Building Blocks for Virtual Learning Environments

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ABSTRACT

This paper discusses the requirements for Virtual Learning Environments from a didactical and implementational point of view, and also identifies structure and typical elements. Following modern educational theories one of the most important aspects is to provide interactive elements in order to "grasp" the learning matter. In this context different interaction types are elaborated. Besides this, the paper also shows that narration, just as with (serious) games and digital storytelling, is another crucial principle that helps to provide the learner with some background information and structure for understanding the new concepts and building adequate mental models. This implies, that meaningful virtual objects and actions should be arbitrarily utilizable and combinable, in order to be able to create Virtual Learning Environments which are customized to the learning matter. Finally methods and building blocks for enabling instructors to "write" interactive 3D learning environments are presented.

Keywords

Virtual Reality, Virtual Characters, Interactive Environments, E-Learning Environments, X3D.

1. MOTIVATION

About 10 to 15 years ago, Virtual Reality (VR) was seen as a new way to use computers, eliminating the separation between humans and computers by providing intuitive interaction through new multimodal interfaces. Soon VR techniques expanded from military and scientific research into other areas like cultural heritage and education. VR provided the feeling of immersion and presence, and it allowed to experience many types of environments, which otherwise would not be available. Therefore VR represented a promising area for supporting learning through first-person experience. But even though it has been shown, that virtual learning environments (VLE) can provide strong tools for different types of learning, ranging from typical training simulator scenarios up to more elaborate cognitive learning targets, there still exists no general theory of Mixed and Virtual Reality (MR/ VR) learning, and research in the area of cognitive theory focuses on the understanding of how to design and use VLEs, in order to support different types of learning, for different types of learners, effectively.

Primarily the most crucial aspect concerning VR was the concept of presence, for which highly immersive environments and special VR-devices are needed, which are still uncommon, usually only available in one size, and in addition quite expensive. Thus even nowadays VLE remain subject to research experiments. But presence not only relies on immersion but also on the possibility to almost arbitrarily interact with the environment – a feature that is also well known from recent computer games. Besides this a feeling of immersion can be achieved by means of a story as well, which furthermore serves as a leitmotif and provides the learner with background information and structure for helping him to understand the concepts and to build adequate mental models.

So, taking into account the issues arising with special VR equipment, the problem is which characteristics of MR/ VR are really important for effective learning. When taking a look at modern, ego-shooter style computer games with their simple story but almost photorealistic graphics, in which the gamers (usually male teenagers) easily immerse their selves, it can be stated, that lightweight solutions like desktop VR or cheap projection based systems are generally sufficient. Thus, with the development of standards for the deployment of interactive 3D graphics like X3D, and the availability of 3D modeling tools, what remains is a consistent model and, based on this, tools for content creation, which also for instance teachers can use for building learning environments that are suitable for a special class or audience.

2. STRUCTURE AND ELEMENTS

Computer Based Learning

Learning software can be distinguished from pure information systems by the fact that its design is based on some conceptual models of teaching and learning. There exist a lot of educational disciplines, which all should be taken into consideration when developing e-learning applications. Didactics hold ready models on teaching and learning, which help to explain, what and how and with whom should be learned, and what types of media could be used, e.g. multi-modal (many sense organs) vs. multi-codal (different symbol systems, e.g. verbal) [Iss02, Jank94]. Pedagogics states that human beings can and must be educated, because they are able to reflect upon themselves and have no pre-assigned behavior. An up-to-date concept of instruction is hands-on learning, which originates from progressive education. Already in the 18th century J.J. Rousseau described in his educational novel "Emile" a holistic and action-oriented approach in which the pupil is exposed to problem situations that are well prepared but appear to be quite natural. They can only be solved by actively thinking and interacting with the contents, which corresponds to the concepts of interaction and immersion of VR systems [Jank94, Kais91].

