Learning science from museums

Museus e o aprendizado da ciência

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This article provides an overview of current understandings of the science learning that occurs as a consequence of visiting a free-choice learning setting like a science museum. The best available evidence indicates that if you want to understand learning at the level of individuals within the real world, learning does functionally differ depending upon the conditions, i. e., the context, under which it occurs. Hence, learning in museums is different than learning in any other setting. The contextual model of learning provides a way to organize the myriad specifics and details that give richness and authenticity to the museum learning process while still allowing a holistic picture of visitor learning. The results of a recent research investigation are used to show how this model elucidates the complex nature of science learning from museums. This study demonstrates that learning from museums can be meaningfully analyzed and described. The article concludes by stating that only by appreciating and accounting for the full complexities of the museum experience will a useful understanding of how and what visitors learn from science museums emerge.

KEYWORDS: free-choice, learning, science, museum, visitors.

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Este artigo oferece uma visão geral das maneiras pelas quais se concebe o aprendizado da ciência associado a visitas a museus que operam como ambientes onde é possível a livre escolha do que se vai aprender. As melhores evidências indicam que se se quiser compreender o aprendizado no nível de indíviduos inseridos no mundo real, o aprendizado difere funcionalmente conforme as condições, isto é, o contexto em que ocorre. Assim, aprender em museus não é a mesma coisa que aprender em qualquer outro ambiente. O modelo contextual de aprendizado fornece meios de organizar um sem-número de detalhes que confere riqueza e autenticidade ao processo de aprendizado em museus, sem impedir uma apreensão holística de parte do vistante. O presente artigo procura demonstrar que, somente quando levamos em conta a complexidade da experiência museal, alcançamos a verdadeira compreensão do que aprendem os visitantes a respeito da ciência, e de como o fazem.

KEYWORDS: livre escolha, aprendizado, ciência, museus, visitante.

As a consequence of visiting a science museum, the public learns science – easy to state, harder to prove! Learning is such a commonly used concept that it would seem that it should be reasonably straightforward to document. However, as those who investigate learning have come to appreciate, learning is common but definitely not straightforward, particularly if one is trying to understand and document free-choice learning – the learning that occurs when individuals have considerable choice and control over what, where, when and how they learn.

Over the years, providing compelling evidence for learning from museums has proved challenging and we are not going to suggest otherwise. Lynn Dierking and one of us (Falk, 1999; Falk and Dierking, 1995, 2000, 2002) have suggested that this is not because the evidence does not exist but rather because museum-learning researchers, museum professionals, and the public alike have not always asked the right questions or investigated museum learning using appropriate measurement tools. The result has been a search for inappropriate evidence of learning, using flawed methodologies.

The most common error was basing investigations of museum learning on school-based models, most of which were predicated on the now largely discredited behaviorist, stimulus-response model of learning. In this traditional view – what psychologists now call the absorption-transmission model (Roschelle, 1995; Hein, 1998) – individuals are assessed to determine whether they have learned specific, predetermined information. This model can be characterized as follows:

> Topic X is presented to a learner either in the form of an exhibition, demonstration, lecture, text, program, film, or immersive experience. Learning is determined by measuring the positive change in the amount of topic X the individual absorbs.

This is the model of learning all of us grew up with; it is simple, straightforward, and seems on the surface totally reasonable. However, this model makes a number of leaps of faith, particularly within the context of museum learning. Just to name a few, it assumes that the learner is predisposed intellectually, emotionally, and motivationally to learn topic X; it assumes that the individual actually attended to topic X (which in a museum is a huge assumption); it assumes that topic X was presented in a form that was commensurate with learning within the limited time and attention constraints of a typical museum experience; and it assumes that change in understanding is always measurable as a quantitative addition of information.

The reality of science learning from museums is much more subtle and complex. If the public does not necessarily learn what we set out to teach them, what does the public learn? It is not that the public does not learn what we intend for them to learn; it is just that the nature of learning in museums is rarely as straightforward as we intend, i. e., that the visitor will learn X and thus does so. Given the free-choice nature of museum experiences, visitors very selectively pick and choose what they want to learn more about, and these decisions are very strongly influenced by what they already know and are interested in. Thus, trying to measure a phenomenon that is very idiosyncratic and highly variable from individual to individual is challenging and requires different approaches and tools than those used to assess learning in settings like schools.

Thomas Krakauer, a science museum director in the U.S., once jokingly said, "We teach people what they almost already know". He may have been joking but he was actually quite close to the truth. Most of the time, the museum-visiting public learns about things that they 'almost' already knew or that they once knew and now 'relearn'. The public comes to science museums with a range of prior understandings, collections of ideas and concepts, most of which are semi-formed and incomplete. Some visitors know quite a bit before arriving, most know relatively little; virtually all are very interested (Falk and Dierking, 2000). Visitors utilize the museum experience to confirm their understandings and shore up their ideas and concepts. Quality museum presentations make this confirmation and shoring-up process easy for visitors; poor museum presentations make this effort more difficult. Whether easy or difficult, though, this is the process the visitor engages in when he or she visits the museum. For example, during a recent investigation of a space science exhibition at the Pacific Science Center in Seattle, in which clever interactives and elegant visuals communicated principles of size and scale to visitors in new ways, one man summarized this very common phenomenon when he said, "I always knew Jupiter was bigger than the Earth, I just never realized how big!" (Dierking, 1999).

So what then is an appropriate model for understanding the nature of learning within a complex, free-choice setting like a science museum?

Towards a usable model for understanding learning from museums

It is human nature to desire simple explanations for complex reality. For example, as presented in a book one of us (Falk) recently read (Hagen, 1997), a physician described how during his days in medical school he was constantly overwhelmed with the quantity of information. He said some teachers could package the information very simply. "Here, this is what you need to know." Medical students loved those teachers, he said. But there were other teachers who always offered two or more (often contradictory) perspectives on things. This the students hated. "It involved more work on our part", said the doctor. "Who wants to be told that some people think this, and some people think that? It was so much easier just to be told what is what." But, he said, as the years went by and he became more and more experienced as a doctor, he realized that the concise, neatly packaged views were wrong. The teachers had chopped off all the rough edges that didn't fit into the system. In the end, the simplest solutions were not always the best solutions.[1]

For better or for worse, it is our opinion that learning is a phenomenon of such complexity that a truly simple model or definition will not result in a sufficiently realistic and generalizable model. You can only simplify the complexities of learning so much before they become less than useful. Consequently, what our colleague Lynn Dierking and one of us (Falk) have proposed is not really a definition of learning but a model for thinking about learning that allows for the systematic understanding and organization of complexity. The Contextual Model of Learning is an effort to simultaneously provide a holistic picture of learning while accommodating the myriad specifics and details that give richness and authenticity to the learning process (Falk and Dierking, 2000).

