7. International Immersive Projection Technologies Workshop
9. Eurographics Workshop on Virtual Environments
J. Deisinger, A. Kunz (Editors)

# The Virtual Showcase as a new Platform for Augmented Reality Digital Storytelling

Oliver Bimber[1], L. Miguel Encarnação[2] and Dieter Schmalstieg[3]

[1]Bauhaus University, Weimar, Germany, email: oliver.bimber@medien.uni-weimar.de
(some of this work was conducted while the author was employed by the Fraunhofer CRCG)
[2]Fraunhofer Center for Research in Computer Graphics (CRCG), Providence, RI, USA, email: me@crcg.edu
[3]Vienna University of Technology, Vienna, Austria, email: dieter@cg.tuwien.ac.atations

**Abstract**
*In this paper we discuss a case study for which we applied a customized augmented reality display –the Virtual Showcase– as a new platform for digital storytelling. Different storytelling components are identified and examples for their specific realization are explained. Our case study focuses on communicating scientific information to a novice audience in a museum context. Addressing first user feedback, we describe our current efforts of improvement.*

**Keywords:**
*Augmented Reality, Digital Storytelling, Multi-User, User Feedback*

Categories and Subject Descriptors (according to ACM CSS): H.5.1 [Multimedia Information Systems]: Artificial, Augmented and Virtual Realities; I.3.1 [Hardware Architecture]: Three-dimensional Displays

## 1. Introduction

Interactive digital storytelling techniques are recently being applied in combination with new media forms, such as virtual reality (VR) and augmented reality (AR).

Thereby the technological progress that is being made within these areas allows shifting interactive digital storytelling more and more into the third dimension[14] and into the physical world.

One of the main advantages of this transition is the possibility to communicate information more effectively with digital means by telling stories that can be experienced directly within a real environment or in combination with physical objects. The user experience is thus transformed from relating different pieces of information to one another to 'living through' the narrative.

The perceptual quality and the unique aura of a real environment (e.g., a historical site) or object (e.g., an ancient artifact) cannot be simulated by today's technology. Thus it is not possible to substitute them with virtual or electronic copies without them losing their flair of originality.

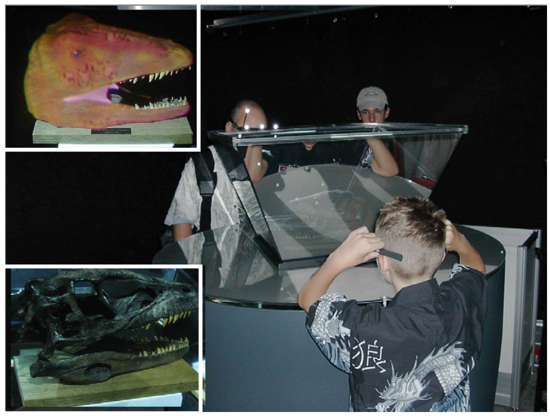

**Figure 1** *Virtual Showcase variation at ACM Siggraph 2002 and snapshots of the presented demonstration.*

This circumstance can be a crucial reason for using augmented reality as a technological basis for interactive digital storytelling.

Several research groups[3, 9, 10, 11, 13] apply personal displays, such as head-mounted displays (HMDs) to realize AR-based new media experiences. These all-purpose display types, however, have to face technological problems that up until today have not been sufficiently solved[1]. These shortcomings cause a substantial credibility gap if a certain level of realism is required.

In this paper, we want to discuss how an application-customized type of augmented reality display –the Virtual Showcase– overcomes most of these technological shortcomings, and how it can be used as a new platform for digital storytelling.

To underline our statements we discuss and evaluate a case study that focuses on using AR digital storytelling to communicate scientific information to a novice audience in a museum context. We have introduced the application that led to our case study in a previous publication[5]. In this paper, we want to describe the technical components that have been developed to realize this application. In addition, we present a first user feedback and illustrate our current efforts of improvement.

## 2. The Virtual Showcase

The Virtual Showcase[4, 7] is a new optical see-through augmented reality display that allows multiple users to observe and interact with an augmented physical content which is presented inside the display.

