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A Content-oriented Model for Science Exhibit Engineering

Marianne Foss Achiam*
Department of Science Education, University of Copenhagen, Øster Voldgade 3, Copenhagen 1350, Denmark

Recently, science museums have begun to review their educational purposes and redesign their pedagogies. At the most basic level, this entails accounting for the performance of individual exhibits, and indeed, in some cases, research indicates shortcomings in exhibit design: While often successful in prompting visitors to carry out intended actions, exhibits do not necessarily promote the intended interpretations of these actions among visitors. Here, the notion of *praxeology* from didactics research is suggested as a model to remedy this shortcoming. The suggested role of praxeology is twofold: as a means to operationalize the link between exhibit features and visitor activities; and as a template to transform scientists' practices in the research context into visitors' activities in the exhibit context. The resulting model of science exhibit engineering is presented and exemplified, and its implications for science exhibit design are discussed at three levels: the design product, the design process, and the design methodology.

Keywords: *Exhibit design; Informal education; Museum; Praxeology*

Introduction

In the present political climate, museums are increasingly being compelled to review their educational purposes, redesign their pedagogies, and account for their performances in order to justify their continued existence (Hooper-Greenhill, 2007). This review process entails accounting for all the institutional levels which determine the museum's educational efforts: from the macro-level of the mission statement to the micro-level of what takes place between the visitor and the individual exhibits (Welsh, 2005). Here, I address this last level.

Museum exhibitions and exhibits constitute open-ended or free-choice learning environments where exhibit interactions, learning outcomes, or both, are established

*Email: achiam@ind.ku.dk

by the visitor (Falk & Dierking, 2000). Although the potential of open-ended learning environments to empower learners with their own meaning making is compelling, designing such environments is not easy. Research shows that insufficiently supported open-ended learning environments within formal science education contexts may lead to students failing to substantially evolve explanations or theories, thereby retaining original misconceptions, failing to engage in reflective thinking and metacognition during inquiry, and failing to utilize evidence to develop coherent explanations (Land, 2000 and references therein). In the same way, there is evidence to suggest that mismatches occur between scientifically acceptable learning outcomes and realized learning outcomes in the open-ended learning environments that are museum exhibits. For example, Borun and Adams (1991) and Borun, Massey, and Lutter (1993) found that an interactive exhibit intended to address the so-called naïve notions about gravity in some cases seemed actually to teach the misconception. Kerrison and Jones (1994) found that after interacting with a science exhibit, primary school students tended to state the results of their interaction in ways that reflected their expectations rather than their actual experiences with the exhibit. Another study showed that based on their interactions with single exhibits, students visiting an interactive science centre constructed knowledge that was unexpected and not in accord with canonical science (Anderson, Lucas, Ginns, & Dierking, 2000). In an astronomy museum context, students were shown to construct unintended interpretations of an exhibit intended to show the seasons of the Earth (Falcão et al., 2004). Finally, two studies found that although learners interacted with science museum exhibits in the intended way, they did not necessarily construct the intended meanings from this interaction (Botelho & Morais, 2006; Mortensen, 2011).

Although these studies do not prove that mismatches between intended and observed learning outcomes occur universally in museum exhibits, they do provide evidence that such mismatches exist. And while open-ended learning environments by definition allow learners to make their own meaning of the displayed phenomena, exhibits that do not provide learners with the means to construct the intended scientific understanding lack what for most museums is a fundamental characteristic. Accordingly, the problem becomes: How can the exhibit design process be systematized and improved in order to optimize the fit between intended and observed learning outcomes?

Aim

I approach the problem of exhibit design using descriptive, empirical results to generate a normative, theoretical model. My lens is one of *science didactics*, which in the continental European tradition refers to the study of the dissemination of science content to certain groups of participants (Chevallard, 2007). Science didactics is based on the constructivist idea that the learner's mind is neither a blank slate nor a passive recipient of knowledge. Rather, this research approach designs educational situations based on an *a priori* analysis of learners' prior knowledge, capabilities, and the content in question. Insights gained from such research are implemented in the design of educational systems in order to achieve improved practice. This process is known as *didactical engineering* (Artigue, 2009). In the same way, I will describe and present a model of *exhibit engineering* that provides a systematic means to (1) describe an exhibit experience in terms of the science-related activities it is intended to promote among visitors and (2) 'translate' that description into a physical installation: the exhibit.

In the first section of the paper, I use the notion of *praxeology* to describe the features of exhibits as well as visitors' interactions with them. In the second section of the paper, I use the notion of praxeology in a normative or design-related way to create a template for exhibit design. Finally, in the third section of the paper, I discuss the process of transforming this template into an exhibit. These three steps result in a model of exhibit engineering.

