# Interaction in an IVR Museum of Color

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## Introduction

Immersive Virtual Reality (IVR)[1] has exciting potential for educational applications, because it can enable students to interact with ideas in new ways. In an IVR environment, students can engage in simulations of real-world environments that are not accessible due to financial or time constraints (high-end chemistry laboratories, for instance), or which are simply not possible to experience, such as the inside of a volcano or the inside of an atom. IVRs also enable students to interact with visualizations of abstract ideas (for example, mathematical equations and elements of color theory). The hands-on, investigative learning most natural to IVR is an excellent way to train new scientists and engineers. In addition, because the environment is computer-generated, it is an ideal future platform for individual and collaborative distance learning efforts.

IVR lends itself naturally to a constructivist pedagogical approach, one that builds on Piaget's view that knowledge is created by learners through interaction with people and the world around them[7] and that it is characterized by first-person, non-symbolically mediated interactions.[20] But the success of such virtual "direct experience" depends heavily on the design of interface and interaction techniques. Although IVR may suggest ease of use and obvious, transparent interface designs, the opposite is, unfortunately, true: IVR presents surprisingly difficult interface challenges. Even techniques as seemingly straightforward as object selection and navigation are the subject of dozens of research papers.[13,14] The design of IVR interaction that feels natural and promotes learning is an almost entirely unsolved problem. We have been tackling some of the interface and interaction challenges of using IVR for education in a Museum of Color in which students can perform a number of science museum-like experiments.

Although IVR environments are still too expensive and fragile for mainstream educational use, the use of VR in training is well-established,[10] and its use in entertainment is growing rapidly.[21,1] Moore's Law is seen in the use of commodity 3D graphics in games and edutainment (the Sony Playstation 2 has more graphics power than most of today's high-end workstations), and suggests that today's esoteric immersive environments will become commodity classroom fixtures in the future. We feel, therefore, that it is critical to conduct educational IVR interface and interaction research today so that educators can take full advantage of IVRs in the near- and long-term future.

## Previous Work

The IVR Museum of Color extends ongoing work done in the Exploratories Project at Brown University (www.cs.brown.edu/exploratory). Exploratories are combinations of science museum-like exploratoriums and laboratories, realized as 2D and 3D explorable worlds. The Exploratories Project has a dual mission: creating innovative educational content for the Web and documenting the experiences of creating such software in a design strategy handbook.

A handbook for 2D and 3D desktop applications is already in progress as part of the Exploratory Project.[8,19] The handbook draws on our own and others'experiences and includes guides, templates, patterns (as in Gamma et al's object-oriented "Design Patterns"), and examples. Topics include assessment of resources, descriptions of different pedagogical categories, patterns for implementation, indexed examples, and, of course, extensive information on interface and interaction design.

The Exploratories project has previously focused on 2D and 3D graphics on the desktop, creating, for example, suites of 2D applets for teaching color theory[2,17] and basic signal processing used in image processing. The project has also worked with 3D desktop graphics, creating modules, for example, for teaching synthetic camera transformations. Recently, we have begun to design for semi- and fully immersive environments, from the Barco Baron table (a rear-projection display) to a four-walled CAVE. Building on the two suites of 2D color theory exploratories we have created, we have begun creating a sequence of CAVE-based exploratories, a Museum of Color.

IVR education projects at a number of universities have already shown promising results: for example, the University of Illinois Electronic Visualization Laboratory's Round Earth project,[12] George Mason University and the University of Houston Virtual Environments Technology Laboratory's NewtonWorld and MaxwellWorld,[16] the University of Michigan Virtual Reality in Chemical Engineering Laboratory's Vicher (Virtual Chemical Reaction) modules 1 and 2,[3] the University of Washington Human Interface Technology Laboratory's Zengo Sayu,[15] and MIT's ALIVE environment,[11] just to name a few. We have been convinced, by reading about these works and seeing demonstrations, that the educational potential for IVR is real, but we have found little specific discussion of interaction issues that are particularly relevant to educational uses of IVR. By conducting projects like the one discussed in this paper and presenting interaction methods that we find successful, we hope to make construction of future educational IVRs easier for ourselves and others.

## Enter the Museum

The Exploratories Project has begun work on an IVR-based Museum of Color to teach difficult-to-understand, often highly abstract aspects of color theory through a series of hands-on experiments that take advantage of immersion in a 3D virtual space and interaction with explanations of abstract concepts. This project has illuminated a number of issues in IVR-based interaction relevant to instructional design; we discuss three of them here.

1. An IVR is created with a combination of immersion (3D graphics rendering that surrounds the user, with the point of view dynamically updated by tracking the user's head position and orientation), and the use of interaction devices such as data gloves. A 3D world seen on a desktop machine monitor does not qualify as an IVR, even when stereo is used, because the sensation of immersion is absent.