Psychology of learning defines learning as the acquirement of knowledge and skills. Here three main theories can be distinguished: Behaviorism is based on the assumption of a simple stimulus-response model and therefore can't be used for teaching problem solving skills [Kais91, Schul02]. A better suited method is discovery learning, which is based on Cognitivism. It regards learning as information processing and states that it takes place through the efforts of the students as they organize, store and then find relationships between information. Cognitive structures develop from the concrete to the more abstract and correspond according to J.S. Bruner to the so-called enactive, iconic and symbolic stages of intellectual development [Schul02]. Finally, Constructivism says that people construct their own understanding and knowledge of the world, through experiencing things and reflecting on those experiences, whereas teachers are considered as a coach, providing a suitable learning environment. Typical contructivistic learning environments are multimedia-based hypermedia systems, for which guidance and narrative structures, i.e. story-telling, are used to counter the problem of the fragmentation of information chunks. Furthermore, just like in class didactical reduction shall be used for preventing from excessive demands. [Iss02, Lang02].

Virtual Learning Environments

VR/ AR allows learning in contexts which otherwise would be difficult, dangerous or even impossible to experience (e.g. historical scenes, the interior of the human body, or even outer space). With the help of VLEs abstract problems and models can be concretised and therefore experienced through the concepts of transduction and reification. Following current learning theories VLEs are especially suited for training affective and motor skills on the one hand, and for teaching younger or disabled children on the other hand, because VR not only supports hands-on learning, but it also enables to "grasp" the learning matter through actions on objects and by using models and pictures. Despite this, educational concepts can also be integrated [Winn03]. Thus, motivating and complex learning environments with situated application contexts enable learning processes that embed new skills in a broader scope; and by also utilizing multiple contexts and perspectives interconnected thinking is fostered and besides this the learners are enabled to transfer knowledge and to critically analyze issues.

VLEs can be distinguished between worlds for…

- *training*: a typical example is the flight simulator, in which complex procedures are trained, but no conceptual knowledge [Schw01];
- *construction*: based on constructivistic ideas, they aim at a deeper understanding and the prevention of inactive knowledge, and are also known as world-building projects; an example is the "Virtual Gorilla Modelling Project" [Hay00];
- *exploration*: like walk-through applications they allow multichannel visualizations of all kinds of information, but usually ancient cities and similar cultural heritage projects are prevalent [Chr01];
- *experimental*: an interactive tool for creating and checking hypotheses by setting parameters for building mental models, often with a schematizing visualization, mostly for teaching natural science; a big problem is still authoring [Doerr07].

In [Walc06] a method for alleviating the latter problem in the context of networked educational systems, by means of a content production database, a special VR modeling language, and so-called VR-Beans for modeling geometry and behavior, was proposed.

Recently research also focused on virtual humans, which have enjoyed the most success in entertainment. In movies virtual characters are used that are almost life-like, but which have completely scripted actions. Characters in games can be autonomous, but the interaction with them is unnatural and limited to pre-programmed commands and behaviors. One day, virtual human experiences may be ubiquitous in education, especially in combination with natural interfaces like speech recognition. But first it has to be validated if educational objectives can be met. In [John07], it is shown with the example of training clinical examination interview skills, that a virtual human experience can be as effective as a real human experience in interpersonal skills education.

Digital Storytelling

Another requirement is to embed the learning experience into a story, which provides a context and some background information, and helps to structure exercises as well as the learning experience itself. This does not only help to motivate, but it also draws attention and makes sure an active processing by providing a purpose and a leitmotif. Last but not least narration leads to emotional engagement and the feeling of presence [Bob99, Dem02, Iss02, and Schw01]. An example for such a guided, narrative environment is the World Heritage "The Messel Pit", the biggest mammal fossil site in Europe, which was created by a maar explosion: Because for the visitor it seems to be nothing than a pit, in an AR based [Strick06] interactive story between a researcher and a child, which can be influenced by the user, its creation is explained (a screenshot is shown in Figure 1, on the left).

