhibit. Here, the visitor was no longer removed from the exhibited objects by a distance of representation, but plunged into the heart of the subject matter;

instead of being just a spectator, the visitor became a participant (Montpetit 1996). Two movements drove this inclusion of the visitor in the exhibit design: a commitment to present scientific knowledge as discourse rather than fact, and an increased competition with other experience-related media forms, in particular those of amusement parks (Belaën 2003).

Figure 5.1. A diorama consists of a three-dimensional life-size simulated environment in which taxidermied animals or models are placed in order to depict a scene or an event.

The new role of the visitor as an active participant rather than as a passive observer promoted a radiation in the immersive exhibit form. The emphasis on experience rather than facts meant that the relationship between the representation and the reference world could diversify; this diversification is described by three models: *reconstitution*, *creation*, and *interpretation* (Belaën, 2003).

The model of reconstitution is the extension of the analogical principle of the diorama. Here, the immersion exhibit refers to an existing reference world and reproduces it within the museum in the most authentic way possible. Examples are life-sized environments such as a forest clearing, a snowy alpine slope, or an urban streetscape which often include authentic objects such as taxidermied animals or real trees, and the layout of such exhibits is thus governed by a logic that exists outside of the exhibit, namely that of the layout of the reference world.

The creation model is based on the principle of metaphor. The reference world has no reality but is created in the exhibit; the logic governing a creation-type exhibit is thus generated by the exhibit itself. An example could be a 'sensory tunnel' in which the intent is to let the visitor explore their five senses one by one as they proceed through a tunnel. The layout of such an exhibit has the goal of providing the visitor with an experience of their five senses and does not correspond to any existing reference world.

Finally, immersion exhibits based on interpretation refer to a world which exists or has existed, but is not reproduced in an authentic way. This is often the case when the knowledge to be exhibited is not associated with a representable human-scale realm, or the significant experiences of the reference world are abstract. Interpretative immersion exhibits thus combine the logic of an existing reference world with the logic generated by their own setting-in-scene. An example could be a walk-through scale model of the human digestive tract. The design of such an exhibit would be based on the logic of an existing reference world (the human digestive tract) interpreted by exhibit engineers to create an analogical representation according to their objectives.

It is worth noting that with the advent of the interpretation- and creation-based exhibits the immersive form began to diverge from the basic 'analogy of resemblance'. Instead of physically resembling their reference worlds, interpretation- and creation-based exhibits rely on an indicative or symbolic relationship with their reference worlds (Figure 5.2). All types of immersion exhibits, however, consist of systems of meaning and symbols which are designed by the exhibit engineers for the purpose of creating a self-contained illusion of a time and place for the museum visitor.

In addition to its type of relationship with the reference world, immersion exhibits also indicate a role for the visitor. Depending on the model of representation and the exhibit's content, the visitor may be more or less integrated in the exhibit. For example, an immersion exhibit which displays an African rain forest with a pathway, as for example in the Hall of Biodiversity at the American Museum of Natural History in New York, may provide a setting and ambience which the visitor can immerse themselves in, playing the role of themselves, i.e. that of a person walking along a rain forest path. A stronger degree of immersion is indicated by exhibits which give the visitor a certain character to play, as for example in Rabbit City at the Copenhagen Zoo, where children can play the role of rabbits in an underground burrow with interconnected tunnels and Perspex peepholes through which they can view an aboveground rabbit exhibit. Finally, exhibits that utilise virtual reality can allow visitors to act on the represented world in real time. An example could be the Three Drops exhibit which is part of NanoWorld, an exhibition about nanotechnology developed by Discover Science and Engineering Ireland. Here, the visitor interacts with water using their shadow on a screen. In the first segment, the image of a shower of water pours down and is broken by the shadow of the visitor. In the second segment, the visitor's shadow is shrunk down a thousand times, and time slowed a hundred times. Here, the visitor can use their shadow to play with a single drop of water which at this scale has a size and surface tension to make it act like a soft beach ball. In the final segment, the visitor uses their shadow to interact with water at the molecular scale–approximately one billionth of their size. In sum, the degree of visitor integration in an immersion exhibit falls within the range from *setting and ambience* and *role play* to *real time modification of environment* (Belaën 2003).