A similar form-factor makes the Virtual Showcase compatible to traditional showcases, as they can be found in museums. The combination with half-silvered mirror beam splitters, allows presenting stereoscopic, three-dimensional overlays together with physical artifacts. Our current prototypes support up to four head-tracked users simultaneously. Video-projectors (called light projectors) are being applied for dynamically illuminating the physical content on a per-pixel basis. This allows creating realistic occlusion effects between real and virtual objects, thus presenting a solution to one of the main problems of optical see-through AR[6].

From our perspective, the Virtual Showcase has the following technical advantages over traditional personal AR display technology, such as head-mounted displays:

- It provides a high and scalable resolution, due to the application of spatial displays instead of head-attached miniature displays;
- Eye accommodation is improved, since the image plane can appear close to its real world focal plane;
- The environments inside and surrounding the Virtual Showcase are better controllable than large-scale or even out-door environments that HMDs can be confronted with. This effects the quality and precision of technical issues, such as tracking and illumination, if stationary storytelling scenarios are implemented;
- Calibration is easier. HMDs can have up to 12 degrees-of-freedom (without pre-distortion and alignment of the image on the display) that have to be re-calibrated for each user/session. Depending on its variation, our current Virtual Showcase prototypes have between 3 and 15 degrees-of-freedom (without pre-distortion and alignment of the image on the display, and without light projectors) that are user/session-independent.

Besides its advantages, the Virtual Showcase certainly has shortcomings, such as its limitations in multi-user support (currently no more than four users can be supported simultaneously with a single setup), and its uselessness for mobile applications. This makes the Virtual Showcase, like a few other approaches[15, 16, 18], an application-specific alternative to head-attached displays, rather than a substitution.

Figure 1 shows a Virtual Showcase variation that was presented together with our Paleontology demonstration[5] in the Emerging Technology Laboratory at ACM Siggraph 2002, San Antonio, TX, USA. It consists of a CRT projector that displays the stereo-images onto the horizontal display screen, a pyramid-shaped half-silvered mirror optics that serves as optical combiner, a ceiling-mounted wireless infrared tracking system, and two light projectors that are also mounted to the ceiling.

## 3. Storytelling Components

For using the Virtual Showcase as a digital storytelling platform, we have identified five major components (cf. figure 2): *content generation*, *authoring*, *presentation*, *interaction*, and *content management*.

In the following sections, we want to discuss these components and their dependencies with respect to the Virtual Showcase as a presentation platform. We give examples of how these components have been realized for our case study.

The goal of this case study was to use the Virtual Showcase for presenting the state-of-the-art scientific findings of a leading paleontologist to a novice audience in an exciting and effective way. Specifically, we wanted to present how soft-tissues, such as muscles, and missing bones have been reconstructed for the skull of a Mid-cretaceous dinosaur[21].

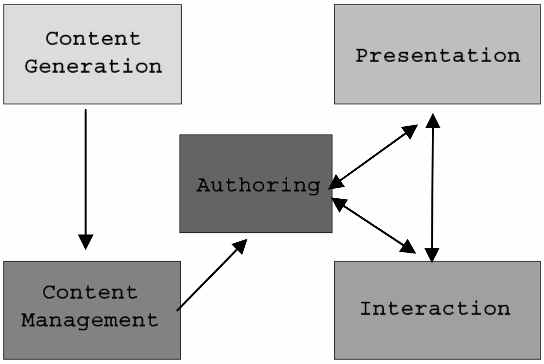


**Figure 2** *Storytelling components and their dependencies.*

### 3.1. Content Generation

The content that is presented with a Virtual Showcase is mainly three-dimensional and consists of real and virtual components.

Off-the-shelf tools, such as 3D modeling and animation software, as well as laser scanning technology can be applied to generate most of it.

Figure 3 illustrates how the three-dimensional content has been created for our case study: We received photographs of the skull from the paleontologists, containing hand-drawings of the soft-tissues' locations within the skull area. In addition we were told how these components interacted during a so-called *power-bite* (a bite sequence in which the dinosaur was believed to rip large chunks of flesh out of its pray).

The physical skull was laser-scanned. A low-resolution version of scanned geometry was used to compute occlusion and illumination effects during the presentation. The reconstructed soft-tissues, such as several muscle components, the paranasal air sinus, the bony eye rings, the skin, as well as text-labels have been modeled and animated with 3D-Studio Max™. Audio files were recorded by the paleontologist in a studio to provide additional verbal information.