The main audience for this paper is the museum education research community. This includes researchers in academia as well as the growing group of professionals who are employed in the research departments of museums. These professionals typically conduct and report research as well as implementing it in collaboration with the museum's exhibition department and are ideally positioned as mediators between theory and practice. It is thus my intention that the present paper contributes to the theorizing of museum education research as well as, perhaps through such mediators, its practice.

Describing the Features of Exhibit–Visitor Interactions

Theory

The interactions between a visitor and an exhibit may be described using three levels, those of *tasks*, *techniques*, and *technology* (Mortensen, 2011). A task is any challenge or assignment we perceive in our surroundings, while a technique is the way we accomplish that task. Our technology is our rationale for our technique: it is the means with which we understand the nature of a task and apply an appropriate technique. Together, a set of tasks, the corresponding techniques, and an overarching technology comprise a *praxeology*: a model of human activity (Chevallard, 2007). Figure 1 exemplifies the relationship between a museum exhibit and its corresponding praxeology.

The strength of *praxeology* is that it defines human practical activity (techniques) and mental activity (technology) as the direct consequence of the tasks that we perceive in our surroundings. In other words, the model operationalizes the link between features of our environment on the one hand and the things we do and think on the other. This can help us understand why a learning environment such as an exhibit engenders the outcomes it does; or conversely, why it does not.

Application

In the following section, I examine a case of exhibit–visitor interactions using praxeology. I exemplify how praxeology can describe both intended and observed

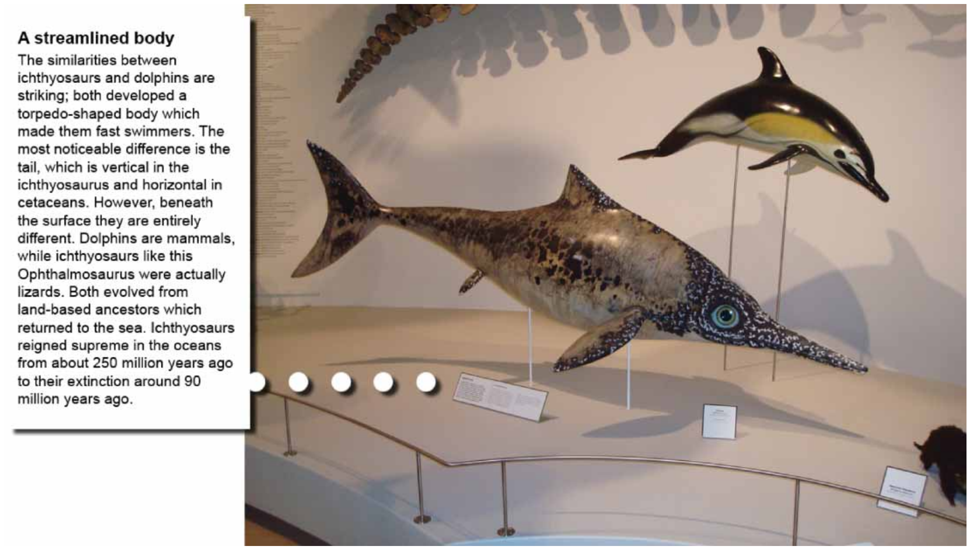

Figure 1 An exhibit about convergent evolution. What is the praxeology the visitor may experience based on this exhibit? Because the ichthyosaur and the dolphin are placed next to each other, the visitor is implicitly encouraged to compare them. The task in this exhibit could thus be for the visitor to perceive the similarities and differences between the ichthyosaur and the dolphin: the differences in the animals evolutionary lineage and the similarities in their shape. Which technique can the visitor use to do this? The similarities in the animals appearances may be seen by directly comparing them. The differences between them are more subtle; here, the exhibit text may be used. The visitor can read how the dolphin is a mammal while the ichthyosaur is a reptile. Which technology can these two practical activities precipitate? The visitor may rationalize their impressions thus: the two animals belong to two distinct evolutionary lineages (mammals and reptiles) and accordingly, their similarities in appearance are not the result of common descent. The two animals are adapted to a life in the sea, so their similarity in appearance could be the result of being subject to the same selection pressure, i.e. selection for swimming fast. The exhibit is part of an exhibition about evolution at the National Natural History Museum in Denmark. Photo: Marianne Achiam.

exhibit–visitor interactions and ultimately diagnose the mismatches between them. The description of the exhibit and the intended and observed learning outcomes are based on the study published by Botelho and Morais (2006); the reader is referred to this publication for additional information. Where unpublished data are referred to, this is indicated in the text.

