A Virtual Reality and Human Factors Analysis of a Renovated Diorama Hall

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Abstract

Four features of the Virtual Reality (VR) computer environment were used to describe advantages of science learning in a museum environment. Like VR, a museum exhibit can be a (1) three-dimensional, (2) dynamic, (3) closed-loop interactive, and (4) an ego-referenced learning environment. A VR conceptualization is especially appropriate for exhibits, like dioramas, that are intended to give visitors a "real world" experience. In addition, applications from human factors (HF) research on information displays can also be applied to exhibit design.

Results from a pre/post renovation evaluation of the Mead Diorama Hall at the Denver Museum of Natural History were interpreted in terms of the four features of VR and HF that enhance learning. The reinstalled Hall displays, with added orientation information, improved graphics and labels, interactive displays, rest areas, and greater overall integrity of design, were shown to enhance Mead Hall's learning potential. This paper will define the four learning features of VR and HF guidelines and show, from evaluation of Mead Hall, how the renovated exhibits fit the effective learning criteria which were developed through VR research. This paper will also present results, derived from methods used to study the immersion experience in museums (Bitgood, 1990), to demonstrate that the renovated museum Hall elicits an experience closer to VR than the pre-renovated Hall.

Virtual Reality and Exhibit Design

Four of the five features of the Virtual Reality (VR) computer environment (Wickens, 1992) also prescribe renovation guidelines for the traditional museum exhibit. The Denver Museum of Natural History (DMNH) sought to improve the learning potential of visitors in their Mead Hall *Explore Colorado*. In order to understand the exhibit planners'

approach, it is useful to consider their changes in terms of the principles of human factors (HF) design, and the components of the VR environment. That is, since the exhibit planners implemented design features that are consistent with principles of HF design and the components of the VR environment, this evaluation investigated outcomes of exhibit renovation primarily in terms of VR learning criteria.

To understand the present evaluation approach, it is necessary to outline the parallel features of the VR environment and some museum environments. Like VR, a museum has the potential to offer a *three-dimensional perspective*, allowing a more realistic view of the subject matter than that which is provided by two-dimensional imagery. A museum, like VR, can exploit *dynamic displays*, such as motion pictures and videos, which more accurately depict scientific phenomena than do static images. Both museum and VR environments can be *closed-loop interactive*—that is, they can place the visitor in an interactive mode with the environment such that he or she determines what part of the learning world or space is visited. Finally, both VR and museums provide the more realistic inside-out frame of reference, in which the image of the world or space on display is viewed from the visitors' moment-to-moment perspective. Thus, in the case of renovated Mead Hall, the visitor becomes an explorer of the virtual world of Colorado, rather than experiencing Colorado from a fixed, outside-in frame of reference (such as is provided by looking at pictures of Colorado in a book).

This *ego-referenced*, rather than world-referenced, viewpoint is arguably more compelling, and may promote the desire to learn. These features, which parallel the benefits of VR, increase visitors' motivation to learn, placing them in a more real-world context than does a traditional setting, and permitting scientific visualization. For a summary and comparison of these features, see Table 1.

The three-dimensional dioramas and the dynamic display (action video) used in the renovated Hall adhere to proposed VR learning criteria. Also, the one feature of VR most consistently associated with improved retention, closed-loop interaction, requires choice and active participation on behalf of the visitor. This characteristic is embodied in the new design of the Hall, which provides visitors with an open floor layout. Theoretically, the choice and active participation necessitated by this architectural feature of the gallery, and many similar galleries, requires effort from the visitor which may improve visitor retention of exhibit information.

Table 1

Four Parallel Features of the VR Computer Environment and the Science Museum Environment, and Associated Psychological Processes

Feature	VR	Museum	Psychological Process
1.	3-dimensional	Diorama-style exhibit, 3-dimensional exhibit environment	Enhanced realism permits field-trip-like experience
2.	Dynamic display	Action video and participatory exhibits	Improved visualization of scientific phenomena
3.	Closed-loop interactive	Open gallery— Visitor controls exploration	Museum visitor is active navigator (effort=greater retention)
4.	Ego-referenced	Visitor immersion— Allows ego-centered perspective (Promotes effort demanding decisions of where and how to proceed through virtual or actual space)	Visitor controls use of perceptual-cognitive resources

Human Factors Considerations

Human factors (HF) research on information display variables that affect human performance can also be applied to the present evaluation's VR learning analysis. There are three principles from this research that are appropriate for prescribing renovation guidelines within a VR conceptualization: consistency, redundancy, and visual momentum (Wickens, 1992). These principles characterize information display parameters that affect visitors' ability to orient themselves and effectively sample information. The DMNH exhibit planners' approach to visitor orientation and information display in renovated Mead Hall was consistent with these basic HF principles.