## 1. Using Architectural Spaces to Structure a Sequence of IVR Learning Modules

One of the first challenges we encountered was how to navigate through a complex series of learning experiences in an immersive environment. In our desktop exploratories, we use customized hypertext structures that we have developed for presenting educational material on the Web.[18] For example, we have structure templates for games, lab-type experiments, and more free-form playground environments. In the Museum of Color, we chose an architectural metaphor that guides the user through various learning sequences and simplifies nonlinear navigation. The 3D structure also serves as a mental model of the lesson structure. While we have not found this type of architectural interface to be terribly successful for the desktop, we have found it to be quite natural in the CAVE. In the Museum of Color, for instance, each floor has the same layout and flow sequence (see Figure 1) and higher-numbered floors house experiments of increasing conceptual difficulty. Simple interactive experiences with different parameters of a color (such as value, hue, and saturation) are on the first floor, experiments dealing with groups of color are on the second, and interactive comparisons of color spaces are on the third. When a user has completed a floor, the architectural metaphor, complete with an elevator ride between floors, enhances both the sense of having traversed a memorable territory and the sense of closure over a set of concepts.

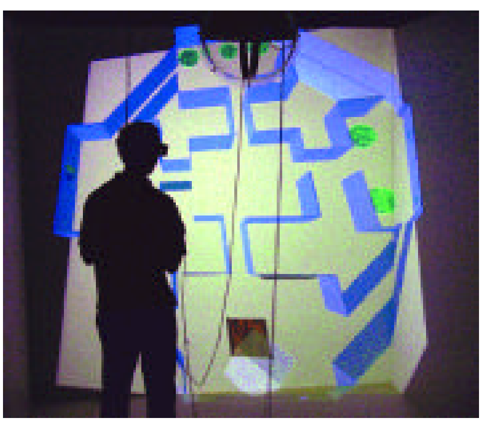

*Figure 1: Flying over the floor plan. On each floor, a central column (which holds the elevator) is surrounded by four rooms.*



## 2. Trade-offs Between Metaphor Integrity and Convenience

We have found that the effectiveness of using an architectural space depends first on its appropriateness to the task, and secondly on the correct balance of spatial integrity and navigational convenience. Faithfulness to the metaphor is essential for establishing it as a mental model. However, undue faithfulness can be irritating. For example, in the Museum of Color, users can take an elevator between floors to emphasize the structure, but we also let users navigate in a nonlinear fashion by selecting rooms on a 2D map. The step outside the 3D realm for map navigation is similar to use of maps in real life. We avoided flying, passing through walls, and jumping or transporting from place to place within the museum. For educators, establishment of the structure can be further exploited by the equivalent of hypertext guard fields.[5] Users can be forced to follow a specific sequence and can be barred from certain rooms until specific conditions have been met, such as conducting a number of prerequisite experiments. Our framework allows for such guiding.

Sometimes the benefits of one approach, such as use of an architectural metaphor, clash with another potential interface or interaction scheme. For example, scale changes are a particularly powerful feature of IVR learning environments, but it is difficult to take full advantage of the potential for relative scaling while still maintaining the visitor-in-a-museum metaphor. In our color-space rooms, users see a number of different 3D color spaces, rendered as wireframes, placed on pedestals like sculptures (see Figure 2). The color spaces can be investigated in a number of ways. A series of visualization techniques helps to show off the internal structure of the spaces (see Figures 2, 3). Two-handed interaction (using data gloves) lets users pick up color spaces and rotate them. Before they were integrated into the museum, it seemed natural to scale the spaces and walk around inside them. Inside the museum, such radical scaling causes the color spaces to become larger than the room and intersect with the walls and ceiling. A partial solution is to restrict the ultimate scale; another approach is to let users "jump" into the color space (See Figure 2).

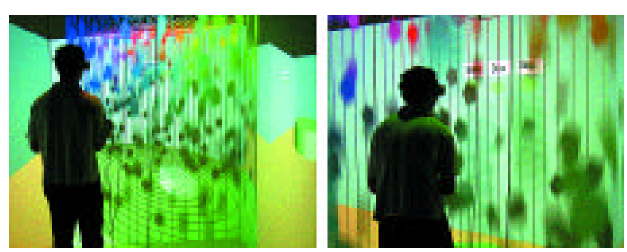

*Figure 2: An HSLcylinder, rendered as a wireframe, with falling disks colored according to their changing locations. The user approaches (left) and then enters the space (right).*

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*Figure 3: Ribbons help to convey the location of colors in an HSL cylinder without obstructing the user's views of the space.*