Visitor Reactions to Immersion Exhibits

Immersion exhibits mediate their message by creating the illusion of a time and place and by integrating the visitor in this illusion (Bitgood 1990). It follows that the extent to which the visitor understands the meaning and message depends on whether they recognise and accept the represented world and the role given to them. This undertaking requires a certain suspension of reality, and not all museum visitors are willing and/or able to do this. Common reactions to immersion exhibits range from *resonance*, where visitors willingly surrender themselves to the immersion principle, to *distance*, where the visitor considers the exhibit form to be disproportionate to its content, and finally to *rejection*, where the visitor figuratively and sometimes literally fails to enter the immersion environment (Belaën 2003). This range of visitor reactions may reflect the visitors' willingness or ability to use their imagination and suspend reality during their exhibit interaction (Mortensen, 2010). Thus visitors who use their imagination to a high degree during a museum visit have no trouble taking on the role offered to them by the exhibit (resonance visitors), while visitors who do not usually employ their imagination during a visit, an estimated 30-40% of all visitors (Dufresne-Tassé et al. 2006), refuse or fail to understand the immersive exhibit form and maintain a critical distance to it (distance and rejection visitors).

Figure 5.2. A diorama which employs the interpretative model. The objects physically resemble their references, but their scaling makes an indicative analogy to the scale of the reference world. Anecdotal evidence suggests that the bottle cap is especially useful in establishing the scale.

5.3 The Immersion Experience as a Cultural Border-Crossing Phenomenon

In the preceding, I have argued that immersion exhibits can be characterised as self-contained systems of symbols and meaning. In this perspective, the key characteristics of the exhibit’s reference world may be thought of as symbols that carry certain meanings; these meanings together form a system of coherent representation. Further, I have argued that immersion exhibits include an intended human interaction or practice, i.e. the visitor’s interaction with the exhibit in terms of the role they are given. These two perspectives lead me to hypothesise that the immersive exhibit form may be understood as a type of culture. Culture is defined as including both a system and a practice (Sewell Jr., 2005). The *system* is a collection of symbols (Geertz 1973, p. 46) and to engage in cultural *practice* means to use these symbols to accomplish some goal. When a person employs symbols in cultural practice, that person may be expected to accomplish a certain goal because the symbols carry certain meanings. These meanings are defined by the relationship between the symbols in question and other cultural symbols–the system (Sewell Jr. 2005, p. 85). Accordingly, I would argue that the environment formed by an immersive exhibit in interaction with a museum visitor constitutes a culture: an ordered system of meaning and symbols in terms of which interactions take place (cf. Geertz 1973, p. 5). In this perspective, the visitor utilises symbols that pertain to the culture of the exhibit (and by representation, the reference world) to achieve a certain goal (the intended exhibit interaction and experience) which is specified by the coherence of the system of symbols (the representation). Because the environment formed by the system and practice are obviously limited in time and space, I designate this culture a *microculture*.

Viewing immersion exhibits as microcultures affords a holistic and intuitive appreciation of the museum visitor's experiences (cf. Aikenhead 1996) which considers both content and form. In this perspective, the goal is for the visitor to acquire the exhibit's culture by making a transition from their own life-world culture into the microculture of the exhibit. Crossing into the exhibit microculture is not just done by physically entering the immersion exhibit, but by entering into its world of meaning. It follows that the visitors' success in carrying out these transitions has implications for the quality of their exhibit experience (cf. Phelan et al. 1991), and accordingly, the existence of the different visitor characteristics found by Belaën (2003) may be evidence of border transitions characterised by various degrees of success.

In the following, I use the notion of cultural border crossing as a metaphor for engaging in learning (Aikenhead, 1996, 2001; Phelan et al., 1991) to explore the question: What are the exhibit design criteria for border-crossing, i.e. the successful transition of visitors into the microculture of the immersion exhibit, in a science museum setting? Or in more practical terms: what might it take to make immersion exhibits work?

Border-Crossing Characteristics of Resonance Visitors

Resonance visitors are visitors who feel resonance with the exhibit at the level of the content or the form by recognising the exhibit's reference world or its participatory form. They have no pre-defined expectations of their exhibit interaction but willingly play along with the immersive experience (Belaën 2005). These visitors' exhibit interactions may be described by what Phelan et al. (1991) call smooth border transitions, in which the movement from one setting to another is uncomplicated. Smooth border crossings take place when the life-world culture of a person aligns so well with the culture they cross into that the borders are barely perceived (Phelan et al., 1991). For resonance visitors, such an alignment does not imply that their life-world culture resembles the reference world of the exhibit, but rather that they effortlessly change gears from one culture to another because they appreciate and comprehend the immersive staging of the exhibit experience. Their exhibit visit is characterised by a dream-like quality (Belaën 2005), described by Bitgood (1990) as complete involvement or absorption, in which visitors use their imagination to anchor the world of meaning they generate from their interaction with the exhibit to their prior knowledge and experience (Dufresne-Tassé et al., 2006).