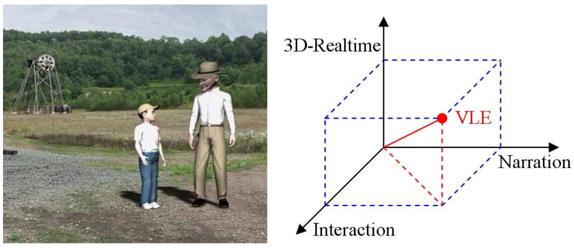

Figure 1. Left: An interactive Augmented Reality story. Right: The base dimensions of VLEs.

For teaching, digital storytelling is used to communicate complex information, mapped to a set of characters with a plot, and information is often represented by spoken dialogue of a character. But storytelling agents can achieve more than simply being virtual guides or tutors, they can also serve as all sorts of sparring partners for players to interact with. In [Spier05] a significant amount of children showed preferences for characters that rather represent co-learners than teachers. Big potential was seen in the integration of small interactive conversations. Training effects occur whilst using language as the interface, providing the construction of knowledge, which therefore appeared to be a more promising application of characters to education, than the all-knowing virtual tutor presenting facts. Unfortunately, tools for creating digital stories are usually quite complex and not intuitionally to use, besides the fact that a connection to graphical components is only rudimental. In order to alleviate this problem, in [Dos05] a multi-tier approach for augmenting MR environments with conversational, pedagogical agents was proposed.

Figure 2. Language learning with virtual characters by responding through solving the tasks.

3. BUILDING BLOCKS

Devices and Framework

Nowadays projection based systems with a beamer (or two, if stereo is needed) are also affordable for institutions with a low budget like schools or small museums. The usage of such systems is convenient for a whole group of learners and therefore encouraging the ability to work in a team. It is not only expedient for visualizing the content, where e.g. the correct perception of a scene's dimensions is important, but as a new kind of medium it can also have a great motivational impact especially on young learners. Because interaction with the scene is required, back-projection or table-based systems are needed.

Due to the already mentioned problems concerning VR-devices like space mice, finger tracking or cyber gloves (the latter also demands knowledge of special metaphors from the user), "simpler" forms of interaction have to be considered. Therefore different types of direct and indirect interaction were evaluated, with special regards to robustness, cost, usability, and adequacy. Accordingly two VLEs were developed based on the InstantReality MR-framework [IR07], which supports immersive environments and provides scene graph nodes for humanoid animation as well. Here, the behavior of the virtual world is defined by a scene graph following the concepts of X3D [X3D07].

Scenario A is an example for indirect interaction and provides additional information in a browser (see Figures 3 – 6). It deals about the medieval age, especially about the way, how cathedrals were build, and is designed to use in a history lesson for 13 years old.

Scenario B aims at learning a foreign language (English in this case) and is designed for ten years old. Here learning occurs in direct interaction with a responsive virtual character, which tells the student what to do and also serves as a guide. In Figure 2, left, a scene is shown, where the character asks the child to put the ball into the basket, what can only be fulfilled correctly when understanding the language. Many techniques used to create this scenario were developed in the Virtual Human project, a screenshot of an earlier application is shown in Fig. 7 [VH06].

System Design and Authoring Aspects

Currently the development of a learning scenario is only possible in collaboration of educators and computer scientists, because lots of expert knowledge in programming and 3D modelling is needed. But for ensuring learning success, the educator should act as lead developer. Hence it should be possible to create interactive environments with professionally designed content also for them. This means that the data has to be partitioned into the scene itself, the behaviour of objects and characters, and the learning content for allowing all specialists access to their data. Integral parts of such an authoring tool are the spatial and temporal sequence of those elements. The virtual objects act as intermediary between user and the knowledge to be acquired. So, it is an essential part of the development to design the objects realistically, fill them with life, and to provide interesting exercises. Therefore many objects, which can be integrated into the learning environment, should be available, i.e. a toolbox with learning contents is needed – even though it does not necessarily need to be obvious, how to gather the information, because as already explained the student is seen as an explorer.