In this article we are focusing on the learning that occurs from museums. This turns out to be important because the where and why of learning does make a difference. Although it is probably true that at some fundamental, neurological level, learning is learning, the best available evidence indicates that if you want to understand learning at the level of individuals within the real world, learning does functionally differ depending upon the conditions under which it occurs. Hence, learning in museums is different than learning in any other setting by virtue of the unique nature of the museum context; and at some important level, learning in a museum in Rio is likely to be different than learning in a museum in Recife. Although the overall framework we are about to suggest should work equally well across a wide range of learning situations – compulsory school-based learning as well as museum-based free-choice learning – the specifics only apply to museums. In the final analysis, if you want to truly understand how, why, and what people learn in places like science museums, specificity is essential. There is no simple, stripped-down, a-contextual framework for understanding learning. Learning is highly situated.

Learning is a dialogue between the individual and his or her environment through time. Learning can be conceptualized as a contextually driven effort to make meaning in order to survive and prosper within the world. The contextual model of learning

[1] Excluded from the current analysis were subsequent reinforcing experiences. We excluded these from this phase of the research since we were only measuring short-term learning – learning while still in the museum. A second phase of this research, currently in progress, involves re-contacting a majority of the visitors initially interviewed one to two years subsequent to their visit. We hope that this second phase will enable us to include this variable in future analyses.

portrays this contextually driven dialogue as the process/product of the interactions between an individual's 'personal', 'sociocultural', and 'physical' contexts. None of these three contexts are ever stable or constant; all are changing across the life time of the individual.

What we call 'personal context' represents the sum total of personal and genetic history that an individual carries with him or her into a learning situation. Specifically, one should expect new learning to be scaled to the realities of an individual's motivations and expectations, which in the case of museums normally involve a brief, usually leisure-oriented, culturally defined experience. One should expect learning to be highly personal and strongly influenced by an individual's past knowledge, interests, and beliefs. One should expect learning to be influenced by an individual's desire to both select and control his or her own learning.

Humans are extremely social creatures; we are all products of our culture and social relationships. Hence, one should expect museum learning to be socioculturally influenced: by the upbringing and culture of the individual, by the interactions and collaborations within the visitor's own social group, as well as potentially by interactions with others outside the visitor's own social group, for example, museum explainers, guides, demonstrators, or performers.

Finally, learning always occurs within the physical environment; in fact it is always a dialogue with that physical environment. Thus, one should expect visitors to react to exhibitions, programs, and Web sites in a voluntary, non-sequential manner, as informed by orientation and organizational cues provided by the setting. One should expect that a myriad of architectural and design factors including lighting, crowding, presentation, context, and the quantity and quality of the information presented affect the nature of the learning that goes on. Finally, one should expect that learning from museums will not only rely on the confirmation and enrichment of previously known intellectual constructs but equally depend upon what happens subsequently in the learner's environment. Learning is not an instantaneous phenomenon but rather a cumulative process of acquisition and consolidation. Thus, experiences occurring after the visit frequently play an important role in determining, in the long-term, what is actually 'learned' in the museum.

A key understanding that flows from this perspective is an appreciation that finding and documenting learning in museums requires setting aside the expectation that learning will necessarily follow a totally prescribed and predictable course. In other words, well-thought out exhibitions and programs can facilitate visitor learning along predetermined pathways, but the learners themselves need to be given an opportunity to help reveal the nature and character of their own learning. Methodologically, this means that expectations that individuals will learn a specific concept or idea need to be tempered; individuals may learn specific concepts and ideas and they may not – but invariably they will learn something. More typically, visitor learning follows two parallel pathways: the learning of global ideas – for example, that science is fun or that there are an amazing number of different kinds of plants and animals in the world – and the learning of very specific but usually idiosyncratic facts and concepts – for example, moving your arms and legs in and out in a gyroscope chair affects how fast you spin or that Amazon dolphins use echolocation to find prey items in the muddy waters of the Amazon. Determining the depth and breadth of visitor learning becomes the challenge of the investigator, as well as what specific variables most significantly contribute to the learning of different types of visitors. Everyone in the process needs to understand and respect that, in the end, what individuals learn depends not only upon the content of the exhibitions and programs but equally upon visitors' prior knowledge, experience, and interest and what they actually see, do, talk, and think about during the experience. Also important is what happens subsequently in visitors' lives that relates to these initial experiences. More so than we have historically believed, all of these factors matter tremendously, and all are different for each person.

Eleven key factors that influence learning from museums

The contextual model of learning provides the large-scale framework with which to organize information on learning; inside the framework hang the details. These details are myriad. The total number of factors that directly and indirectly influence learning from museums probably number in the hundreds, if not thousands. Some of these factors are apparent and have been summarized previously (Falk and Dierking, 2000); others are either not apparent or are not currently perceived by us to be important. After considering the findings from hundreds of research studies, eleven key factors – or, more accurately, suites of factors – emerged as fundamental to museum learning experiences, and directly amenable to study and manipulation. These eleven factors are:

Personal context

1. Motivation and expectations
2. Prior knowledge and experience
3. Prior interests and beliefs
4. Choice and control

Sociocultural context
5. Within-group social mediation
6. Facilitated mediation by others

Physical context
7. Advance organizers
8. Orientation to the physical space
9. Architecture and large-scale environment
10. Design of exhibits and content of labels
11. Subsequent reinforcing events and experiences outside the museum

Individually, and collectively, these eleven factors significantly contribute to the quality of a museum experience, though the relative importance of any one of these factors may vary between particular visitors. When any of these eleven are not supported, meaning-making is more difficult. What follows is a brief summary of each; for greater detail see Falk and Dierking (2000).