The case presented here is the physics-based interactive exhibit 'The Hot Air Balloon' examined by Botelho and Morais (2006), located at the Knowledge Science Center in Lisbon, Portugal. The exhibit is based on Charles's Law, which states that assuming that pressure remains constant, the volume and absolute temperature of a quantity of gas are directly proportional: each 1°C temperature increase produces the same volume increase (Sternheim & Kane, 1991). Thus, heating up a gas also increases the volume of that gas, and if the pressure is unchanged, this will decrease the density of the gas, making it 'lighter'.

It will be useful to the reader to recall that when the air inside a hot air balloon becomes warmer than the ambient air, the expansion of the warm air forces some of the air out of the vent at the bottom of the balloon. The resulting decrease in density of the air inside the balloon causes the balloon to rise. Conversely, if the air inside the balloon is allowed to cool, it contracts, allowing more air to enter the balloon through the vent at the bottom. This increases the density of the air inside the balloon, causing the balloon to descend.

The exhibit The Hot Air Balloon consists of a non-expanding fabric balloon which is mounted on a stand bearing a heater. The bottom of the balloon is not sealed; this allows for the heating and venting of the air inside the balloon. A panel on the stand explains how to operate the exhibit in three steps: (1) press the red button to begin heating up the air inside the balloon, (2) wait until the temperature indicator on the panel shows 90°C, and (3) press the green button to release the balloon, which then moves upwards along a steel wire. The intended learning outcome of this interaction is the realization that the balloon goes up because the air inside it is heated and allowed to expand, thus achieving a lower density than the air outside; the balloon goes back down when the air inside it has cooled, contracted, and its density again gone up to the ambient level. The exhibit's features (or tasks), its intended interactions (or techniques), and learning outcome (or technology) are described in terms of praxeology as shown in Figure 2.

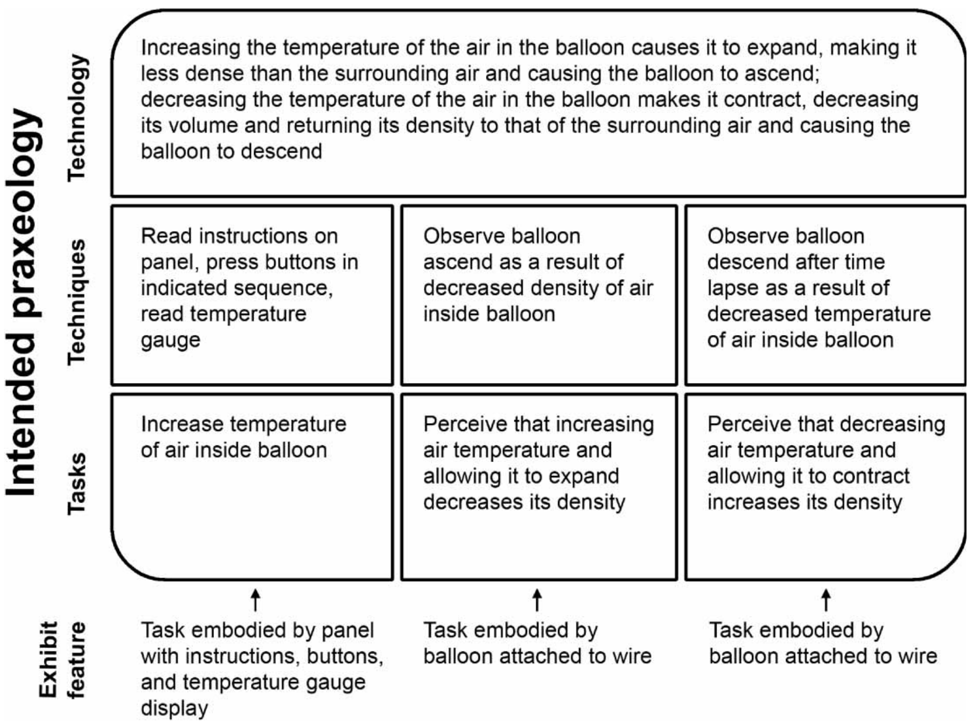

Figure 2 The intended praxeology embodied in the exhibit The Hot Air Balloon.

In their study of eight Portuguese seventh graders' interactions with the exhibit The Hot Air Balloon, Botelho and Morais found that all the students were all able to operate the exhibit using the correct procedures: they read the instructions on the panel, pressed the buttons in the indicated sequence to heat the air in the balloon, read the temperature gauge, and observed the balloon ascend and descend as a result. In other words, they were seemingly able to identify the tasks embodied in the exhibit, and to accomplish these tasks using the intended techniques. However, the students' interpretations of the events (their technologies) did not all reflect the intended learning outcome. When asked to choose between four explanations to explain why the balloon went up, seven of eight students chose the correct answer *the balloon goes up because the air inside is hotter than the air outside*. When asked to elaborate this answer, two students were able to provide an explanation involving the expansion of the air inside the balloon, e.g. 'the balloon goes up because the hot air inside the balloon expands, causing the balloon to be lighter than the air outside' (Miguel) (A. Botelho, personal communication, March 3, 2011). Two students explained that the hot air was lighter than the surrounding air, but did not invoke density, e.g. '[The heating of the air] makes it lighter than the remaining air, making it go up' (Sofia) (A. Botelho, personal communication, March 3, 2011). Finally, three students were not able to elaborate why the balloon ascended as a result of the heating of the air inside.