Beside these conventional types of content (i.e., 3D computer graphics, animations and audio) the Virtual Showcase allows presenting and creating unconventional content types that are specific to augmented reality, or the Virtual Showcase itself.

Our controlled projector-based lighting allows creating static illumination effects directly on the surface of the physical object. This is realized by moving a mouse-controlled cursor over the physical surface to interactively draw light and shadows into the frame/stencil buffer of the light projector. The static light content can be saved and loaded on demand after it has been created. While the base in figure 5 has been interactively painted with a static white light, the skull was illuminated dynamically to create consistent occlusion effects depending on the observers' perspectives. Three-dimensional techniques for painting with projected light onto tracked real objects using a tracked stylus-like input device are described by Bandyopadhyay et al.[2]. In contrast to these techniques, our approach is purely two-dimensional and does not require a direct access to the real object.

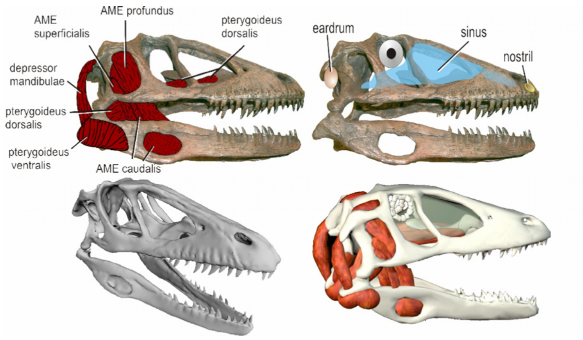


**Figure 3** *Creation of conventional three-dimensional content. Photographs (top) and scanned/modeled content (bottom).*

Our latest light-painting interface applies off-the-shelf drawing and painting software, such as Adobe Photoshop™ instead of simple 'self-made' painting tools for creating static illumination effects directly on the real objects. This allows to benefit implicitly from a rich pallet of powerful tools and techniques that are well know to artists and designers. The final images are simply blended with dynamic illumination effects (such as view- or time-dependent blending effects, outlined in sections 2 and 3.2) and then beamed as registered projective texture-maps onto the physical surfaces during presentation. A dynamic blending between multiple pre-created images during the presentation is also possible.

### 3.2. Authoring

Authoring tools and techniques allow us to describe how and when the created components play together to form a digital story. The type of authoring that is supported depends strongly on the provided content, the capabilities of the presentation soft- and hardware, and on the offered interaction techniques and devices. The most common story types are *linear timeline based stories* and *hierarchical event-based stories* that are usually expressed in form of story grammars.

In the linear case, a story follows a sequential timeline whose continuation cannot be influenced from the outside. Stories that are authored on a hierarchical basis apply a multi-dimensional graph structure (such as trees or more general graphs) and offer a branching into different continuations (i.e., into sub-timelines) at certain points. The branch selection is event-based and can be triggered by, for instance, user interactions or state changes within the story's environment, etc.

In our case study, a linear timeline-based authoring has been chosen. The animation timeline of the modeled/scanned components that was defined in 3D Studio Max™ served as main timeline. The entire animation was exported into the format of a game-engine (RenderWare™ in our case) that is integrated into our player software.

Other content components have been authored by adding them to the main timeline. These attachments were defined within an ASCII file that was created and edited with an external text editor. The description consists of a simple timeline oriented grammar that represents our storyboard.

The audio pieces, for example, were configured by defining when to play which fraction within the main timeline.

Dynamic illumination effects allow us to fade in/out specific parts of the real objects by simply not or partially illuminating them with our light projectors. This enables us to make real objects (or portions of them) temporarily invisible and consequently to make seamless transitions on the mixed reality continuum[12]. Consequently, we can define when to illuminate which portion with a specific light intensity. The intensities are linear interpolated between the given sample-points. This allows generating seamless fading effects. In our case study we applied this technique to temporarily replace the physical skull by its virtual counterpart during the power-bite sequence. An alternative mechanical animation of the physical skull would be impossible to realize with a valuable museum artifact.