Motivation and expectations – People go to museums for many reasons and possess predetermined expectations for their visit. These pre-visit motivations and expectations have been referred to as the visitor's 'agenda' (Falk and Dierking, 1992). A visitor's agenda directly affects what a person does and learns during a visit. Usually the public's agendas are closely matched to the realities of the museum experience, but not always. When expectations are fulfilled, learning is facilitated. When expectations are unmet, learning suffers. Intrinsically motivated learners tend to be more successful learners than those who learn because they feel they have to. Museums succeed best when they attract and reinforce intrinsically motivated individuals.

Prior knowledge and experiences – Prior knowledge and experience play a tremendous role in all learning. All learning is filtered through the lens of prior knowledge and experience. Thus the meaning that is made of museum experiences is, by necessity, framed within and constrained by prior knowledge and experiences. Because of the constructed nature of learning and the heterogeneous nature of museum-visiting populations, the prior knowledge and experience of museum visitors varies widely across and even within museums. Since no two visitors will ever possess the exact same prior knowledge and experience, learning in museums is always highly personal and unique.

Prior interest – By virtue of their prior interests, learners actively self-select what and when to learn. Within the museum context, prior interest affects whether to go to a museum or not, which type of institution to visit, what exhibitions to view or programs to participate in, and which aspects of these experiences to attend to, and, literally, what's worth learning. At a very fundamental level, in the absence of appropriate prior interests, no one would ever go to museums and no one would ever learn anything there even if they did. The vast diversity of visitor interests is a major contributor to the highly personal and unique nature of learning from museums.

Choice and control – Learning is at its peak when individuals can exercise choice over what and when they learn, and feel like they control their own learning. Museums are quintessential settings for allowing free-choice learning; they more often than not afford visitors abundant, appropriate opportunities for both choice and control. When museums try too hard to mimic compulsory education or force specific learning agendas on the public they undermine their own success and value as learning institutions. Like many of these factors, choice and control are affected by other factors, for example, a visitor's agenda and the nature of the visitor's social group composition.

Within-group social mediation – The vast majority of visitors go to museums as part of social groups – groups with histories, groups which separately and collectively form communities of learners. Parents help children understand and make meaning from their experiences. Children provide a way for parents to see the world with 'new' eyes. Peers build social bonds through shared experiences and knowledge. All social groups in museums utilize each other as vehicles for deciphering information, for reinforcing shared beliefs, for making meaning. Museums create unique milieus for such collaborative learning to occur, and as a consequence collaborative exchanges influence the nature and quality of the resulting learning.

Facilitated mediation by others – Socially mediated learning does not only occur in museums within an individual's own social group; powerful socially mediated learning can occur with strangers perceived to be knowledgeable. Such learning has long evolutionary and cultural antecedents. Consequently, few other museum experiences afford as much potential for significantly affecting visitor learning. Many such interactions occur with museum explainers, docents, guides, and performers and they can either enhance or inhibit visitor learning experiences. When skillful, the staff of a museum can significantly facilitate visitor learning.

Advance organizers – A wide range of studies have shown that people learn better when they are informed, prior to a learning experience, about the 'big ideas' or conceptual 'messages' of the experience. Visitors assume that the designers of the museum were trying to communicate something to them; they appreciate knowing 'what is expected of them'. Providing these conceptual advance organizers significantly improves people's ability to construct meaning from experiences by providing the intellectual scaffolding on which to hang the ideas they encounter.

Orientation to the physical setting – Study after study has shown that people learn better when they feel secure in their surroundings and know how to successfully navigate through the physical space. Museums tend to be large, visually and aurally novel settings. When people feel disoriented, it directly affects their ability to focus on anything else; when people feel oriented in museum spaces, the novelty enhances rather than diminishes learning.

Architecture and physical space - People are always aware, even if sometimes only subconsciously, of their physical surroundings. The temperature, size, crowdedness, novelty, and even the color of the setting can influence how and how much a person learns. Museums tend to be architecturally unique places that most people only visit rarely. For both of these reasons awareness of space is particularly acute.

Design – Whether exhibitions, programs, or Web sites, learning is influenced by design. Exhibitions, in particular, are design-rich educational experiences. People go to museums to see and experience real objects, placed within appropriate environments. Two-dimensional media they can see elsewhere, computer terminals they can find elsewhere, text they can read elsewhere; not so in the case of authentic, real 'stuff' placed within meaningful settings. Appropriately designed exhibitions are compelling learning tools – arguably one of the best educational mediums ever devised for facilitating concrete understanding of the world.

Subsequent reinforcing events – Learning does not respect institutional boundaries. People learn by accumulating understanding over time, from many sources in many different ways. Learning from museums is no exception. The public enters the museum with understanding, leaves (hopefully) with more, and then makes sense of this understanding as events in the world facilitate and demand that understanding. In a very real sense, the knowledge and experience gained from museums is incomplete; it requires enabling contexts to become whole. More often than not, these enabling contexts occur outside the museum walls, weeks, months, and often years later. These subsequent reinforcing events and experiences outside the museum are as critical to learning from museums as are the events inside the museum.

Preliminary results from a recent research study help to demonstrate how this model can be applied to better understanding both the processes and products of science learning from museums.

Investigating the contextual model of learning: the Californian Science Center's World of Life Exhibition

With support from the American National Science Foundation, we recently set out to use the contextual model of learning as a framework for better understanding the nature and extent of science learning from a museum (Falk and Storksdieck, 2001; in prep). We began with the assumption, based as previously stated on an extensive review of the literature, that all of the eleven key factors described above dramatically affect visitor learning. However, it was not known to what extent each of these eleven variables contributed to learning outcomes, nor was it known how, if at all, these variables interacted. At various times, a wide range of authors have made a case for one of these variables being 'the' critical variable. Never before had anyone attempted to directly measure all of these variables simultaneously. Although we have asserted that all are important, perhaps it was true that one or two of these variables are more important than the others. In other words, can one or more of these variables explain most of the short-term (i. e., immediate) variance related to science learning from a science center exhibition? Or, alternatively, did none of these variables, individually, explain much of the variance? This research study was intended as a first attempt towards answering these questions. In particular, three of the questions posed by this study were: 1) How do specific independent variables individually contribute to learning outcomes? 2) How do collections of independent variables contribute to learning outcomes? 3) Does the contextual model of learning provide a useful framework for understanding learning from museums?

Design

The study was based on a repeated-measure design that included pre/post interviews (closed and open-ended questions, self-report items, and test items) and observational and behavioral measures obtained through unobtrusive tracking of all respondents throughout the duration of their entire visit to a specific science exhibition (Table 1).