However, Mortensen (2010) identified a potential hazard of smooth border crossing: that visitors' perceptions of what, exactly, is represented may be different from the exhibit designers' intentions. When faced with an exhibit, visitors freely decide on an interpretation of it based on their abilities (Falcão et al. 2004), and if they cannot decipher the exhibit as intended, they unconsciously apply the codes they use for deciphering known situations (Montpetit 1996). For example, in the case studied by Mortensen (2010), an immersion exhibit representing a scaled-up version of a cave insect habitat (an interpretation type exhibit) was deciphered by visitors as being a to-scale representation of a cave from a human perspective (a reconstitution type exhibit) because the exhibit contained inconsistent cues as to the scaling. Accordingly, exhibit design should carefully consider visitors' prior conceptions and knowledge about the reference world it displays in order to avoid unintended deciphering. Incidentally, Figure 5.2 gives an example of how visitors can be provided with a cue to scaling by including in the scenery an unmistakable object–the bottle cap–in an obviously scaled-up version.

Border-Crossing Characteristics of Distance Visitors

Distance visitors are, in a sense, amateur visitors of immersion exhibits. They comprehend and lend themselves to the immersive principle to experience its effects, but at the same time maintain a critical distance to it (Belaën 2005). The distance visitor's participation is restrained due to their more conservative conception of what exhibits should be and their resulting irritation with what they perceive to be an exaggerated setting-in scene (Belaën 2003). In short, distance visitors may physically enter the immersive environment, but do not enter it mentally because it is not personally meaningful to them.

The characteristics of distance visitors may be caused by the differences between their life world culture and the microculture formed by the exhibit. Again, such differences are not due to the physical differences between the visitor's life-world culture and the microculture of the exhibit, but rather from the visitor's reluctance to accept the premise and conditions of the immersive exhibit environment. This perceived boundary between the two cultures does not necessarily prevent distance visitors from carrying out border crossings (cf. Phelan et al. 1991), but such border crossings result from the visitor's knowing how to 'play the game' rather than a effortless transition. In this case, the visitor appears to be interacting with the exhibit as intended while in fact they are just going through the physical motions. In order for distance visitors to get the intended experience from their interactions with the exhibit, their border crossings must accordingly be managed (cf. Aikenhead 1996).

For learners of this type, knowledge worth learning is probably organised around everyday issues and results from analysis and reflection (Aikenhead 1996). A way of managing the transition into the microculture of the exhibit is therefore to build bridges from the visitors' life-world to that of the exhibit content, using concepts from these visitors' daily lives as anchors or founder notions. Anchors (Clement et al. 1989) or founder notions (Küçüközer 2006) are commonly held conceptions that do not conflict with what is to be learned, but can serve as the basis for concept construction. Consider the following example from physics education:

> *Many students refuse to believe that static objects can exert forces. They refuse to believe the physicist's assertion that a table exerts an upward force on a coffee cup sitting on the table. However, almost all students believe that a spring will exert a constant force on one's hand as one holds it compressed. In teaching that inanimate objects can exert forces, this intuition about springs can be built on as an anchor (Clement et al. 1989, p. 554).*

Anchors or founder notions, such as the intuition about springs described by Clement et al. (1989), may set the stage for the experience to come by providing a frame of reference for the distance visitor that is rooted in their everyday life. For example, the bottle cap in Figure 5.2 mentioned previously may provide the visitor with an anchor with regards to scale.

Once the initial transition has taken place, i.e. the visitor has accepted the premise of the exhibit form, it is then important to for the design to follow through by forming a framework of meaning sufficiently strong and consistent that the visitor's imagination can be constructively supported to clarify and deepen the subject matter in terms that are personally meaningful to them (Dufresne-Tassé et al. 2006).