Explaining why the balloon went down, five students chose the correct answer *the balloon goes down because the air inside cools down*. However, none of these five students used the concept of contraction in the elaboration of their answer. Two students stated that the cooling of the air made it heavier, e.g. 'the cold air is heavier and makes the balloon go down' (Miguel) (A. Botelho, personal communication, March 3, 2011), and two students did not elaborate on the answer. Finally, one student gave an explanation which seemed at odds with her previous answer, namely 'the balloon went up there and hit the ceiling and began to go down' (Sara) (A. Botelho, personal communication, March 3, 2011).

The students' interactions with The Hot Air Balloon and their subsequent interpretations are summed up in Figure 3. This observed praxeology outlines the commonalities of the interactions and interpretations (techniques and technologies) realized by the students in their encounter with the exhibit.

Comparing the intended praxeology of The Hot Air Balloon with the observed praxeology (Figures 2 and 3) shows that they differ slightly from each other at the level of task and technique, leading to large divergences at the level of technology. In other words, although the students were doing what they were intended to be doing in terms of practical activities, they were not interpreting these actions in the intended way. This was because the exhibit's tasks were not clearly embodied in the exhibit. In particular, the second and third tasks in the intended praxeology, namely to perceive that heating and cooling air causes it in turn to expand and contract, are weakly embodied in the exhibit design in that there is no obvious way for visitors to observe air leaving or entering the balloon through the vents at the bottom. Coupled with the common conception of air as lacking matter or substance

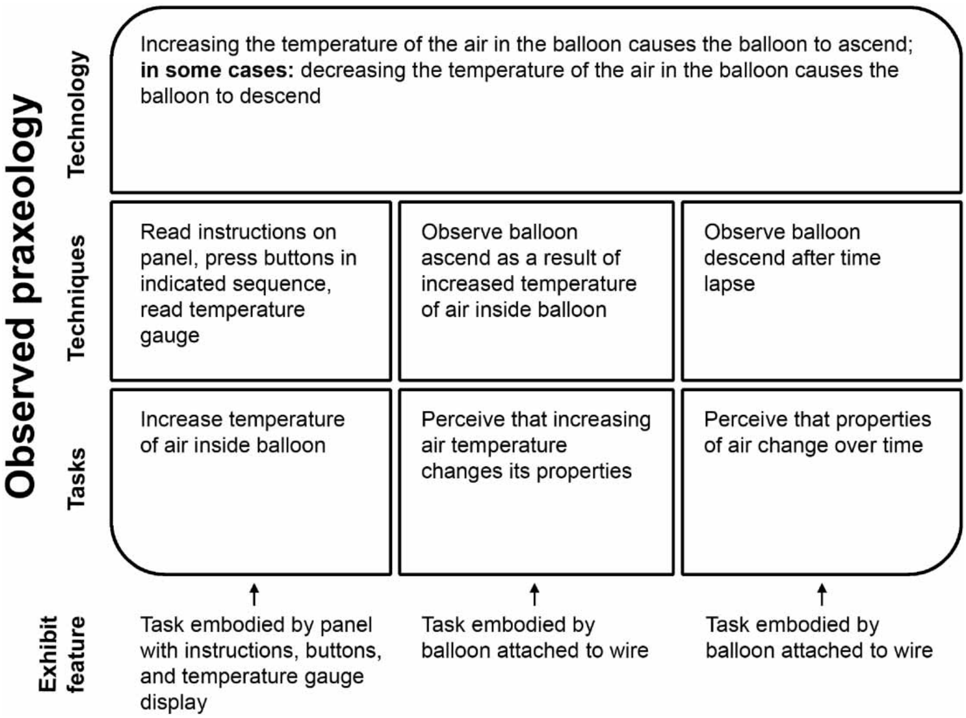

Figure 3 The observed praxeology realized by students visiting the exhibit The Hot Air Balloon.

(cf. Wiebe & Stinner, 2010), the observed interaction between the students and the exhibit constitutes a case of learners who, when lacking sufficient support for the construction of the intended technology, construct an alternative interpretation based on their own conceptions and experiences (cf. Land, 2000).

As shown in the preceding, using praxeology to describe science exhibits can clarify both intended and observed exhibit–learner interactions and ultimately diagnose the divergences between them. Having diagnosed such a divergence in the case of The Hot Air Balloon, I turn now to the problem of recasting the process of exhibit design in a way that can help generate strongly structured supports for visitors' construction of an appropriate interpretation.