Setting and content

The site for this investigation was the California Science Center (science center), a major interactive science museum located in Los Angeles, California. Totally redesigned and rebuilt in 1998, the science center charges no admission fee and comprises two permanent exhibitions and a series of traveling exhibitions. The focus of this investigation was on one of the two permanent exhibitions, the World of Life. This exhibition was designed to

Table 1
Summary of methods

Entry interview	Tracking	Exit interview
Mean duration: 17 min.	Mean duration: 47 min.	Mean duration: 16 min.
Self-report and test measures	Behavioral measures	Self-report and test measures
- Personal Meaning Mapping - Open-ended, focused questions - Multiple-choice questions - Self-report items	Unobtrusive observation (tracking)	- Personal Meaning Mapping - Open-ended, focused questions - Multiple-choice questions - Self-report items

communicate a single large overall message – that all life, whether composed of a single cell or many specialized cells, must perform certain life processes to survive. The five basic life processes described in the exhibition are living things all: take in energy; take in supplies and get rid of wastes; react to the world around them; defend themselves; and reproduce and pass on genetic information to their offspring. In addition, the 15-minute BodyWorks-presentation that combined a 15-meter long animatronic model called Tess with an animated cartoon character conveyed the importance of keeping a metabolic balance (homeostasis) under varying external conditions, and pressed the notion that organs in our body work together to maintain homeostasis.

Both front-end and formative evaluations were completed during the exhibition's development and in 1998 a complete summative evaluation was conducted to determine how successfully these messages were conveyed (Falk and Amin, 1998). In this earlier study, a large sample of visitors to the exhibition were tracked, observed, and interviewed (within the museum). Visitors were asked a series of questions related to their understanding of life processes and the relationship of humans to other life forms, both prior and subsequent to their visit to the World of Life. The results revealed that there was significant change in public understanding of the overarching message and conceptual change in understanding relative to four out of the five life process areas. Based on this initial research, we felt that this exhibition would lend itself well to an investigation of science museum learning. It is a popular, well-liked exhibition, combining a mix of media and presentation styles, which demonstrably facilitates significant short-term learning. But significantly for this study, visitors evidenced a range of learning outcomes. Thus, the exhibition afforded the variability necessary to test the assumptions of this study.

Sample

Between December 2000 and April 2001, a random sample of 217 adults visiting the science center alone or as part of a family group participated in the study. The study involved 7 dependent (learning measures) and approximately 65 independent variables (at least 3 semi-independent methods of measuring 10 of the 11 factors described above, plus variables such as age, gender, time of day, day of week, race/ethnicity, residence, etc.). The sample included roughly equal numbers of males and females, from a wide diversity of socioeconomic, educational, and racial/ethnic backgrounds. The study sample was functionally identical to the overall visiting population of the science center.

Only adults, defined as visitors over the age of 18 years, were included in this study. Ninety percent of the adults were visiting as part of a social group – 70% of visitors were visiting with children (primarily under the age of 12 years) and 20% were visiting as part of an all-adult group. Ten percent of visitors were by themselves, at least while visiting the World of Life exhibition.

Methodology

The basic research design was to develop a series of scaled measures for each of the ten key independent variables (actually suites of variables). An interview guide was developed on the basis of the contextual model and the type of answers necessary to address the relationships within the model (Kidder, 1981; Sudman and Bradburn, 1982). From the elements in the model, hypotheses were derived from which concept variables and then measured variables were developed. The measured variables were turned into questions for a pre- and post-interview guide (Foddy, 1993; Kvale, 1996; Stangor, 1998).

The measures used to assess prior knowledge and experience, interest, agenda, orientation, awareness and attention to advance organizers, choice and control over the visit, within-group social interaction, between-group social interaction, and interaction with exhibition elements were based upon existing measures developed for use in other science museums by a range of researchers. In addition, a range of traditional independent variables such as gender, race/ethnicity, time of day, day of week, etc. was collected. The major dependent variables were comprised of a series of repeated measures of visitor learning. Three different approaches to measuring change in learning were utilized. The first approach utilized three topic-relevant standardized, multiple-choice questions from a biology textbook widely used by California high schools.

The second involved two focused questions closely related to the content of the World of Life exhibition administered by face-to-face interview. This measure was identical to the instrument developed for earlier assessments of the World of Life exhibition. The third and final set of measures utilized a method called Personal Meaning Mapping (PMM). This is a relatively new instrument similar to concept mapping, based on constructivist theories of learning (Falk, 2002; Falk, Moussouri and Coulson, 1998). All instruments were developed in consultation with a research methodology committee, piloted and assessed for content validity and reliability.

All visitors in the study were intercepted prior to their entry into the exhibition. After receiving permission, visitors were interviewed to determine their prior understanding and knowledge of life science and their motivations for visiting the science center in general and this exhibition in particular. Visitors were then unobtrusively tracked through their entire World of Life visit. Particular attention was paid to whether or not visitors utilized and attended to the introductory sections of the exhibition, the nature and extent of their social interactions, whether or not visitors interacted with science center explainer staff, the nature and number of exhibit elements they attended to, and the total time visitors engaged in exhibition viewing behaviors. Following their visit, all visitors were given an exit interview.

Results and discussion

The first result of the investigation was that, overall, visitors to the World of Life exhibition did, indeed, evidence learning. All three of the different approaches to measuring learning showed significant change across visitors. Interestingly, though, there was very little correlation between the three methods. In other words, some individual's change in learning was best measured by the multiple-choice questions, others by the focused, interview questions, and yet another group by the PMM measures. There was no evidence that any of these approaches, by themselves, totally captured the change in science understanding of visitors. Collectively, these measures did seem to measure changes in visitor learning. Thus, for the purposes of further analysis, a composite measure of learning was constructed by scaling and combining all three measures.

The second interesting result was that all of the ten factors investigated did, in fact, significantly influence visitor learning along one of the various learning measures employed, but most only significantly influenced one or at most two of the dependent measures of learning. Also, although each of the ten factors significantly influenced learning, overall, not all variables had comparable impacts on specific individual visitors. For instance, some visitors might have been influenced by the quality of the exhibit design, while others might have learned significantly in the World of Life independently of this factor; some might have been bothered by crowdedness, while others may not have minded.