We can also attach augmented-reality specific techniques to the main timeline. An example that was also being used for our case study was to trigger the state of virtual phantoms – the registered geometric representations of physical objects that are applied to create occlusion effects with virtual objects[8]. During the power-bite sequence, for example, these phantoms had to be deactivated to avoid wrong occlusion effects with the virtual replacement of the skull. Before and after this sequence, the phantom was activated to create correct occlusion effects with the muscles and other virtual components.

Finally, all these components were synchronized with the main timeline during the presentation.

### 3.3. Presentation

One of the main goals that we follow with the Virtual Showcase is to achieve a high degree of realism while presenting an augmented scene. The Virtual Showcases' technical advantages that have been discussed in section 2 contribute to this.

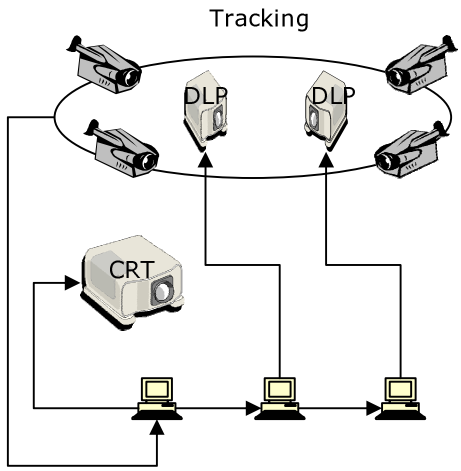


**Figure 4** *Hardware configuration that was used for our case study.*

Responsible for the presentation is a 'player' software. Our current implementation of this player contains the following features:

- Virtual Showcase specific display drivers and basic rendering techniques to support different prototypes;
- Import capabilities for several 3D and 2D data-formats, storyboard descriptions and animations;
- Multiple integrated render-engines, such as polygonal-based, point-based (splatters), and a game engine;
- Support for single and multiple users;
- Projector-based illumination;
- Head-tracking and simple mouse-based interaction;
- Distributed and progressive rendering techniques;

- Automatic synchronization of distributed scene information and timeline components, triggered by animation events and interaction events;

Figure 4 illustrates the hardware configuration supported by the player that was used in combination with the prototype illustrated in figure 1 and the case study that is discussed in this paper.

One PC was connected to the infrared tracking device and drove the CRT projector to create the stereo images for two users. Two additional PCs were used to illuminate the real scene from different sides. All PCs were running the same player software and were synchronized over a local TCP/IP daisy-chain network.

Figure 5 shows a snapshot* of the presented story, photographed from the perspective of one user.

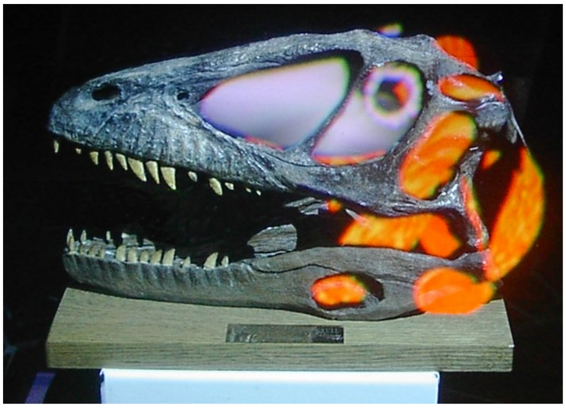

**Figure 5** *Snapshot of the presented story.*

### 3.4. Interaction

To develop interaction techniques and devices for the Virtual Showcase that can be integrated into digital stories is a very challenging task – especially if multiple users are involved.

We can differentiate between *story-dependent* and *story-independent* devices and techniques.

Story-independent methods address general interaction techniques and devices that are useful in combination with the Virtual Showcase – regardless of the story. Examples are some indirect techniques that are also being applied for projection-based VR displays, such as ray-casting and indirect or remote interaction techniques/devices (e.g., the ones classified by van de Pol et al.[19]).

A story-dependent approach focuses on developing techniques and tools that are adapted to the story. Examples are hand-held props that can be associated with the story (e.g., a toy gun).

Interaction events can be used to influence the continuation of the story if an event-based, hierarchical storyboard has been defined. For multiple user scenarios, we can additionally differentiate between a *guided*, *individual* and *cooperative* interaction.