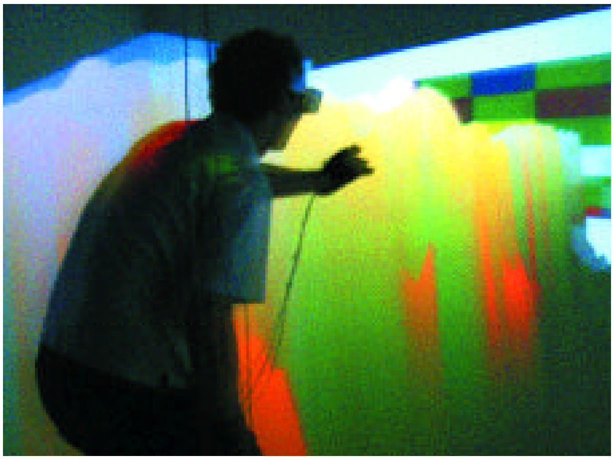

*Figure 4: A researcher uses a pinching motion to warp the height field, in this case making a pale blue area more saturated by drawing it upward.*

## 3. Concept Visualization

An interaction area important for making IVR useful for the widest possible range of educational topics is the use of 3D representation (and thus manipulability) of parameters not usually visualized in 3D, an approach that we call concept visualization, similar to Winn's "reification."[20] The first room of the Museum of Color teaches the concepts of value and saturation with this method. Traditionally, users manipulate a value or saturation parameter with a slider or dial, or by moving a brush-type tool over an area of their image. In the CAVE, we present the changes to either parameter in an image as a height field (with the image mapped onto it) that users can drag and push with gloves to get a sense of what happens when you shift either parameter of a color (see Figure 4). Interacting with a 3D representation of value or saturation gives the user a new mental model of its properties and lets manipulation draw on use of the fingers, hand, arm, and even full body. The 3D representations of these abstract parameters will, we hope, give them a more tangible reality for students and continue to enrich artists' and designers' vocabulary for talking about the use of value. For example, artists already often describe black as heavy and white as light or refer to light or dark areas as receding or advancing. Interestingly, the model of saturation and value as height appears to persist in users outside of the CAVE, and anecdotal reports show that it helps users create and analyze 2D works in the real world.

Visualization of color spaces is more direct. Usually, three parameters are involved, such as hue, saturation, and value or red, green, and blue, and the visualization of each parameter's values along an axis serves to make these somewhat arbitrary parameters more tangible. For beginning students of color theory, it is often not clear why one needs so many different color spaces and what their different purposes are. One of the most important distinctions is between spaces that are perceptually uniform (an equal-distance step along any axis results in an equal amount of perceived change in the quantity of the axis's parameter) and those that are not. We are able to let users compare perceptually and non-perceptually based spaces by using a fully manipulable cutting plane that is flat in a perceptually based space but maps to a warped shape in spaces that do not have perceptually linear changes along the axes of their various parameters. Although one can do this on the desktop, we found the immersive experience to be qualitatively different. The ability to step inside a color space, move the plane with one's arms, and easily examine the results from any point of view gave us a much better intuitive sense of shapes of the spaces and the areas in which perceptual changes become more and more nonlinear.

## Conclusion and Future Work

The interface challenges discussed here are only a few of the many issues confronting educators who want to tap the enormous potential of IVRs as learning environments. In addition to work being done on basic IVR UI techniques, such as those needed for navigation, selection, and multimodal interaction (for example with gesture and voice recognition),[4,6,9] we hope that particular attention will be paid by educators to IVR interaction support for educational needs such as note-taking or record-taking, narrative structures, scenes that change adaptively to respond to a learner's growing sophistication, tracking and remediation of user mistakes or misconceptions, collaborative learning and problem solving, and performance measurement.

We plan to continue to add content to our Museum of Color, and to create further educational IVR experiences. But our long-term goal is to document both our experience and that of others to codify solutions to some of the many problems that arise when using IVR for educational purposes. Although a number of successful IVR education projects have been completed (see Previous Work, above), a source for clear guidelines and examples will, we believe, do a greater service to the field than simply creating more content. We plan to write an IVR section for our design strategy handbook that will contain discussions of specific issues, like those presented in this paper, as well as lists and examples of the relevant IVR techniques found in today's research literature. Widespread dissemination of practical results in the handbook will make our work available to a broad range of potential end users, from research scientists to high school educators.

Our thanks to Andy van Dam for his critical reading and to David Karelitz and Jean Laleuf for feedback during the creation of the Museum. We would like to thank Adobe Systems, Inc. for their generous support of this work. We would also like to thank the other sponsors of the Brown University Computer Graphics Group and the CAVE at Brown: Advanced Network & Services, the Technology Center for Advanced Scientific Computing and Visualization, the Department of Energy, IBM, Intel, Microsoft, the NSF Science and Technology Center for Computer Graphics and Scientific Visualization, and Taco, Inc.

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