Figure 3. "Grasping" of medieval tools (cruciform goniometer, hammer, etc.) in authentic context.

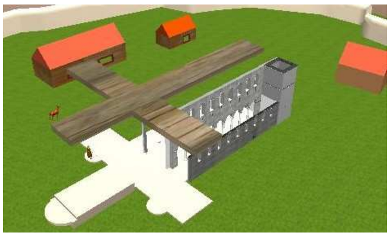

Figure 4. Correlations by multiple perspectives (animated wooden cross above the building shell of a cathedral for exemplification).

Therefore the so-called "LearningEnvironmentManager" manages the learning environment and important Use Cases, such as "walk-through 3D-world", "manipulate objects", and "gather information", as well as "help learners", "adapt content" and "control learning success" (the latter three mainly concern the educator), and it also coordinates respective user interactions. Here it is important to note, that the sequence of actions, which results from the given story, should not be entirely linear in order to allow an individual exploration. Another important object is the "LearningContent", which not only contains the 3D models, but which is also concretised with appropriate interaction objects and corresponding methods.

One big issue here was the question what abstraction level, ranging from simple geometry to an own behaviour and data repository, is needed and still manageable: Besides the rendering part at least the handling of the respective information including corresponding behaviour and the learning steps are needed. Another interesting question concerns the interaction metaphors that have to meet the needs and skills of the target audience, in order to allow full concentration on the VLE. The following basic interaction types are distinguished in this context:

- Navigation (for exploring the environment);
- Construction (requires knowledge of the structure to be build-up, etc.; see Figure 5);
- Selection (can include fully 3D multiple-choice "tests" with consecutive learning steps);
- Transport (needs for instance knowledge of the terrain and the usage of objects; Figure 6b);
- Grasp (understanding holistically through manipulating/ acting with the objects; Fig. 3);
- Interpretation (animated, additional visualization for another or a new perspective; Fig. 4).

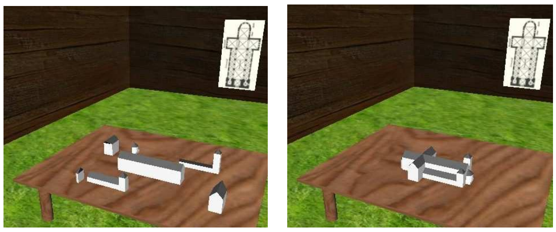

Figure 5. Construction task with additional hint at wall (left: before…; right: after reconstruction).

Especially for the interaction types construction and transport we extended X3D by an additional Snapping component, for an exact positioning of objects in VR scenes. That is also very useful for assembly simulations, because this component provides the modelling of snapping connections between parts of the scene, e.g. a shape can snap into a specified location by bringing it close to it. The mechanism distinguishes between the location where to lock in (the 'SnapIn'), and the part that should snap in (the 'SnapSensor'). The latter acts as a filter between an X3D pointing sensor and the transform node it controls. If the SnapSensor is close to a compatible SnapIn, it will adjust the incoming transformation to match the SnapIn's constraints.

The proposed "LearningEnvironmentManager" also contains a backpack – a metaphor well known from computer games that can be used as a toolbox for exercises, an additional help function for providing some guidance, a unit for controlling levels and states like in games that implicitly also controls learning success, and finally a module for handling special needs of the target audience.

Types of Interaction

3.1.1 Indirect Interaction types

Interaction can be accomplished in many ways. First an indirect interaction type, as realised in scenario A is explained. Here the scenario is divided into two parts, a 3D virtual world (see Figure 6b; the red colour of the pedestal is a feedback that indicates that the target position isn't reached yet), and a 2D web based part (Figure 6a, above). The latter not only serves as an additional knowledge base with textual information and other multimedia content like videos, pictures and sketches, but – in order to alleviate the above mentioned problems concerning VR-devices in the sense of an "augmented" VR – also, as our tests have shown, as a very efficient means for navigating through and interacting with the virtual environment. An easy-to-use and -understand navigation panel is shown in the lowest frame of the web interface.