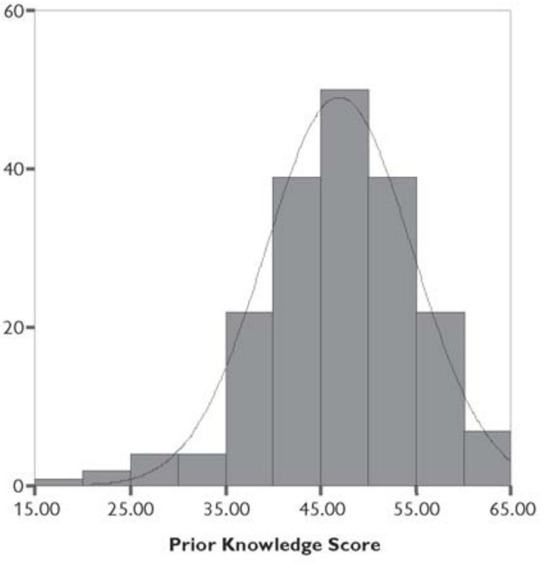
Finally, perhaps most importantly, none of the ten factors, in and of themselves, explained much of the observed variance in learning. At best, 4 to 9% of the learning variance was explained by individual factors. In other words, all of these factors have some influence on science learning from museums but none of these factors alone provided much explanatory power in understanding the changes in learning that visitors showed. In order to best understand what influenced visitor learning within the museum required looking at groups of factors. And which group of factors was influential depended upon which visitors you were looking at.

Another important finding was that among the vast array of other variables we measured, including such traditional demographic variables as age, gender, or race/ethnicity, none had significant explanatory power. In fact, these demographic variables explained even less of the variance than did the psychological variables, and none of them emerged as significantly influencing learning.

One impediment to understanding the impact of the various factors on learning was the great heterogeneity of the visiting population we sampled. Since learning was the key variable we were interested in assessing, it made sense to begin to segment visitors according to their prior knowledge. It was possible to divide the sample of visitors into five roughly equal-sized groups based upon their prior knowledge – low knowledge, below-average knowledge, average knowledge, above-average knowledge, and high knowledge (Figure 1).

Not surprisingly, what someone knew upon entering the World of Life exhibition strongly influenced what they knew when they exited ($R=.61$, $p <.0001$; see also Table 2); those with the most knowledge upon entering were still those with the most knowledge upon exiting. However, this did not mean those with the most knowledge upon entering the exhibition learned the most. Actually, the opposite was the case. In general those visitors with the lowest pre-visit scores showed the greatest gains, while visitors with the highest pre-visit scores showed the least gains (Table 2). In fact, significant learning, using the composite learning measure, only occurred in the three visitor groups that represented low to average prior knowledge. The scores for the group of visitors that entered the World of Life with the highest degree of prior knowledge actually declined significantly.

Figure I
Frequency distribution of visitors' composite knowledge scores prior to entering the World of Life*



* The class-size is set to 5, scores are represented by the x-axis, and the count is given on the y-axis. Five categories of visitors were defined by their prior knowledge scores: scores below 40 ("low", n=33), between 40-45 ("below average", n=39), between 45-50 ("average", n=50), between 50-55 ("above average", n=39), and above 55 ("high", n=28).

Table II
Change in learning as function of prior knowledge

	Repeated Measure*				
Prior knowledge level	Pre composite knowledge score	Post composite knowledge score	Mean change pre/post	Standard deviation	Change pre/post t-Value, P-Value
Low prior knowledge (pre-score<40; n=33)	35.11	43.53	+8.42	6.64	7.28; p<.0001
Below-average prior knowledge (pre-score 40-45; n=39)	42.62	49.51	+6.89	5.28	8.15; p<.0001
Average prior knowledge (pre-score 45-50; n=50)	47.61	50.67	+3.06	5.65	3.82, p=.0004
Above-average prior knowledge (pre-score 50-55; n=39)	52.24	53.09	+.85	4.6	1.15, p=.26
High prior knowledge (pre-score>55; n=28)	57.73	55.09	-2.64	3.39	4.11, p=.0003
Totals (n=189)	**46.85**	**50.34**	**+3.49**	**6.44**	**7.34, p<.0001**

* Prior Knowledge (A): df=4; Sum of squares=10914; Mean square=2729; F-test=106; p<.0001
Repeated measure (B): df=1; Sum of squares=1148; Mean square=1148; F-test=82; p<.0001
Interaction (AxB): df=4; Sum of squares=1293; Mean square=323; F-test=23; p<.0001.
One case deleted with missing values.

Table 2 describes the results of a 2-factor repeated measure ANOVA (pre/post) for the composite measure of learning, with prior knowledge as Factor 1 and the repeated measure as Factor 2. Independently, paired t-Tests were conducted to assess whether learning occurred within each of the five visitor samples that were based on prior knowledge.

The mean change scores in learning between the five groups overall was significantly different ($F=23$; $p=.0001$). A post-hoc analysis for individual group differences (Fischer PLSD) finds three groups: highest degree of learning occurred in the two groups with low and below-average prior knowledge scores (their scores were not significantly different from one another), followed by the average prior knowledge group; the lowest (in fact no or negative) learning occurred in the two groups with the highest prior knowledge. However, it is important to appreciate that there was variability within each of these five groupings, with some visitors showing great gains and others only limited gains.

With visitors now meaningfully segmented, we then looked at the factors that most significantly influenced learning in each of these five groups (Table 3). As can be seen, within these five groupings of visitors three of the factors had no significant impact on visitor change in learning (prior knowledge, choice and control, and facilitated mediation by others), while seven of the factors did (expectations and motivations, prior interest, within-group social interactions, advance organizers, orientation, architecture and physical space, and design). None of the factors significantly influenced learning for all five groups, and most only influenced one group. Let’s analyse these influences, one group of visitors at a time.

Table 3 describes the results of a series of regression analyses conducted separately for groups of visitors with varying degrees of prior knowledge. The dependent variable was always the score change (pre/post) in the composite learning measure. Highlighted numbers (grey cells) indicate that the linear regression is significantly different from zero for $p<.1$. Significant differences for $p<.05$ were also highlighted in boldface. Slope scores indicate the direction of change.

Low knowledge – This group represented roughly one-sixth of the visitors (17%) in our sample. As compared to the entire sample of visitors we interviewed, this group possessed the lowest understanding of life science; for all intents and purposes, this group knew very little about biology and the life processes that influence living things. As with all visitors, virtually all of the factors we measured had some influence on learning; however, only two factors emerged as significantly affecting changes in conceptual understanding of life science: prior interest and the design of the exhibitions.