Creating a Template for Exhibit Design

Theory

The introduction of praxeology has two implications for a model of exhibit engineering. First, as we have seen, praxeology is a means to link the embodiment of an educational situation with its learning outcomes in a coherent way. The second implication is related to the nature of the praxeology as an *answer to a question* (Chevallard, 2005). In this sense, the intended praxeology embodied by the exhibit The Hot Air Balloon (Figure 2) represents an answer to the question 'why does increasing the temperature of a gas make it lighter?' 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 a scientist in a research context: 'why does increasing the temperature of a gas make it lighter?' Using praxeology to design a situation thus suggests that the original (research) context that produced an object of knowledge may serve as a template for the design of an educational situation that aims to generate or re-produce the same object of knowledge in learners (Brousseau, 2002).

Thus, I argue that praxeology can model the milieu, actions, and reflections that produced a body of knowledge in the original research context and that this praxeology at the same time is a reference for the conditions required for a learner to re-produce that knowledge in an educational situation (see Barbé, Bosch, Espinoza, & Gascón, 2005 for an example). This idea is not new to the exhibition research community. Indeed, as Lewis (1980) 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?'. (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 engineering of an exhibit featuring that knowledge. More recently, Schauble (2002) 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. (p. 235)

And Bain & Ellenbogen (2002) 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. (p. 153)

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). Further, the concepts developed by researchers do not always map exactly onto the design parameters in the practical terms necessary for planning activities for museum visitors (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 embodiment process itself is described in the section entitled 'Transforming the template into an exhibit'.

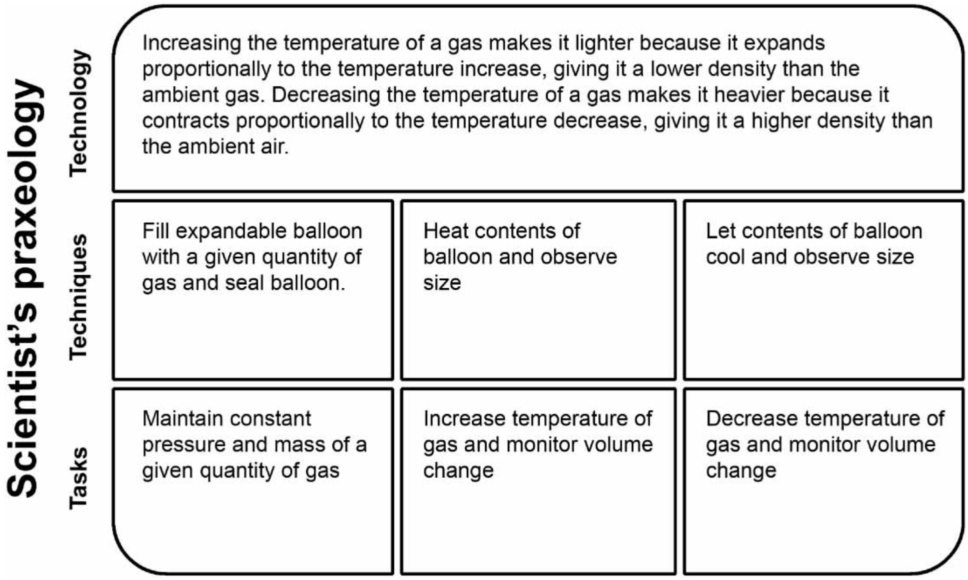

Figure 4 Jacques Charles praxeology, which eventually gave rise to Charles Law or the law of volumes.

Application

What are the original scientist's actions and reflections in the case of the exhibit The Hot Air Balloon? The praxeology in question is that of the French physicist Jacques Charles (1746–1823), to whom Charles' Law is attributed. Briefly, Charles conducted a series of experiments using expandable balloons. He filled five balloons with different gases to the same volume. He then increased the temperature of the balloons and observed that all five balloons increased in volume by the same amount. From this series of experiments, he essentially derived the law of volumes or Charles' Law, although it was only published after his death (Gay-Lussac, 1802). Charles' praxeology is summed up in Figure 4.

It is immediately apparent from Charles' praxeology that the tasks of perceiving the increase and decrease of the volume of the air in the balloon are clearly embodied in the expandable balloons used in the experiment. Thus, taking the scientist's praxeology into account can pinpoint the conditions and obstacles which characterize the pursuit of answers to certain scientific questions, and these conditions and obstacles can inform the engineering of exhibits that aim to re-create such scientific pursuits among learners (*knowledge archaeology* as discussed by Foucault, 1969/1972). In the following section, I explain how the template of the scientist's praxeology can be transformed and embodied in a physical exhibit.