Figure 6a. Additional textual and multimedia-based information in a web browser.

Figure 6b. Corresponding 3D interaction (transporting task from stonecutter to building shell).

Furthermore, the additional 2D part has the great advantage that on the one hand text is much better readable compared to (especially stereoscopic) 3D applications, and on the other hand that tests are easily to integrate by using common techniques well known from CBT/ WBT applications. The 2D part is also useful for providing information, which cannot be embedded expediently into the virtual world and therefore cannot be decoded without cognitive effort.

Some usage scenarios here are for example PDA's or tablet PC's for the 2D part, and a CAVE or PowerWall for the 3D part.

3.1.2 Direct interaction types

Especially in the context of language learning and social sciences one of the most direct types of interaction is the communication with a virtual character, but rendering has a lot of challenges: Flexible control of the character requires a flexible animation system including body movements and mimics, which is still an open area of research, besides the problem, that the quality of low-cost TTS systems is not convincing – which was a problem in Scenario B. Realism also means to have realistic models and gestures. Finally everything has to be done in real-time, because the interface must react immediately to user input. It has been shown [Mart89], that utilizing pointing devices in combination with speech input can lead to an increase in performance of up to 60 percent compared to only using pointing devices, but currently speech recognition systems are expensive and have to be trained, what contradicts the intended use, and still work best for grown-up males and worst for girls.

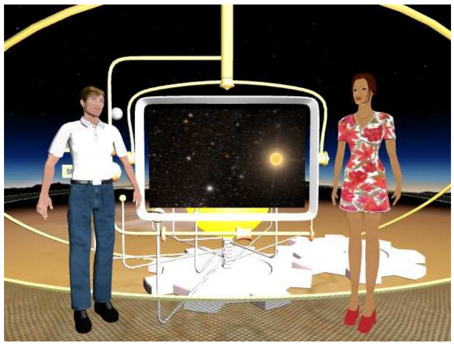

Figure 7. A VLE for learning astronomy by talking to virtual characters via speech input.

Grasping usually implies using the hands, but as already mentioned the usage of typical VR-devices has a lot of drawbacks. Therefore some more or less 2D based interaction methods that are especially suited for PowerWall-like systems were developed. They are based on the observation, that interaction or navigation via pointing seems to be perfectly natural here. Because the user should be confronted with as few devices as possible and without any additional markers etc. the pointing was designed to work in the same way as with a standard computer mouse, except that the user has to hold the pointing device in his hands. We therefore tried two different approaches – one is based on optical tracking and the other one on magnetical. The IO- subsystem of the InstantReality framework includes advanced image processing functions, which are utilized to provide marker as well as marker-less tracking, and the framework also can deal with typical VR-devices like the Polhemus magnetic tracking system for measuring 6D positions. Although distortions of the magnetic fields caused by many types of metal can be equalized very well [Zach97], this does not work for non-static fields which are timely varying due to lots of wires or mobile phones like e.g. on trade fairs. Therefore other tracking methods have to be evaluated, too.

3.1.3 Tracking

Hence the detection of the interaction device, containing an infrared LED because of the highly reflective environment, is realized using tracking methods for LED and laser points. For our first trials we used two cameras, mounted next to the screen. The cameras shutter values are set accordingly to make the light spots from the IR-LED easy and unique to detect in the camera images. Detection is done by finding the pixels in the image and connected components that form a circular spot. The center of a spot becomes the 2D point. When the points in at least two camera images are successfully detected, a triangulation is started. The 2D points and extrinsic data are fed into a linear least squares triangulation algorithm, which results in the final 3D point. Because on the one hand for our proposed interaction scheme we do not need full 3D information and on the other hand the point tracking isn't robust enough in very bright and reflective environments, we have built up another simplified setup with only one camera, which is positioned behind the silver screen. It works without any triangulation, but only undistorts the camera image of the screen, detects the 2D blobs of the IR-LED in this image and finally undistorts the blobs – a technique which also works well for (multi-) touch tables.