The interaction with a story can be guided by a dedicated user, while the other users observe the same outcome and continuation. An individual interaction allows each user to interact with its own variation of the same story. In this case, each user is completely independent of the others. A cooperative interaction allows each user to influence the continuation of the same story that is observed simultaneously by all users. In contrast to the other approaches, mechanisms that resolve conflicting interaction and continuation situations are required for this case.

Note that we currently support only linear timeline based stories. For this, only a mouse-based, story-independent and guided interaction is offered to transform single virtual components.

### 3.5. Content Management

To ensure a certain level of reusability, the different types of content that have been created for a digital story, as well as the stories themselves have to be stored and managed in an organized way. Content management systems that are developed on the basis of flexible databases, such as Oracle™, and online access protocols, such as SOAP™, provide a platform for doing this. These systems can be set up as centralized server or decentralized cluster that collect, manage, and provide content and digital stories on-line or off-line. This offers interesting opportunities for content providers.

Note that we have not yet realized or integrated this component. This rather represents work in progress. Consequently, the content and the storyboard that have been used for our case study were duplicated and stored on the local hard disks of the presentation PCs. Links to the corresponding content components were defined within our storyboard.

* The photograph has been taken from reference 5.

## 4. First User Feedback

To receive a first feedback on the Virtual Showcase technology being used as an AR digital storytelling platform we asked participants at Siggraph 2002 to fill in a questionnaire after watching the presentation.

Within five days our throughput was approximately fifteen-hundred users. Three hundred-eighty-five users – between 16 and 78 years of age (average: 35 years)– returned a valid questionnaire.

The questions and the average answers are presented in figures 7 and 8[*].

Although our overall results are quite positive, the answers in the visual impression section (figure 8) give evidence that the technology can be improved further. Specifically, a more seamless integration of the display into habitual environments and a less obtrusive combination of real and virtual artifacts is required.

Question no. 5 reveals that many users were confined that our approach is suitable for museums. However, several participants argued that the technology might not be affordable to them.

## 5. Towards Realism and Affordability

To increase the level of realism of a presented augmented scene, and to decrease the cost of the technology, we are continuously developing new variations of the Virtual Showcase. A first experimental prototype is illustrated in figure 6.

In contrast to the previous prototypes, such as the one shown in figure 1, this variation utilizes four CRT monitors, instead of a single CRT projector. This reduces the cost of the entire display to a fraction of the cost of a suitable CRT projector.

In our earlier approaches, multiple users were supported by partitioning the screen area (as well as the image resolution) into five sections: one for each of the four possible users, and one for the image area that is located underneath the mirror optics. The monitor-based setup provides an UXGA resolution per screen and consequently increases the image resolution per user by factor five.

[*] We are aware of the fact, that SIGGRAPH visitors are not necessary the 'normal' museum visitors. But the results give us certain tendencies, which we will use to continue our evaluations.

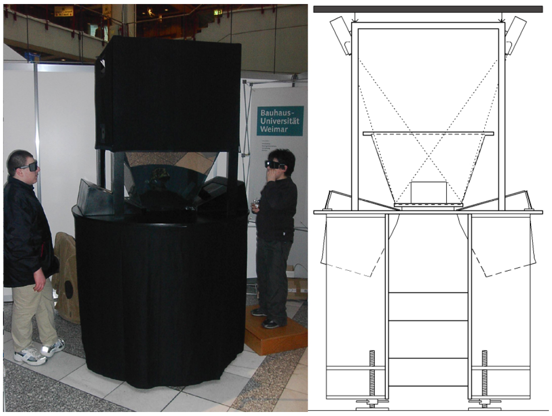


**Figure 6** *Monitor-based Virtual Showcase prototype at Learntec 2003.*

The display panel of the monitors has been coated with a light directing foil. This foil directs the light exclusively from the monitor towards the mirror optics, which makes the stereoscopic images appear only inside the mirror optics – not on the monitor. Thus, observers are not distracted by the source images[†] on their own, or on the opposite display anymore.

Since the monitors can be tilted towards the mirrors by an arbitrary angle, it is possible to cover the entire height of the mirror assembly by graphical overlays.