Table 3

Multi-factor analysis

	Dependent variable: change pre/post in the weighted sum of learning variables (min=-3; max=24)														
	Low prior knowledge (pre-score<40; n=33)			Below- average prior knowledge (pre-score 40-45; n=39)			Average prior knowledge (pre-score 45-50; n=50)			Above-average prior knowledge (pre-score 50-55; n=39)			High prior knowledge (pre-score>55; n=28)		
Independent variables	r2	P	slope	r2	P	slope	r2	p	slope	r2	p	slope	r2	P	slope
Expectations and motivations	.02	.39	.48	0	.95	.03	.13	.01	-.91	.01	.61	.18	.15	.04	-.68
Prior knowledge	.01	.59	-.12	0	.95	.04	.02	.38	-.46	0	.69	-.23	.08	.15	-.45
Prior interest	.07	.08	.82	0	.71	.18	0	.86	.07	0	.96	.02	0	.85	.07
Choice and control	0	.74	.18	.01	.66	.16	.02	.41	-.24	.05	.17	.56	.01	.66	.13
Within-group social interactions	.05	.23	.03	.02	.37	-.02	.02	.29	.02	.07	.09	.03	.03	.36	-.01
Facilitated mediation by others	0	.79	-.60	.04	.20	-1.42	0	.83	-.20	.04	.21	1.14	.02	.50	-.54
Advance organizers	.01	.63	.24	.04	.25	-.33	0	.78	-.09	.20	.005	.65	0	.74	-.07
Orientation	.07	.14	-2.62	.14	.02	-2.2	.03	.24	1.19	.02	.40	-.86	.03	.38	-.7
Architecture and physical space	0	.78	.46	0	.88	-.13	.15	.005	-2.12	.01	.48	.60	.12	.07	-1.44
Design	.16	.02	.09	.08	.07	-.06	.04	.14	.04	.27	.001	.07	.11	.08	-.04

The fact that all of these individuals possessed limited knowledge did not mean that they all possessed limited interest, quite the contrary. Some had considerable interest in the topic, others virtually none. This turned out to be extremely important. Those visitors with a strong interest in life sciences, independent of their knowledge, showed significant gains in understanding. However, those who entered with both low knowledge and low interest pretty much remained the same – the combination of low interest and low knowledge was not a good recipe for learning.

This low knowledge group also seemed to be aided by the design of the exhibitions they encountered. Embedded within the design measure were several dimensions, in particular both a quantity and quality dimension. The quantity dimension measured the number of exhibit elements viewed by the visitor; the quality dimension measured how well each of the exhibit elements in the exhibition communicated about life science. Although both of these dimensions significantly contributed to learning in this group, a closer analysis of the data revealed that quality rather than quantity was most important. Not all the exhibits within the World of Life exhibition were of equal quality. Spending time at a good exhibit, relative to learning, provided much greater benefit than spending time at a poor exhibit. Given the low level at which these visitors began their learning journey, it was far more important that the exhibition provide a clear message than it was that they saw all the exhibition elements. Spending a reasonable amount of time at the exhibit elements that most clearly and unambiguously communicated science concepts would have been essential for a visitor starting with a low understanding. Individuals with greater knowledge could compensate for missing or ambiguous messages; not so someone with low knowledge. For this group of visitors, exhibition design quality was essential.

Below-average knowledge – Twenty-one percent of the visitors in our sample possessed a relatively poor understanding of life science as determined by the three sets of measures used to judge visitors' understanding of the life science concepts presented in the exhibition. Although a wide range of factors seemed to influence this group, only two factors were significantly influential in affecting changes in conceptual understanding of life science: orientation and design.

Although we used a wide range of measures to determine whether visitors' felt oriented or not in the exhibition, the primary measurement we relied upon was the investigator's direct observation of visitors in the exhibition. In particular, we tracked each and every visitor and noted down the exact pathway the visitor followed through the exhibition. In addition, we rated these pathways along a continuum of 'deliberate' to 'random' – the more random, the higher the score. Hence, the negative slope of this effect suggests that those visitors whose pathway through the exhibition were the most 'deliberate' – meaning that rather than bouncing around the exhibition like a pinball, these visitors seemed to know where they were going and went there – showed the most learning. Some of these individuals used the maps provided by the science center, others just seemed to invest time in making sure they had a sense of where they were. There were other visitors who possessed maps but never seemed to use them, and still others who just bounced around with their children. They either did not use them or, in some cases, they appeared not to know how to use them effectively. The World of Life exhibition, arguably, is not the most spatially obvious exhibition; in fact, it is quite a jumble of exhibits and experiences, organized in topical areas which many visitors do not necessarily recognize as such. It is quite easy for one to get disoriented and/or feel 'lost' within the space. For this group of visitors, the presence or absence of that feeling seemed to emerge as an important contributor to learning.

This below-average knowledge group also seemed to be affected by the design of the exhibitions they encountered; however, the slope of the effect was negative. What this means, given both the quantity and quality dimensions of this factor, is that those visitors who viewed fewer exhibits and/or viewed lower-quality exhibits learned more. In other words, visitors' engagement with what was considered the 25% most effective exhibits correlated negatively with this group's learning. The most logical explanation for this puzzling finding would be the former explanation – viewing fewer exhibits contributed to learning. Although seeing the best possible exhibits would surely have been a benefit for this group, just as it was for the lowest knowledge group, it seemed like a strategy of less being more was more important. The World of Life exhibition was divided into six sections, the different exhibits within each section being designed to support different areas of scientific content. A credible explanation for this affect would be that those visitors who tried to 'see everything' were overwhelmed by all the information they encountered. Given the limited knowledge of this group, being exposed to a smaller subset of exhibit experiences was most conducive to learning. However, it is worth acknowledging that interpretation of this affect is anything but straightforward.

Average knowledge – The average knowledge sub-group was the largest of the five sub-groups in our sample, including slightly more than one of every four visitors (26%). Individuals in this group possessed an average knowledge of life science (Note: average as compared with the other individuals in this study). Two factors above all others stood out as important in this group: entering expectations and motivations for the visit, and architecture and physical space.