Transforming the Template into an Exhibit

Theory

The procedure of physically embodying scientific content in an exhibit has been described as a process of *museographic transposition* (Simonneaux & Jacobi, 1997): a systematic deconstruction and reconstruction of content matter in order to express it according to the specifics of a given exhibit type (Mortensen, 2010b). The process can be divided into two distinct phases. The first phase is characterized by the dialectical development of exhibit content and exhibit form and results in the curatorial brief, which translates the chosen content into the specifications appropriate for the work at hand (Miles, 1988). The second phase, *execution* (Gouvêa de Sousa et al., 2002), is characterized by the physical installation of the exhibit in space. This phase involves a modality change from the text of the curatorial brief to the three-dimensional installation of the exhibit (Mortensen, 2010b).

In extension of the arguments presented in the preceding, I suggest we think of the content undergoing the transposition process as a praxeology rather than just as an object of knowledge. The first phase of transposition then becomes critical in deconstructing and reconstructing the scientist's praxeology in relation to the chosen exhibit form in order to create what we could call the *tentative praxeology* in the curatorial brief. The second phase of transposition transforms the tentative praxeology in the curatorial brief into the praxeology physically embodied in the exhibit or, indeed, the intended praxeology (Figure 5) (Mortensen, 2010a).

The first phase of museographic transposition. In the first phase of transposition, the development of the content may be described as a process of *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, 'problem' refers to the practical activities at the core of the desired learning as well as the rationales for them. In other words, what should be framed in this process are the key tasks in the scientist's praxeology and the interpretations that they engender.

Due to its content-specific nature, it is difficult to generalize 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, &

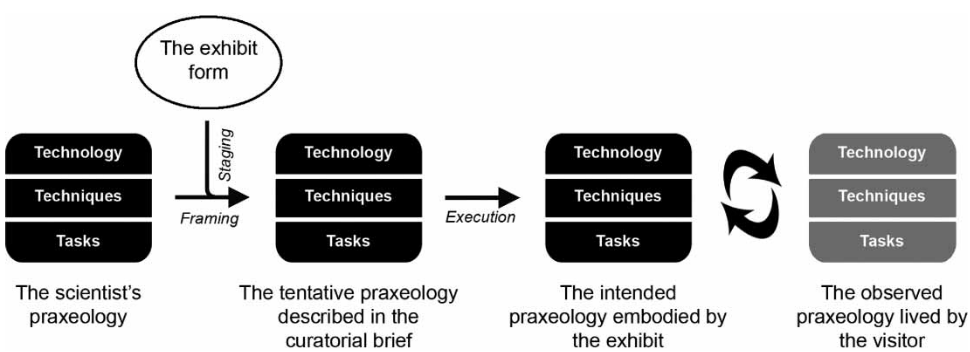

Figure 5 The model of exhibit engineering.

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. For an exhibit to be educationally appropriate, the framing of its content should consider visitors' existing conceptions about the content (Borun et al., 1993; Schauble & Bartlett, 1997).

Concurrently with the process of framing, a development of exhibit form takes place. This process ideally involves a review of the pedagogical ends and means of the chosen exhibit type 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 an environment which incorporates problem situations that can stimulate the intended experience (cf. Ruthven et al., 2009). The nature of these 'problem situations' is of course determined by the chosen exhibit type; for example, for a hands-on exhibit, the problem situations must be expressed in terms of hands-on activities.

Clearly, clarifying the pedagogical means and ends of the chosen exhibit form or type is important to the successful staging of content. Much exhibit engineering takes place without due consideration of the dialectic between the scientific content and the exhibit form (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 a given exhibit form or type and what types of activities and reflections it can realize among visitors is an important prerequisite to choosing the optimal exhibit form for a certain content-to-be-taught (Afonso & Gilbert, 2007). In a larger perspective, a systematic classification of the main exhibit types, continuing and expanding the work on interactive exhibits begun out by Gilbert and Stocklmayer (2001), would be of great service to the museum community.

The second phase of museographic transposition. The second phase of transposition, or execution, marks the physical implementation of the tentative praxeology from the curatorial brief into the three-dimensional exhibition environment. At this point, the curatorial brief should provide the framework for the exhibit development, leaving scope for creative work during the implementation (Miles, 1988). While this scope is a condition for exhibit engineers to exercise due creative license, it also entails certain risks, for example the relaxation of *epistemological vigilance* (cf. Chevallard, 1991; see Mortensen, 2010a for an example). In other words, the curatorial brief should provide sufficient guidance that the exhibit engineers do not lose sight of the scientific content, yet leave room for the engineers to utilize their professional resources and inspiration. How, then, can the execution process be conceptualized in a way that leaves room for creative development while adhering to the specifics of the content and form set out in the curatorial brief?