All technology, such as PCs, tracking system, monitors, video beamers and sound system have been integrated seamlessly into the frame of the display. They are not visible from the outside anymore.

Our player software is able to drive two monitors simultaneously with an UXGA resolution. Consequently, only two PCs[‡] are required to drive a four-user configuration. Depending on the requirements, additional PCs are needed to support a projector-based illumination.

This Virtual Showcase variation has been presented to a large audience at the Learntec 2003 conference/trade fair in Karlsruhe, Germany. The same demonstration and software platform have been used as at Siggraph'02. The throughput during the four days exhibition was approximately six hundred-fifty users. Two hundred-sixty-four users –between 18 and 72 years of age (average: 34

[†] Stereoscopic images that appear on the screens before they are reflected or transmitted by the mirrors.

[‡] With appropriate graphics boards that provides two VGA outputs.

years)– returned valid questionnaires. Note that as at Siggraph, several children have watched the presentation. However, they were not able to fill out the questionnaire.

The feedback that was received with the enhanced version of the display is compared to last year's results in figures 7 and 8. Slight improvements can be observed in almost every section – even with much less expensive technology.

## 6. Summary and Future Work

In this paper, we have presented how the Virtual Showcase serves a new platform for AR digital storytelling.

Five major storytelling components were identified and examples of their early realization were discussed: *content generation*, *authoring*, *presentation*, *interaction*, and *content management*.

On the one hand, we have shown examples of *conventional content types* (such as 3D models, animations, and audio, etc.). On the other hand, *unconventional content types* exist that are specific to augmented reality, or even to the Virtual Showcase itself.

For example, we have identified static and dynamic illumination of the real objects as such an unconventional content that can be created, authored, managed, interacted with and presented within a story.

In future, we will explore this feature further by developing techniques that will allow the interaction of physical and artificial light between real and virtual artifacts. Physical illumination effects, for example, could be created interactively (e.g., by using real spot-lights, etc.), recorded with cameras and played-back with light projectors during presentation. We believe that a visual feedback of the real content which can be analyzed to influence how the real content is illuminated and the virtual artifacts are rendered is an essential next step. Thus, we are working on combining our light projectors with video cameras to support exactly this task.

We have differentiated between *linear timeline-based*, and *hierarchical event-based* story types. More advanced types exist, such as autonomous agent-based systems that apply artificial intelligence techniques to automate the creation of specific actions during runtime (e.g., less relevant side actions). The supported authoring technique and story type strongly depend on the interaction level and on the presentation capabilities of the storytelling platform. We have classified interaction as *story-dependent* and *story-independent*. For multi-user scenarios, this classification can be extended to *guided*, *individual* or *cooperative* forms. An interesting and challenging further dilatation of these forms is the interaction among multiple users along multiple networked Virtual Showcase platforms. This form can then be categorized as *tele-cooperative*.

A first implementation of the player software was described together with some of its internal components. We are planning to enhance this player, but focus on integrating selected components into other existing frameworks (e.g., the Studierstube framework[17]) that already provide a large pallet of useful tools and techniques.

The implementation of a content management system to collect and offer components and stories in an organized and effective way is already in progress.

The specification of an enhanced middleware language –*the Virtual Showcase Modeling Language (VSML)*[20]– that links the different components together is currently being developed.

By taking the first user feedback into account, we have started to improve the Virtual Showcase technology with respect to affordability and realism.

The cost of our new prototype has been reduced by factor 5-7.5 (from approximately 150kUSD at Siggraph'02, down to 20-30kUSD at Learntec'03). Thereby the visual quality (e.g., resolution has increase by factor 5) and the acceptance of the display have been increased.

We also found out as part of our questionnaire, that the average audience is willing to accept an increase in price of approximately 2.5USD/Euro per ticket, if Virtual Showcase technology is available in museums.

These enhancements will continue in future while taking product design issues into account. The application of auto-stereoscopic screens (e.g., parallax barrier displays or lenticular displays) might be a next step towards a more seamless integration of the technology into museum environments. We believe that, due to Virtual Showcase's technological and conceptual advantages, a higher level of realism between real and virtual artifacts will be achieved. These two aspects will increase the acceptance of the Virtual Showcase, and possibly of augmented reality digital storytelling in general.