Figure 8. Left: Tracked aerosol can with IR-LED. Right: Spraying "graffitis" intuitively with it.

The calibration process is easy and always the same, independent of the chosen input device. First three given points on the screen, defining the viewing plane, are selected successively. Then, because 2D information is sufficient, the plane with maximum projection is determined. This is done by calculating the coordinate with the highest absolute value of the plane normal. By only using the other two coordinates in subsequent calculations and doing a simple window-viewport transformation beforehand based on the screen size, mouse-like 2D coordinates for an easily to understand interaction are obtained.

3.1.4 Evaluation

For evaluating usability and robustness of the interaction method a pure entertainment scenario for spraying graffiti, quite popular for adolescents, was developed, which was shown at the IAA 2007 in Frankfurt/ Germany (Figures 8, 9). Here the interaction device is an optically tracked aerosol can with a joystick axis as spray nozzle. This device is not only well known to everybody, but it can also be regarded as being fully immersive in the context of the application, because its usage intuitively maps to the real-world experiences of the users. Just as in reality they simply point towards the wall and press the button for painting. The farther away they are, the worse the blob detection works, because the light of the LED gets too weak – but it doesn't matter, because it's exactly what they would expect from an aerosol can. And by using a joystick axis instead of a button, another typical effect can be achieved: The stronger the nozzle is pressed, the more intense the color is. Hence, the users were able to produce nice images and the overall acceptance of the application was very high.

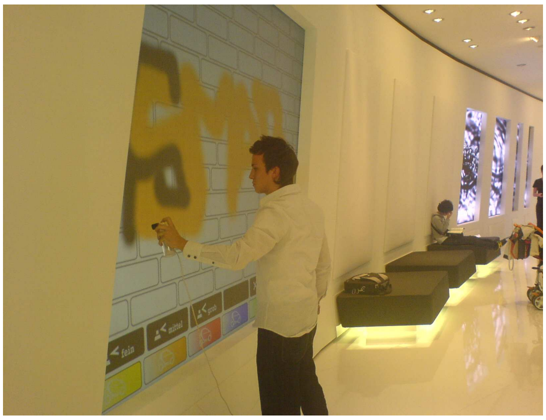

Figure 9. Natural Interfaces: Virtual Graffiti on the International Motor Show (IAA, Sept. 2007).

4. CONCLUSION & FUTURE WORK

In this paper MR/ VR learning was discussed also from an educational point of view and upon this important features and requirements were outlined. Virtual learning environments allow first-person experiences, even if this would be impossible or too dangerous in real life. Despite a free exploration the manipulation of content is essential for a deeper understanding. Therefore important interaction tasks were classified and novel interfaces were proposed, which are also useful for other application types. Furthermore it was shown that contextualizing and structuring exercises are needed for learning applications, preferably embedded within a story.

To prove this, two different learning scenarios were developed, whereas first tests have shown, that the one with additional browser based information (scenario A) led to a more sustainable learning experience then the pure 3D-based one. But that also might be due to the fact, that it still was much easier to create interactive and information rich 2D-based environments than fully immersive ones, with realistic virtual characters as multimodal dialog partners.

There are still too few learning environments which could be used in class, because for actually meeting the students' needs, as educational sciences have shown, VLEs have to be adapted to the students and the current lesson. Thus, for enabling teachers to create fitting environments, the objective is to allow usage and combination of arbitrary objects and actions already on a more conceptual level, comparable to the preparation of an instruction plan.

Future work will focus on the evaluation and further development of suitable methods and authoring tools for mixed reality learning systems. These also include (living) narrative environments with virtual characters as a type of action driven interface for serious games and the training of social skills.