The consistent format of interpretation in the dioramas of Mead Hall satisfies the principle of *consistency of representation*. The presentation of information in a variety of forms (three-dimensional models, written text, diagrams) satisfies the principle of *redundancy*. This feature creates multiple representations in visitors' memory to increase resistance to forgetting, and allows visitors to choose the format most consistent with their cognitive style. The principle of *visual momentum* is also exploited by the museum staff. The consistent diagram (i.e. continuous map) at each diorama (the same diagram of a mountain and a color-coding of the ecologically distinct area represented in the diorama), with the highlighted anchor of the ecosystem being recreated, demonstrates the relation of the diorama to previous dioramas, and results in graceful transitions between dioramas. Research has demonstrated (Knepp, Barrett, & Sheridan, 1982) that a display concept supporting the search and retrieval of information from multi-dimensional data bases can be achieved by using continuous maps.

The dioramas, which give visitors an inside-out perspective, are connected with text, graphics, and maps (traditional instructional stimuli which allow visitors an outside-in perspective). This connection between dioramas and traditional instructional stimuli results in a potentially powerful learning environment. The linkage of the semi-direct experience (dioramas) with the abstract level of language, equations, and graphics are consistent with HF design principles developed from research on computer-based, information-rich environments (Wickens, 1992). Summative evaluation indicated that the combination of VR-like design features and HF design principles may improve exhibit effectiveness.

Summative Evaluation

Summative evaluation provides exhibit designers with information on how the exhibit is working overall (Screven, 1990). The present study used VR learning criteria and HF information display design principles as a guide to summative evaluation. This approach is appropriate when the museum area under evaluation possesses design features that are similar to

the VR environment, such as dioramas or elaborate theme parks that depict particular times and places, and when information displays are required to convey important and complex information. Thus, HF and VR research can offer museum professionals concrete criteria on which to critically appraise and assess the effectiveness of these types of exhibits.

The present study contends that museum exhibits lie somewhere on a continuum of virtual reality or fidelity, as defined by the features discussed earlier. The hypothesis upon which this work was conducted was that DMNH's Mead Hall prior to renovation, and other traditional exhibits, would fall rather low on this continuum, while post-renovation Mead Hall would fall substantially higher, and thus elicit a higher degree of visitor commitment. In order to test this hypothesis, visitor behavior in Mead Hall before and after the renovation was investigated with a visitor exploration tracking method. For this project, the independent variable was Mead Hall, before vs. after renovation. Several dependent variables of interest to museum professionals (described below) were measured. A second methodology was also used to compare visitor perceptions of Mead Hall with perceptions of another hall in the museum that would fall lower on the proposed VR continuum. The second method is reported below under the heading Study 2.

STUDY 1

Method and Results

Visitor behavior in Mead Hall before (n=165) and after (n=266) the renovation was investigated with a visitor exploration tracking method that measured two dependent variables: total time spent in the hall and time spent at each individual diorama and text panel.

Overall, as shown in Figure 1, survival analysis (as suggested by Menninger, 1991) indicated that post-renovation visitors stayed significantly longer in the whole Hall than did pre-renovation visitors (Lee-Desu=37.75, $p<.001$). It is important to note that this treatment of the data controlled for time spent attending to a video learning game presentation in post-renovation Mead Hall by subtracting the time spent watching the video game exhibit from the total time spent in the Hall, prior to the comparison. Furthermore, analyses of variance indicated that post-renovation visitors explored a greater number of the quartiles in the Hall than did pre-renovation visitors ($F[1,429]=5.9$, $p<.02$), and read more of the 11 side text panels of the 11 dioramas than did pre-renovation visitors ($F[1,42])=11.7$, $p<.001$).