## Acknowledgments

The realization and evaluation of the case study was mainly funded by the Fraunhofer Center for Research in Computer Graphics (CRCG), Inc, in Providence, RI, USA. We thank the ART GmbH, Hewlett Packard, and BARCO for providing hardware and support during Siggraph 2002. The

Virtual Showcase project is supported by the European Union, IST-2001-28610.

**References**


1. Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., MacIntyre, B. Recent Advances in Augmented Reality. IEEE Computer Graphics & Applications, vol. 21, no.6, pp. 34-47, 2001.
2. Bandyopadhyay, D., Raskar, R., and Fuchs, H. Dynamic Shader Lamps: Painting on Real Objects. In proceedings of IEEE and ACM International Symposium on Augmented Reality (ISAR'01), pp. 207-215, 2001.
3. Billinghurst, M., Kato, H., Poupyrev, I. The MagicBook – Moving seamlessly between reality and virtuality. IEEE Computer Graphics and Applications, vol. 21, no. 3, pp. 6-8, 2001.
4. Bimber, O., Fröhlich, B., Schmalstieg, D., and Encarnação, L.M. The Virtual Showcase. IEEE Computer Graphics & Applications, vol. 21, no.6, pp. 48-55, 2001.
5. Bimber, O., Gatesy, S.M., Witmer, L.M., Raskar, R. and Encarnação, L.M. Merging Fossil Specimens with Computer-Generated Information. IEEE Computer, September, pp. 45-50, 2002.
6. Bimber, O. and Fröhlich, B. Occlusion Shadows: Using Projected Light to Generate Realistic Occlusion Effects for View-Dependent Optical See-Through Displays. In proceedings of International Symposium on Mixed and Augmented Reality (ISMAR'02), 2002.
7. Bimber, O. Interactive Rendering for Projection-Based Augmented Reality Displays, Ph.D. Dissertation, Darmstadt University of Technology, 2002.
8. Breen, D.E., Whitaker, R. T., Rose, E. and Tuceryan, M. Interactive Occlusion and Automatic Object Placement for Augmented Reality. Computer and Graphics Forum (proceedings of EUROGRAPHICS'96), vol. 15, no. 3, pp. C11-C22, 1996.
9. Kretschmer, U., Coors, V., Spierling, U., Grasbon, D., Schneider, K., Rojas, I., and Malaka, R. Meeting the Spirit of History. In Proceedings of the International Symposium on Virtual Reality, Archaeology and Cultural Heritage, pp 161-172, 2001.
10. MacIntyre, B. Lohse, M., Bolter, J.D., Moreno. Ghosts in the Machine: Integrating 2D Video Avatars into a 3D AR System. In proceedings of International Symposium on Mixed Reality (ISMR'01), 2001.
11. MacIntyre, B. Bolter, J.D., Moreno, E., Hannigan, B. Augmented Reality as a New Media Experience. In proceedings of IEEE/ACM International Symposium on Augmented Reality (ISAR'01), pp. 197-206, 2001.
12. Milgram, P., Takemura, H., et al. Augmented Reality: A Class of Displays on the Reality-Virutality Continuum. In proceedings of SPIE: Telemanipulator and Telepresence Technologies, H. Das, SPIE. 2351, pp. 282-292, 1994.
13. Moreno, E. Alice's Adventures in New Media: An Exploration of of Interactive Narratives in Augmented Reality. In Proceedings of Conference on artistic, cultural and scientific aspects of experimental media spaces (CAST'01), pp. 149-152, 2001.
14. Murry, J.H. Hamlet on the Holodeck: The future of narrative cyberspace. ISBN 0-262-63187-3, MIT Press, 1998.
15. Ogi, T., Yamada, T., Yamamoto, K. and Hirose, M. Invisible Interface for Immer sive Virtual World. In proceedings of the Immersive Projection Technology Workshop (IPT'01), pp. 237-246, Stuttgart, Germany, 2001.
16. Raskar, R. Welch, G., Low, K.L., and Bandyopad-hyay, D. Shader Lamps: Animating real objects with image-based illumination. In Proceedings of Eurographics Rendering Workshop (EGRW'01), 2001.
17. Schmalstieg, D., Fuhrmann, A., Hesina, G., Szalavari, Zs., Encarnação, L. M., Gervautz, M., Purgathofer, W. The Studierstube Augmented Reality Project. PRESENCE - Teleoperators and Virtual Environments, vol. 11, no. 1, pp. 32-54, MIT Press.
18. Stetten, G., Chib, V., Hildebrand, D., Bursee, J. Real Time Tomographic Reflection: Phantoms for Calibration and Biopsy, In proceedings of IEEE/ACM International Symposium on Augmented Reality (ISAR'01), pp. 11-19.
19. van de Pol, R., Ribarsky, W., Hodges, L. Interaction Techniques on the Virtual Workbench. In proceedings of Virtual Environments'99, pp. 157-168, 1999.
20. VSML - An integration tool to bridge the various components of the VS software framework, http://www.studierstube.org/virtualshowcase/details/vsml.html, 2002.