The process by which a learner appropriates or re-creates a praxeology takes place in a *didactic process* which is conceptualized in six moments (see Barbé et al., 2005 for a translation; Chevallard, 1999). The first moment is the first encounter, in which the learner meets the scientific content, 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 technology to explain 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 praxeology. This step is linked to the sixth evaluation moment in which the learner examines the value of what has been done (Chevallard, 1999). The six moments are not defined in a chronological or linear sense, but rather as different aspects of the scientific activity (García, Gascón, Higueras, & Bosch, 2006).

I suggest that viewing the execution phase as the work of mobilizing the tentative praxeology in the curatorial brief *via the framework of the didactic process* into a praxeology embodied in the three-dimensional exhibition environment can promote epistemological vigilance and create more coherent and integral 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 operationalize the praxeology in the curatorial brief in terms of visitors' stepwise interactions and interpretations, the risk of 'short-circuits' in the implementation of the exhibit is minimized.

Application

The following section exemplifies how the notions of framing, staging, and execution can be applied in a theoretical design iteration of The Hot Air Balloon. It is not an attempt to second-guess or criticize the creators of an exhibit which is successful in its own right, but rather to use the case to illustrate how the work presented here can inform the decisions made in exhibit engineering.

The first phase of museographic transposition: framing and staging. Taking Jacques Charles' praxeology (Figure 4) as the point of departure, the first task is to establish a given quantity of gas and to maintain that gas under constant pressure. An important point to consider in the framing of this task is the aforementioned commonly held conception of air as being non-material (Wiebe & Stinner, 2010). Any problem that attempts to illustrate points about the material nature of air (such as pressure, density, and volume) should ideally address this conception.

Staging this activity entails considering the pedagogical specifics of the chosen exhibit form-in this case, the interactive exhibit. Dicks, Soyinko and Coffey (2006) suggest that interactive exhibits primarily mediate mechanical, practical, and applied science through the mechanism of human-initiated physicality. Accordingly, staging the first task of the praxeology should focus on providing the visitor with a physical assignment that results in a reaction in the exhibit.

Through the processes of staging and framing, we arrive at a suggestion for the first task of the tentative praxeology: an activity in which the visitors themselves cause air to enter into an expandable balloon and close off the balloon when they are done. This activity would emphasize the critical fact that a quantity of *something* (air) was entering the balloon, and the fact that this quantity was being held constant.

Consider now the second task of Charles' praxeology, namely to increase the temperature of the gas inside the balloon and monitor the volume of it (Figure 4). This activity is at the core of the desired learning outcome, and its framing should ensure that it is strongly embodied in the tentative praxeology. In the process of staging, we could once again take advantage of the fact that interactive exhibits primarily communicate meaning through action–reaction sequences (Dicks et al., 2006) and that visitors to science centres are aware of this and indeed expect it (Falk, Scott, Dierking, Rennie, & Cohen Jones, 2004). Providing the visitor with a means to heat up the air inside the balloon would probably, with very little prompting, direct them to observing the balloon to see what happens.

The staging and framing suggestions I make here are not exhaustive, but they do illustrate how an activity from the original 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 phase of transposition (Figure 5). The suggested activities not only emphasize key variables of the exhibit experience (cf. Land, 2000), they are also structured around a rationale because the transposition of praxeology, rather than content, ensures the transposition of the rationale for those activities. This shows how the strong link between the levels of practical and mental activity in a praxeology can provide the basis for epistemological vigilance in the transposition process.

The second phase of museographic transposition: execution. The second phase of transposition, or execution, consists of the physical implementation of the exhibit outlined in the curatorial brief. This process entails a creative embodiment or concretization of the tentative praxeology into an intended praxeology, using the didactic process as a guideline. Recall that the first moment in the didactic process is the first encounter. In a classroom-based 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.

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. Based on the relative ease with which participants recognized and operated the existing exhibit The Hot Air Balloon (cf. Botelho & Morais, 2006), executing the tasks in the tentative praxeology along roughly the same lines as the existing exhibit would make sense, although with a strong focus on embodying the pertinent aspects of the tentative tasks. Thus, the visitor's first encounter with the redesigned Hot Air Balloon exhibit could be introduced with a title formulated along the lines of 'Can you make your own hot air balloon fly?' The chosen title could be boldly displayed on the exhibit to establish the nature of the experience-to-come. In addition, the presence of balloons made by previous visitors would help visually amplify the meaning of the exhibit (cf. Land, 2000).