Border-Crossing Characteristics of Rejection Visitors

Visitors of the rejection category do not grasp the meaning of the exhibit form, lacking the keys of reading to be able to interact with the exhibit as intended (Belaën 2003). This is due not only to a mismatch between the expectations of visitors and the exhibit premise as was the case with the distance visitor, but especially to the fact that these visitors are unable to grasp the meaning of the layout. Rejection visitors figuratively and sometimes literally do not enter the exhibit (Belaën 2005).

The characteristics of rejection visitors may be caused by a complete non-alignment between their life-world culture and the microculture of the exhibit. Learners of this type must adjust and reorient considerably when moving across contexts, and frequently experience unease and estrangement when they find themselves in situations where norms and behaviours are in opposition to what they encounter in their life-world culture (Phelan et al. 1991). Unaided, learners with these characteristics may carry out hazardous border crossings in which they circumvent the intentions of the context they enter into (Aikenhead 1996). In an immersion exhibit context, learners of this type (i.e. rejection visitors) unconsciously navigate around the premise of the immersion exhibit and do not apprehend the intended meaning. Rejection visitors, if they enter the immersion exhibit at all, only superficially go through the motions of interacting with the exhibit.

Designing for rejection visitors entails making the features of the immersion microculture recognisable to the visitors on their own terms instead of expecting them to assimilate the exhibit microculture. The first step could be to relocate the visitors' initial attention from the exhibit content to the exhibit form, i.e. emphasising the experiential aspect of the exhibit (Belaën 2005). The subsequent engagement with the exhibit should then take the form of a guided tour where the visitor is assisted in moving back and forth between their own subculture and the exhibit microculture and helped to resolve any conflicts that might arise (Aikenhead 1996). Each side of the cultural border should be explicitly marked to make it overtly clear which microculture the visitor is in at any given time and when a border crossing is taking place (Aikenhead 2001).

5.4 Immersion Exhibits as Culture Brokers: An Example

The preceding discussion has indicated that designing immersion exhibits as cultural border crossing environments entails acknowledging and respecting the perspectives of the visitors. In other words, the immersion exhibit must be able to function as a culture broker; neither ignoring nor marginalising the various viewpoints and approaches of the diverse types of visitors it receives (Aikenhead 2001). In the following, I will utilise an ad hoc hypothetical case of immersion exhibit design to illustrate how exhibits can be constructed to make transitions across borders easier for the visitors by transforming hazardous border crossings into manageable ones or manageable border crossings into smooth ones.

The Forest Floor

This hypothetical immersion exhibit is loosely based on the diorama shown in Figure 5.2 and features a 50 times magnified section of Danish deciduous forest floor which the visitor may walk through. It is thus an interpretation-type exhibit, where the existing Danish forest habitat provides the characteristics and layout of the exhibited objects, but where all the objects are scaled up according to the exhibit premise. The integration of the visitor into this immersion exhibit requires the visitor to perceive and 'play along with' this scaling; the role of the visitor is thus that of a 50 times scaled down (i.e. 3-5 cm tall) human being. The intention of this hypothetical immersion exhibit is for the visitor to gain an understanding of the diversity of invertebrates on and in the forest floor and their interactions, an area which is underrepresented in children's conceptions of biodiversity (Snaddon et al. 2008).

Design: Some Ideas

The first design consideration is that the staged scene should be easily recognised by approaching visitors in order for them to initially apply the correct deciphering keys. This is important for both resonance and distance type visitors. The initial recognition can be facilitated by an introduction of the exhibit theme in the title or introductory text so that visitors can easily use the reproductive component of their imagination to establish a first link between what the exhibit offers them and their own bank of experience or knowledge (Dufresne-Tassé et al. 2006). The exhibit should provide obvious cues as to the scaling and the nature of the setting by incorporating easily recognisable, yet obviously scaled-up objects at the entrance to the exhibit. For example, research shows that insects are universally characterised by children aged 5-15[1] as being small, crawling creatures with antennae and legs (Barrow 2002; Braund 1998; Shephardson, 2002). A 50× enlarged model of a typical forest insect, for example an ant, would accordingly be easily recognisable as an insect (due to its legs, antennae, and crawling posture) while its scale would establish the exhibit as a representation of a scaled-up world. It would accordingly serve as an anchor upon which the visitor could build their initial understanding of the exhibit's premise.