STUDY 2

Method and Results

A 20-item survey was distributed to 223 visitors in Mead Hall, and to 98 visitors in another hall (Standley Hall) at DMNH that was considered to fall substantially lower on the hypothesized VR continuum. Standley Hall had yet to be renovated, making it an appropriate baseline for comparison. The items for the survey were developed on the basis of previous research conducted by Bitgood (1990) on the role of simulated immersion in exhibition. Simulated immersion is the degree to which an exhibit involves, absorbs, engrosses, or creates for visitors the experience of a particular time and place (Bitgood, 1990). Feeling immersed in an exhibit makes it a more exciting, interesting, vivid, engaging and meaningful experience for the visitor. Thus, the model of simulated immersion put forth by Bitgood (1990) is a means of understanding the factors that influence visitor experience. It was expected that measures of immersion would be correlated with exhibit design features, such that the higher the fidelity of the exhibit (i.e. the closer it is to satisfying VR learning criteria), the higher would be its ratings of perceived immersion. If results indicated that the sense of immersion was greater in the renovated Hall, then it could be concluded that it elicited a visitor experience closer to VR than did a hall very similar to pre-renovated Mead Hall.

The survey items were tailored to suit specific evaluation needs of this investigation, but were of the same general nature used by Bitgood. The purpose was to investigate visitor experience in Mead Hall by comparing it, via the survey, to visitor experience in Standley Hall. On the basis of Bitgood's (1990) previously discussed theory, research items were developed to measure aspects of the museum experience. To examine the visitor experience, this research employed a factor analytic approach (Rummell, 1977).

Though this approach is exploratory, it can provide researchers with clues for determining *what* variables or survey items are correlated and *why* they may be so. Items that measure the same aspect of a psychological construct (e.g. satisfaction) are expected to be highly correlated since they are measuring essentially the same thing. If the items predicted to be correlated are indeed so, then it may be possible to identify the underlying theme binding them together.

To achieve this description of the patterned variation among the survey items, factor analysis first separates systematic from random variance in the responses to the items, then focuses on the systematic variance to mathematically define their commonality—the correlations between the variables/items in terms of common variance. This technique is most useful when researchers have a theory to drive the selection of items such that they will group together well. Thus, in order to obtain high

commonality between variables, researchers must carefully select or construct the survey items. As mentioned above, the present study used Bitgood's (1990) theory on the role of simulated immersion in exhibition to drive survey item preparation. It is important to note that in this phase of the research the present study is not testing a hypothesis but simply reducing a large set of variables (twenty) into composites to render them more understandable. An exploratory factor analysis (using the SPSS-X Data Analysis System, Release 3.0; 1988) was performed and resulted in four factors. An examination of the items/variables constituting the first factor suggest that the latent variable reflects a sense of immersion for the visitors. See Figure 2 for a summary of the factor loadings for the first two factors whose independent solutions combined to account for 53.9% of the variance among items.

Analyses of variance were performed on the composite scores for each of the four factors, indicating that there was overwhelmingly more positive affect, and a greater sense of immersion, in Mead Hall than there was in Standley Hall. The results of the analyses of the four factors, conveniently identified as "immersion" (factor 1), "stimulation" (factor 2), "comfort" (factor 3), and "meaningfulness" (factor 4), follow respectively: 1) $F(1,319)=58.1$, $p<.001$, 2) $F(1,319)=50.6$, $p<.001$, 3) $F(1,319)=59.8$, $p<.001$, and 4) $F(1.319)=28.2$, $p<.001$.

Discussion

Pre- and post-renovation comparisons of visitor behavior indicate that the new design of Mead Hall enhanced the visitor experience. This was indicated by the findings that visitors stayed significantly longer in post-renovation Mead Hall, stopped at more of the exhibits, and read more of the text. Furthermore, comparisons between post-renovation Mead Hall, and another hall at DMNH that would fall much lower on the VR continuum, show that visitors report significantly more positive affect in post-renovation Mead Hall. The latter result suggests that affect, positive or negative, is associated with the immersion experience. Thus, the results of the present studies combine to suggest that the renovated Mead Hall effectively immerses visitors in the time and space depicted in the Hall, and provides them with a positive experience.