21. Witmer, L.M. The Evolution of the Antorbital Cavity of Archosaurs: A Study in Soft-Tissue Reconstruction in the Fossil Record with an Analysis of the Function of Pneumaticity, Journal of Vertebrate Paleontology, vol. 17, supplement to no. 3, pp. 1-73, 1997.

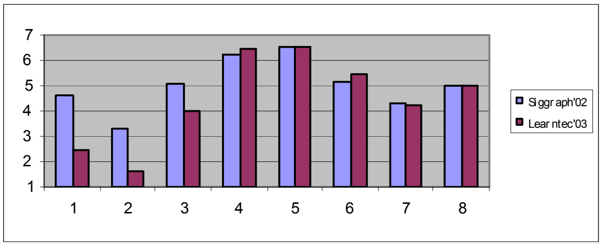


**Figure 7** *User feedback on previous experience and acceptance.*

1. Do you have any previous experience with Virtual Reality? (1= none, 7= many)
2. Do you have any previous experience with Augmented Reality? (1= none, 7= many)
3. Do you have any previous experience with Computer Games? (1= none, 7= many)
4. Would you try out the same or a similar technology again? (1= not at all, 7= yes, very much so)
5. Do you think such technology is suitable for Museum exhibits? (1= not at all, 7= yes, very much so)
6. Did the virtual representation and the supporting technology deteriorate in any way your experience with the real object? (1= yes, very much so, 7= not at all)
7. Would you pay a higher entrance fee in order to see Virtual Showcase technology in a museum? (1= not at all, 7= definitely, if reasonable)
8. Would you prefer to go to a Virtual Showcase display rather than a traditional artifact exhibit of the same object in a museum? (1= not at all, 7= definitely)

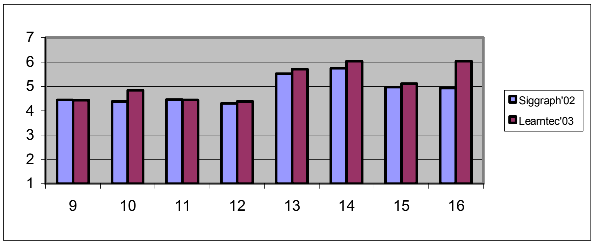


**Figure 8** *User feedback on visual impression.*

9. How would you rate the comfort of the 3D glasses? (1= bad, 7= very good)
10. Did you have the impression that the virtual objects belonged to the real object (dinosaur skull), or did they seem separate from it? (1= separate from the real object, 7= belonged to the real object)
11. Was watching the virtual objects just as natural as watching the real world? (1= completely unnatural, 7= completely natural)
12. Did you have the impression that you could have touched and grasped the virtual objects? (1= not at all, 7= absolutely)
13. Did the virtual objects appear to be (visualized) on a screen, or did you have the impression that they were located in space? (1= on screen, 7= in space)
14. Did you have the impression of seeing the virtual objects as merely flat images or as three-dimensional objects? (1= only as image, 7= as three-dimensional object)
15. Did you pay attention at all to the difference between real and virtual objects? (1= not at all, 7= yes, very much so)
16. Did you have to make an effort to recognize the virtual objects as being three-dimensional? (1= yes, very much so, 7= not at all)