If even stronger mediation of the immersive exhibit form is needed in the initial stage to manage the border transition of rejection type visitors, it may be necessary to focus the interest of the visitor on the experiential nature of the exhibit, for example by providing them with a strong initial question which can generate a line of inquiry for them to pursue (cf. Mortensen, 2010). The title of the exhibit could be a challenge such as 'What would the forest be like if you were five centimetres tall?'. This question could lead to questions regarding the daily activities of life (eating, moving around, or interacting with others–activities which are meaningful to both insects and visitors) the pursuit of which should then be supported by the entire exhibit structure as discussed in the following.

Once the resonance, distance, and rejection type visitors have approached and initially accepted the premise of the immersive exhibit form, it is important that their subsequent experiences are sustained by the exhibit design in order to clarify the subject matter on their own terms. In other words, the design should have a depth that acts as an imaginative space for the visitor to constructively explore their conceptions of the subject matter (Dufresne-Tassé et al. 2006). It is beyond the scope of this paper to present the type of in-depth development of the forest floor biodiversity theme and the subject of animal interactions involved in this type of exhibit design; however, one suggestion could be for the exhibit to directly reflect the complexity of the body of knowledge in question. Accordingly, when the visitor enters the exhibit they are thrown into the entire complexity of the forest floor habitat, an experience which is more aesthetic than purely scientific and thus may appeal especially to distance-type visitors. In this complexity, there could be space for many individual tableaux of animals engaged in natural interactions that are recognisable by visitors based on their prior knowledge. Examples of such tableaux could be 50× models of a centipede eating a worm, an ant 'milking' an aphid, or a caterpillar eating a leaf. Such tableaux provide the distance-type visitor with repositories of events that can be 'raided for what [they] can contribute to the achievement of practical ends' (Layton et al. 1993, cited in Aikenhead 1996, p. 31); the 'end' in this case being achieving an overview of the types of interactions that occur on the forest floor. In this sense, the collection of tableaux comprises a buffet where the visitor can focus on what they find interesting and relatable, and pay less attention to the rest. It follows that the exhibit should be richly equipped with various tableaux featuring a variety of animals and interactions in order to cater to the various levels of entrance knowledge of distance visitors.

To sustain the engagement of the rejection-type visitor, the exhibit should ideally function based on a tour guide metaphor. This could entail, in continuation of the above-mentioned exhibit structure, maintaining a focus on the experiential nature of the exhibit form by using parallels to the everyday life of the visitor. To emphasise the visitor's experiential role, the exhibit design could extend into the visitor pathway. An example could be a spider web (at 50× magnification) that reaches partially across the visitors' route through the exhibit. The visitor's natural avoidance reaction (ducking or swerving) would mimic that of a forest floor animal perceiving a danger, at the same time directing the visitor's interaction with the exhibit in the context of their everyday world (cf. Aikenhead 1996).

Another way of creating explicit parallels between the exhibit microculture and the rejection-type visitor's life-world culture could be to equip each of the above-mentioned tableaux with video screens showing a split view of the animal activity represented in the exhibit and a corresponding human activity. For example, the screen could show a split view of an ant 'milking' an aphid and a human milking a cow[2]. Comparisons between human and animal activities would provide the rejection-type visitors with common-sense analogies of the activities taking place and thus helps them negotiate the cultural border.

Although the ideas presented in the preceding by no means constitute an exhaustive plan for the design of an immersion exhibit representing a scaled-up version of the forest floor, I suggest that they illustrate how the notion of facilitating border-crossing for various types of visitors can be carried out. Exhibit development is usually a rigorous development process; this process has been purposefully omitted here in the interest of brevity. In the following, I discuss the implications of applying the notion of facilitating border-crossing to immersion exhibit design and the generalisability of the approach.

5.5 Discussion

My main argument has been that immersion exhibits are self-contained systems of meaning and symbols–microcultures–which require a certain decoding by the visitor in order for the intended exhibit interaction and outcome to take place. It follows from this argument that the way in which the visitor relates to this system determines what type of visitor they are. In consequence, my suggestions about how to accommodate the individual visitor types are formulated in terms of the system of meaning and symbols, because changes in how the microculture is manifested in the exhibit will result in changes as to how well the exhibit facilitates successful visits by visitors of a given type. This line of reasoning begs the question: can an individual immersion exhibit be designed to cater to all visitor types?