The finding that visitors tended to stay longer in post-renovation Mead Hall may be explained in terms of the new Hall's ability to orient and immerse visitors. Perhaps the new Hall's improved performance is partially due to it's ability to avoid diverting visitors' cognitive resources to irrelevancies—a phenomenon that may occur in museum galleries whose design lacks adherence to HF design principles and VR learning criteria. The results of the present evaluation suggest that the transfer of knowledge from the virtual/museum space to the visitor is facilitated by the new design of the Hall that incorporates HF principles and VR learning criteria.

Though learning was not directly studied in the evaluation, it is clear that spending more time in the Hall, stopping at more exhibits, and reading more text are indicative of improved exhibit effectiveness.

The results of factor analysis suggested that the survey items were well-constructed. The structure of the factor loading matrix after rotation was clear and simple. That is, the items expected to group together or measure the same phenomenon did indeed have high mathematical commonality. Those items that measured different phenomena had low commonality. Thus, items designed to measure perceived immersion were highly correlated with each other, but had low correlation with items designed to measure comfort or meaningfulness. Factor analysis, and subsequent comparison, showed that a sense of immersion, amount of stimulation, comfort level, and perceived level of meaningfulness in a museum environment are all important features that define visitor experience. The finding that post-renovation Mead Hall elicited a greater sense of each of the four above-mentioned factors than did a hall very similar to pre-renovation Mead suggests that visitors had an overall stronger, more VR-like experience in Mead Hall after renovation.

In summary, the present study shows that the exhibit staff at DMNH have created a visitor-sensitive (i.e. user-friendly) environment in the new Mead Hall. Choice and active participation appear to facilitate the transfer of knowledge from the virtual/museum space to the visitor. The results of this evaluation indicate that the Hall's potential for learning is greatly improved. Indeed, Koran, Foster, and Koran (1989) showed that the best predictor of learning in a museum environment was level of attention. The findings that visitors stayed longer, viewed more of the dioramas, and read more of the text in renovated Mead Hall is evidence that the renovation did facilitate greater attention. Furthermore, the finding that Mead Hall elicited a more positive response by visitors responding to the survey item, "This hall makes me want to learn more about the subject," than that which was elicited in a a hall much lower on the hypothesized VR continuum, is evidence that the potential for learning is greater in an exhibit that falls high on the VR continuum.

Museum environments which are high on the virtual reality continuum offer an alternative to learning and retention of isolated facts. This alternative is one which museums have been offering to visitors for years. The concepts of virtual reality and immersion appear to be very similar, and may provide exhibit planners with preliminary design guidelines. It is also interesting to note that the VR analogy is consistent with Moscardo's (1992) mindfulness/mindlessness model. A high fidelity exhibit is more likely to elicit a mindful mode of information processing than a low fidelity exhibit. The present research showed that renovated Mead Hall, which is relatively high on the VR continuum, elicited a much greater sense of immersion than did a hall which is much lower on the VR continuum. Learning associated with either virtual reality or immersion in actual exhibit

settings is more experience-driven than it is information-driven, thereby theoretically bolstering retention of exhibit information (Bitgood, 1990; Wickens, 1992). Thus, the modern museum environment that exploits the concepts of virtual reality and human factors research in developing information aids, provides visitors with a sense of immersion and a valuable supplement to traditional modes of learning such as lectures, textbooks, or even traditional museum exhibit environments.

References

Bitgood, S. (1990). *The role of simulated immersion in exhibition.* Technical Report No. 90-20. Jacksonville, AL: Center For Social Design.

Koran, J. J., Jr., Foster, J. S., & Koran, M. L. (1989). The relationship among interest, attention and learning in a natural history museum. In S. Bitgood, A. Benefield, & D. Patterson (Eds.) *Proceedings of the Annual Visitors Studies Conference, Volume 2.* (pp. 239-244). Jacksonville, AL: Center For Social Design.

Knepp, L., Barrett, D., & Sheridan, T. B. (1982). Searching for an object in four or higher dimensional space. *Proceedings of the 1982 IEEE International Conference on Cybernetics and Society* . Seattle, WA, pp. 636-640

Menninger, M. (1991). The analysis of time data in visitor research and evaluation studies. In A. Benefield, S. Bitgood, & H. Shettel (Eds.), *Visitor Studies: Theory, Research and Practice Volume 3* (pp. 104-113). Jacksonville, AL: Center For Social Design.