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 the first task from the tentative praxeology in the curatorial brief, namely the activity in which the visitors cause air to flow into an expandable balloon and close off the balloon when they are done. It is important that this activity (as well as the following ones) is sufficiently motivating in itself that the visitor chooses to continue to invest time in the exhibit (Allen, 2004). The task should thus be embodied with immediately apprehendable controls: air valves, taps, and balloons. Continued exploration leads the visitor to the second task of the tentative praxeology, namely that of heating the air in the balloon and monitoring the volume. As discussed in the preceding, providing the visitor with apprehendable means to do this would be sufficient to promote their further attention, as the expansion of the balloon would serve as a reaction to the visitors' actions. Providing visitors with miniature harnesses and gondolas for their balloon could serve to further hold their interest.

Of course, these descriptions are just suggestions as to how the activities 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.

Consider now the third moment in the didactic process: The emergence of an interpretation of the practical activities carried out by the learner. Here, it may be useful to review the rationales for the practical tasks in the scientific practice and the curatorial brief. For example, why did Jacques Charles fill balloons with a given quantity of gas (Figure 4, first task/technique)? Because he needed to keep pressure and mass constant in order to see what effect varying the temperature would have. Which activity in the tentative praxeology does this correspond to? It corresponds to when the visitor causes air to flow into an expandable balloon and closes off the balloon when they are done. And finally, does the physical execution of this activity allow the visitor to perceive that the quantity and pressure of the air in their balloon is constant? If the exhibit is successful, the answer is yes: The visitor is able to generate a partial explanation or interpretation of their practical activities which is in accordance with the stated learning goals of The Hot Air Balloon.

Recall that 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 the exhibit. Studies suggest that visitors rarely return to an exhibit they have already engaged with (Bitgood, Patterson, & Benefield, 1988). This could imply that the physical design of an exhibit should address visitors who will interact with it only once. That is, it should be possible for visitors to 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 is 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 content 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.

As mentioned in the preceding, in the sixth moment of the didactical process, the visitor evaluates the lived 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 lived praxeology may entail comparing it with other, related praxeologies and assessing their commonalities and differences. In a museum context, related praxeologies could be 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.

Summary

The preceding account has illustrated how the model of exhibit engineering (Figure 5) can be applied to content from the discipline of physics to guide the museographic transposition of this content into an interactive 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. Furthermore, I have not accounted for the multitude of alternative meanings visitors in an open-ended learning environment may make of the exhibit. My errand has simply been to address the issues of how to deconstruct and reconstruct knowledge in a way that maintains epistemological vigilance and ensures the development of a coherent educational milieu. In the following, I offer a reflection on the implications of the model.

Discussion

The development of the model of exhibit engineering took its starting point in the notion of praxeology. Praxeology was used to address the problem of mismatches between the intended and observed learning outcomes of visitor interactions with exhibits. In this perspective, the main contribution of praxeology is probably its role of sensitizing museum researchers and professionals to critical issues regarding the outcomes of the design undertaking, rather than its ability to define a particular course of action (Ruthven et al., 2009).

How widely can the notion of praxeology be generalized? The central idea of praxeology, namely that neither activities nor reflections 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) emphasize 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 realization that practical and mental activities go hand-in-hand in the process of knowledge construction is also reflected in studies here. For example, Feher's (1990) 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 realizations. Thus, it seems there is a need for a coherent and systematic means of expressing or characterizing desired visitor learning outcomes and the trajectories that can lead to them in exhibit research. I suggest that praxeology constitutes this means.

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 to create or promote actions and reflections among museum visitors that are transposed versions of the original researcher's actions and reflections. Is the original researcher's praxeology the only praxeology that can be used as a template for a museum exhibit that intends to mediate certain content? 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!

Finally, I have suggested the process of museographic transposition with its subprocesses of framing, staging, and execution as a design methodology that lays out a sequence of tasks and describes the objectives and processes for each step of developing an exhibit. In essence, the methodology I advocate can be characterized as a didactic approach in the continental European sense. Clément (2000) emphasizes that the problems relevant to the didactics of a science are those that are focused on the dissemination of that science, not only 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 physics exhibit development to be a case of physics didactics. Although I concur that a content-oriented approach is necessary for the development of successful exhibits, in a sense this is bad news for museum researchers and professionals alike 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 content, the specifics of the exhibit type, and the corresponding public dissemination of scientific culture (Clément, 1991). This may seem a daunting prospect. 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.

Concluding Remarks

I have described, presented, and argued the merits of a didactics-derived model of exhibit engineering as a systematic means to construct museum exhibits as educational environments. However, designed educational situations are the products of many influences beyond theoretical design models (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 instance of exhibit engineering is subject to – and should be subject to – museum professionals' craftsmanship, instincts, and knowledge about good exhibits. These influences contribute enormously to the visitors' open-ended experiences and are not addressed by the model presented here. However, the model of exhibit engineering can provide new content-related or context-related insights that have the potential to systematically improve design efforts. As such, it may be seen as a framework which addresses a broader class of phenomena, namely science exhibit engineering, and which is customizable to specific contexts.

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