For purely economical reasons (of both space and funds), the idea of designing an exhibit that facilitates successful visits from all visitor types is tempting. However, it seems easy to predict how exhibit elements which may facilitate the border-crossing of some visitors may interfere with the completeness of the illusion perceived by other visitors. Ideally, all the exhibited objects should coherently support the representation in order to facilitate the immersion of the visitor (Belaën 2003), and clearly, if the attempt is made to implement one exhibit design that can cater to all visitor types, the choice and arrangement of the various exhibit elements is an important design consideration.

In this theoretical study I argue for a one-design-fits-all approach. Allen (2004) advocates such an approach but emphasises that it is critical to support the design process with a strong program of research and development (see also Schauble & Bartlett 1997). One of the benefits of empirical research is that it can provide valuable insights on the nature of visitor differences; insights that could contextualise and analyse these differences rather than celebrating them (cf. Macdonald 2007) or in other words, allow for the development of a design that accommodates various visitor types without compromising the possible experiences of each type. For example, Allen (2004) found empirical evidence that enhancing an exhibit's immediate apprehendability[3] increased the engagement of all types of visitors with the exhibit. Immediate apprehendability, Allen argues, depends on the prior knowledge of the museum visitor but can be considered a property of the environment to the extent that visitors share perceptions and conceptions. Allen thus provides empirical support for the theoretical idea that one exhibit design can cater to all visitor types. To exemplify my point: utilising founder notions or anchors to bridge the gap between the immersion exhibit microculture and the life-world culture of the distance visitor does not, according to Allen's findings, necessarily compromise the experience of the resonance visitor.

How Generalisable is the Notion of Border-Crossing in Science Exhibit Design?

In analysing the special class of immersion exhibits, I have interpreted the idea of border crossing rather extensively, taking the notion from curriculum design and applying it to the very local level of immersion exhibit design. This interpretation and application has merit, in my opinion, due to the nature of the immersion exhibit as a self-contained representation of a reference world which provides the visitor with a certain role in a certain setting, or, in a very true sense, a *culture*. The empirical findings on visitor reactions reported by Belaën (2003, 2005) and Dufresne-Tassé (2006) lend credit to this cultural perspective. Accordingly, I suggest that the idea of designing immersion exhibits to facilitate the border-crossings of a variety of visitors has considerable potential, regardless of the employed model (reconstitution, interpretation, or creation) or the level of visitor integration implemented in the exhibit. But what about other types of science exhibits?

The border-crossing idea was originally presented in a formal science education context. Aikenhead (1996) suggested that viewing science (and school science) as a subculture consisting of norms, values, beliefs, expectations, and conventional actions is more accurate than viewing it as an eternal 'truth', and that science education accordingly should treat the acquisition of science as the acquisition of a culture.

The border-crossing discussed by Aikenhead is thus the border-crossing between the life-world culture of a science learner and the subculture of school science in a classroom setting. This type of border-crossing obviously has a much wider perspective, both temporally and with regards to the content domain, than the brief border-crossing that takes place during the course of an interaction with one museum exhibit. It follows that the contribution of the border-crossing notion to science exhibit design in general (i.e., not just immersion-type exhibits) might fruitfully consider the exhibition as a whole, rather than single exhibits. Indeed, this is the case in a study of the interactive exhibition *A Question of Truth* which is analysed in terms of its culture-brokering characteristics (Aikenhead 2001). In this case study, perhaps, the full contribution as well as the original intention of the notion of border-crossing is applied to informal science education.

5.6 Conclusion

In this study I use education theory, namely the notion of cultural border-crossing, to analyse and synthesise design guidelines for a special exhibit form: immersion exhibits. Immersion exhibits lend themselves well to the idea of cultural border-crossing because they constitute microcultures in which the visitors are required to immerse themselves. The application of the notion of border-crossing to the design of immersion exhibits yields constructive and systematic ideas on how to create exhibits that appeal to a broad range of visitors, thus exemplifying the merit of applying education theory to a field which is to some extent still governed by tacit experience and professional know-how.

5.7 Notes

1. At the time of writing I was unable to locate research literature on adults' conceptions of invertebrates; thus visitors' conceptions of invertebrates are modelled on those of children.

2. To preserve the authenticity of the immersion exhibit, these screens could be placed close to the floor so as to not interfere with the vista of the forest floor scenario.

3. 'The quality of an [exhibit] such that people introduced to it for the first time will understand its purpose, scope, and properties

almost immediately and without conscious effort.' (Allen, 2004, p. S20).

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