This first factor was determined based on the reasons visitors reported for why they chose to visit the museum that day, and what they hoped to do and accomplish. Virtually all visitors reported that they hoped to have an enjoyable time at the science center, and virtually all perceived that the science center was a place for learning. But not all visitors perceived that the science center afforded the same learning opportunities for all visitors. In other words, not all visitors had the same view of who should actually learn. Some of the visitors stated that they came to learn themselves, while others stated that they only came so that their children could learn. They themselves did not expect to learn. It turned out, for this group of average knowledge visitors, that this distinction made a big difference in how much learning actually occurred but in a counter-intuitive way. Those individuals who stated that they themselves hoped to learn actually learned less than those who came to facilitate their children's learning. Those individuals who stated that they only came so that their children could learn ended up learning themselves. Presumably, because of their efforts to facilitate the learning of their children, these adults ended up significantly facilitating their own learning. Also, those visitors who came to the California Science Center "to have a good time" learned less than those who did not support this statement as strongly. Presumably, parents with children who perceived the visit as primarily fun and a family outing without an equally strong educational component might not have seen themselves in the role of facilitators and thus not have acted that way. Consequently, they themselves learned less. Adult visitors without children who came primarily to enjoy themselves were also less likely to pay close attention and may thus have not learned as much as those who were upfront about the educational component of their visit. Hence, a very important determiner of learning amongst roughly a quarter of the science center's visitors was set in motion prior to the visitors actually even getting inside the front door.

Visitors were asked to rate how pleasing and conducive to learning was the architecture and physical space that surrounded them in the California Science Center. The underlying reason for having visitors rate the physical space was that less pleasant, more threatening surroundings have been shown to interfere with learning. Most visitors in this study seemed to feel the building's design and architecture was pleasant and conducive to learning. On a 6-point scale where 1 = poor-quality space and 6 = high-quality space, the majority of visitors (56%) rated the building a 6, with most of the remaining visitors giving ratings of either 4 or 5. Apparently, even this small amount of variability in attitude towards the physical space was significant, since learning in the average prior knowledge group was strongly influenced by this factor. Individuals who perceived the science center architecture to be less than optimal showed diminished learning relative to those who found the setting optimal.

Above-average knowledge – About one in five visitors in our sample were in this group (21%). Although as a group they did not display learning, they were the group with the largest set of factors that significantly influenced the learning that did occur. Three factors had a significant impact: within-group social interaction, advance organizers, and exhibit design. This was also the group where the combination of factors we measured showed the greatest robustness: nearly half of the variance (45%) in the dependent variable 'learning' was explained by the combination of these factors.

Although social interaction was part of virtually all visitors' museum experience (90% of our sample visited the exhibition as part of a social group), only in this group of visitors was the social nature of the visit a direct contributor to learning. Given that nine out of ten visitors we studied displayed social interactions, it was interesting that this factor only emerged as significant in this particular sub-group of visitors. Our observations of visitors suggested one possible explanation for this finding. The conversations engaged in between visitors possessing greater knowledge of life science were much more likely to be on topic than were the conversations of visitors with less knowledge, perhaps because these were the individuals who knew enough to have a reasonable topic-related conversation. This appeared to be the case for adults in this group whether they were talking to children or other adults. If this explanation is true, then it would appear that 'informed' social interaction between visitors in the museum facilitated learning, while 'uninformed' social interaction between visitors did not.

Considerable research has shown that advance organizers facilitate learning but it emerged as strikingly important only in this group. The staff of the science center, based on previous research by one of us (Falk) and others, had wanted to insure that the exhibition contained a whole series of advance organizers for visitors, starting with a 'big message' statement at the entrance to the exhibition and an advance organizer exhibit experience as the first thing visitors would see and do. Unfortunately, the contract designers of the exhibition undermined these good intentions through a series of poor design decisions. The result was that only a relatively small percentage of visitors – less than half of all visitors – actually saw any of the advance organizers. However, given their interest and, as it turns out, knowledge of the subject, this group of visitors was best able to utilize the information provided when they did see the information. In fact, amongst this group of visitors, those who saw the advance organizers showed huge gains in understanding as compared to their comparably knowledgeable counterparts who did not see the information.

Finally, exhibition design also significantly contributed to learning in this group. As previously stated, embedded within the design measure were several dimensions, in particular both a quality and a quantity dimension; the quantity dimension measured the number of exhibit elements viewed by the visitor and the quality dimension measured how well each of the exhibit elements in the exhibition communicated about life science. Although it is likely that both of these dimensions contributed to learning in this group, it is our sense that quantity rather than quality was most important. Since the exhibition was divided into six sections, spending time in only one section of the exhibition would have limited a visitor's opportunities for knowledge gain relative to a visitor who spent time in all sections of the exhibition. However, this was likely only true for those visitors with sufficient background to make sense of the entire exhibition. Unlike the visitors with limited prior knowledge, where we hypothesized that seeing more information undermined learning, the above-average visitor group seemed to benefit from seeing more of the exhibition. Because of their greater prior knowledge, seeing the full range of ideas presented in the exhibition increased the visitor's overall understanding of the subject as well as increased the probability that the visitor would find specific topics worth exploring in greater depth. Undoubtedly, seeing better-quality exhibits did not hinder learning. Arguably, though, exhibit quality was not as crucial to this group as it was to the lowest knowledge group.

High knowledge – Finally, we come to the smallest group of visitors (15%), those who entered the science center already possessing a reasonably thorough understanding of the content presented in the World of Life exhibition. Our ability to understand the factors that affected this group are seriously constrained. First, as a group, knowledge scores actually declined rather than increased pre- to post-exhibition assessment. We would suggest that this decline was in part due to a ceiling effect caused by our methods rather than an actual decline in visitor understanding; our assessment tools provided most of these individuals little room for change except down. It is also possible that the nature of the setting itself contributed to this apparent decline. Looking a little more closely at this group's scores revealed that the high knowledge group actually did significantly increase their scores on the multiple-choice part of the learning assessment, from an average of 18.32 pre to an average of 18.61 post ($p=.043$). However, this group's significant decline in the composite learning scores was primarily caused by the large significant decline in the qualitative parts of the learning measure. This latter effect was undoubtedly due to the fact that members of this group were disinclined to restate or re-elaborate on answers that they felt they had already satisfactorily provided to the researcher. Hence, post-test responses were frequently shorter and less involved than pre-test responses. (Note: In an ironic twist, this unwillingness of visitors to 'cooperate' on such a repeated measure assessment provides support for our longstanding assertion that these types of research interventions in the museum setting create relatively little bias. Visitors do not perceive themselves as being 'judged' by these investigations, or if they do, they do not really care, since they make little or no additional effort to 'do well' as would typically be the case in a comparable school-based investigation).