Moscardo, G. M. (1992). A mindfulness/mindlessness model of the museum visitor experience. Unpublished doctoral thesis, Townsville, Australia: Dept. of Psychology, James Cook University of North Queensland.

Rummell, R. J. (1977). *Applied factor analysis.* Evanston, IL: Northwestern University Press.

Screven, C. G. (1990). Uses of evaluation before, during and after exhibit design. *ILVS Review, 1*(2), 36-66.

SPSS-X. (1988). *SPSS-X Data Analysis System, Release 3.0.* Chicago, IL: SPSS Inc.

Wickens, C. D. (1992). Virtual reality and education. *Proceedings of the 1992 IEEE International Conference on Cybernetics and Society.* Seattle, WA.

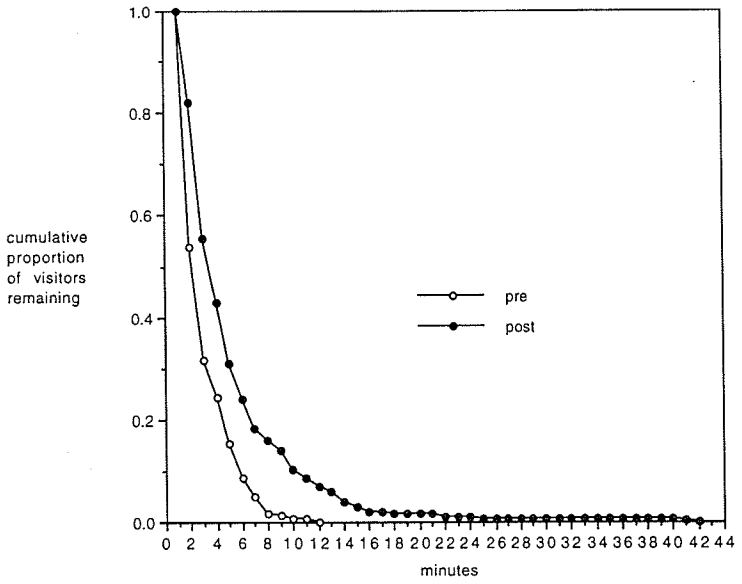

Figure 1. Pre/post comparison of proportion of visitors remaining in Mead at two minute intervals. Post-renovation visitors remained significantly longer than pre-renovation visitors, Lee-Desu=37.75, df=1, p<.001.

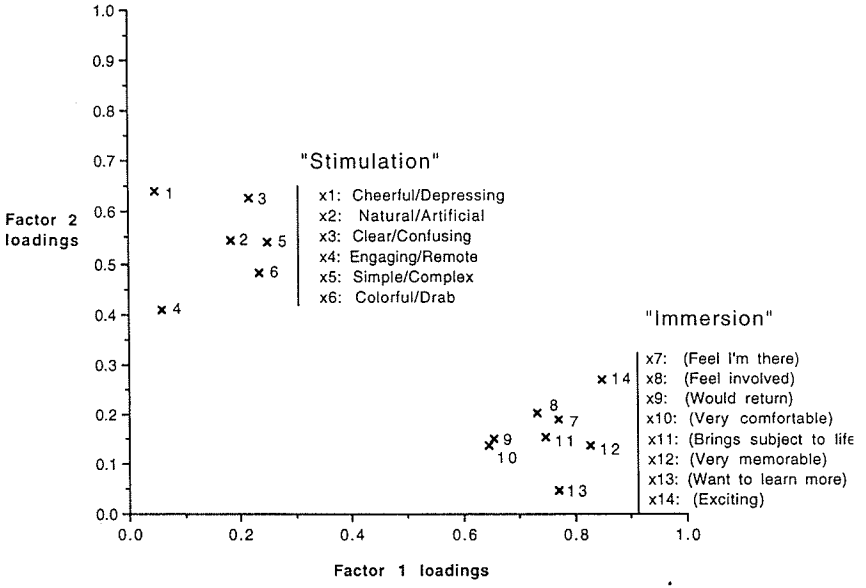

Figure 2. Orthoganally rotated factor loadings. Although factor loadings were based on a four factor solution, only the first two factors are shown which accounted for 53.9% of the variance.