The high prior knowledge group also happened to be the one group with the lowest level of variance in the learning measure (see Table 2), a factor that lowers the likelihood that we will be able to detect the factors that significantly affect learning. Adding to this problem is that the sample size was the smallest of the five groups, i. e., only 28 individuals; smaller sample sizes also decrease the statistical power of the analysis. Hence caution should be used in generalizing from these findings. Actually, this caution applies to all of the above analyses as well since all the results are preliminary, generated from a relatively small sample of visitors, and based upon a single exhibition in a single museum.

That being stated, three factors did seem to emerge as important for this group of very knowledgeable visitors: expectations and motivations, architecture and physical space, and design. The reason why the first of these three factors – expectations and motivations – was important in this group is likely quite different from why this factor impacted visitors with average prior knowledge. Although it probably did make a difference as to why these individuals perceived they were visiting (for themselves or for their children), more important was whether or not they perceived they *could* learn anything at the museum. Some in this group believed, and stated, that since the science center was for children, all of the information they were likely to encounter in the exhibition was going to be much too basic for them. This ended up being a self-fulfilling prophecy; whether the information was or was not too basic, they perceived it as such, and consequently gained little if any new knowledge. However, other visitors in this group said they were hoping to find out something new, since you can always learn new things. These individuals were open to discovering the bits and pieces of information that built upon and extended their knowledge, and appeared willing to seek out those bits and pieces. This too was a self-fulfilling prophecy; the individuals with this attitude did in fact gain new knowledge.

Architecture and space likely impacted this group in ways similar to those described in the average knowledge section. Although, for this group, in addition to diminishing the opportunity for learning, a less than stellar architecture may also have been an annoyance factor, with visitors attending to the failings of the building rather than the benefits of the exhibits.

Design emerged a significant factor for this group of visitors also, but like the below-average group, the slope was negative: the fewer exhibits seen, the greater the gain. Although this finding is difficult to interpret, it would seem that once again, less is more. As we have suggested already in the previous group, possessing a strong understanding of the content, prior to the visit, should make the quality of the exhibits less of an issue. Perhaps this was once again an issue of seeing fewer exhibits improved performance. However, unlike the visitors with below-average knowledge, the issue was not one of being overwhelmed. For this group it was likely just a function of being selective. This group was capable of more in-depth understanding, and perhaps those visitors who exercised that option, choosing to look at fewer exhibits in greater depth, benefited the most from the exhibition experience.

Conclusions

Although much could be said about the findings presented here, we will focus only on the fact that the results of this research reinforce two important points we have been trying to make in this article. The first is that visitors to science museums do in fact learn science. In fact, these results would suggest that science museums are particularly useful for facilitating science learning amongst the least knowledgeable citizens; the less visitors to the California Science Center knew about life science, the more they learned. The evidence for learning from museums was overwhelming in this study. Our sample included a very diverse range of visitors. The sample included visitors of all ages, incomes, occupations, levels of education, and – of particular importance to this study – with a wide range of prior knowledge of biology. Our sample included individuals with only the most rudimentary knowledge of life sciences, as well as individuals with graduate degrees in biology working in life sciences careers. Virtually all of these visitors exited the World of Life exhibition at the California Science Center with a measurably enhanced understanding of life science. It is essential to note though that it took three very different types of learning measurement tools to capture the learning of all these different visitors; any one tool alone would have missed changes in some percentage of the visitors sampled.

The second important point is that the exact nature of the learning that occurred in the World of Life exhibition varied considerably between visitors and was influenced by a whole range of factors. The contextual model of learning provided a useful framework for beginning to unravel the complexities of learning from the science center. As the preliminary results reported here so clearly revealed, depending upon who the visitor was, what they knew, why they came, and what they actually saw and did, the outcomes of the museum experience were dramatically affected. However, equally critical to point out is that this model, along with studies such as the one summarized here, provide the beginnings of a more conceptually-based and empirical approach to understanding learning from museums.

The promise of this research is that further analysis of the data collected here, combined with additional data from similar studies, will begin to yield an ever-more refined model of learning from museums. We believe that this study has demonstrated that learning from museums is indeed a complex phenomenon. More importantly though, we believe that this study demonstrates that learning from museums, although complex, is indeed subject to analysis and ultimately is amenable to predictive description. This predictive description is likely to be less like Newtonian physics and more like quantum mechanics. Predictions of the behavior of electrons are not done with certainty but with probabilities; so too might be the behavior of people. This is in large part due to the fact that all systems, even systems as simple as electrons in atoms, are subject to random factors that limit predictability. The opportunities for randomness within a complex human system like a science museum are immense. For example, a good deal of the variability in visitor behavior and learning we observed in the World of Life exhibition was random variability. A visitor might have wanted to stop and read the exhibition's introductory panel and thus avail themselves of an advance organizer, but the presence of a crowd of visitors in front of that panel at that very moment made him or her decide to move on rather than wait for the crowd to move. Another visitor might have passed up the introductory panel because his or her child ran off into the exhibition ahead of them, so again despite intentions to read the advance organizer, the behaviour of others in the social group prevented this person from reading it. We observed multiple examples of both of these scenarios, neither of which were seemingly anticipated by the designers of the exhibition, both of which limited the predictability, and arguably the likelihood, of learning from the exhibition. Over the course of an hour's visit to the World of Life exhibition, dozens of such random events affected the visitor's experience.

Still, enough of the events in the exhibition were predictable to allow an initial understanding of which factors contributed most to which groups of visitors. Although none of the ten variables we investigated emerged as uniquely important, all emerged as collectively important, some more important for particular groups of visitors than others. Hence, one take-away message is that all ten factors must be considered when designing museum learning experiences and all ten must be accounted for when attempting to understand the learning outcomes of museum experiences as well. However, the real take-away message of this article is that simple, reductionist, linear approaches to understanding learning from museums will simply not suffice. Only by appreciating and accounting for the full complexities of the museum experience will useful understanding of learning from museums emerge. Once accounted for, though, we can in good faith unequivocally state and with great certainty document that science museums facilitate public understanding of science.

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