5. REFERENCES

[Bob99] Bobick, A. / Intille, S. / Davis, J.: The KidsRoom: A Perceptually-Based Interactive and Immersive Story Environment. In: Presence: Teleoperators and Virtual Environments, 8 (1999), 4. pp. 367 - 391.

[Chr01] Christopoulos, D. / Gaitatzes, A. / Roussou, M.: Reviving the past: Cultural Heritage meets Virtual Reality. In: Proceedings of the 2001 Conference on Virtual Reality, Archeology and Cultural Heritage. New York 2001. 103 - 110.

[Dem02] Demantowsky, Marko/ Schönemann, Bernd (Hrsg.): Neue geschichtsdidaktische Positionen. Dortmunder Arbeiten zur Schulgeschichte und zur historischen Didaktik; Bd. 32. Bochum 2002.

[Doerr07] Dörries, G., Geiger, C., Heinze, C., Lehmann, A., Klompmaker, F.: Visuelles Authoring interaktiver 3D-Inhalte für den Einsatz in der Lehre. 4. GI VR/AR Workshop, Shaker Verlag. 2007.

[Dos05] Doswell, J. T.: It's virtually pedagogical: pedagogical agents in mixed reality learning environments. In: ACM SIGGRAPH 2005 Educators Program. ACM Press, New York, 2005.

[Hay00] Hay, K. E. / Crozier, J. / Barnett, M.: Virtual Gorilla Modeling Project: Two Case Studies of Middle-School Students Building Computational Models for Inquiry. 2000.

[IR07] InstantReality: http://www.instantreality.org/

[Iss02] Issing, Ludwig J. / Klimsa, Paul (Hrsg.): Information und Lernen mit Multimedia und Internet - Lehrbuch für Studium und Praxis. 3., vollst. überarb. Aufl., Weinheim 2002.

[John07] Johnsen, K., Raij, A., Stevens, A., Lind, D. S., and Lok, B.: The validity of a virtual human experience for interpersonal skills education. In: Proc. of the SIGCHI Conf. on Human Factors in Computing Systems '07. ACM Press, 1049-1058.

[Jank94] Jank, Werner / Meyer, Hilbert: Didaktische Modelle. 3. Aufl. Frankfurt am Main 1994.

[Kais91] Kaiser, Arnim / Kaiser, Ruth: Studienbuch Pädagogik: Grund- und Prüfungswissen. 6. Aufl. Frankfurt am Main 1991.

[Lang02] Lang, Martin / Pätzold, Günter: Multimedia in der Aus- und Weiterbildung: Grundlagen und Fallstudien zum netzbasierten Lernen. Köln 2002.

[Mart89] Martin, G.: The Utility of Speech Input in User-Computer Interfaces. In: Int. Journal of man – machine Studies, 30(4), 1989. 355-376.

[Schul02] Schulmeister, Rolf: Grundlagen hypermedialer Lernsysteme: Theorie - Didaktik - Design. 3., korrigierte Auflage. Oldenbourg 2002.

[Schw01] Schwan, Stephan / Buder, Jürgen: Virtuelle Realitäten: Ein pädagogisch - psychologischer Überblick. Abstract des Überblicksreferats auf der 8. Fachtagung Päd. Psychologie. Landau, 2001.

[Spier05] Spierling, Ulrike: Beyond virtual tutors: semi-autonomous characters as learning companions. In: ACM SIGGRAPH 2005 Educators Program. ACM Press, New York, 2005.

[Strick06] Stricker, D.; Zoellner, M.; Bisler, A.; Lutz, B.: Traveling in Time and Space with Virtual and Augmented Reality. In: Baltsavias, E.; ETH Zürich: Recording, Modeling and Visualization of Cultural Heritage. London, 2006, pp. 431-439.

[VH06] VirtualHuman: http://www.virtualhuman.de/

[Walc06] Walczak, K.; Wojciechowski, R.; and Cellary, W.: Dynamic interactive VR network services for education. In: Proceedings of the ACM Symposium on Virtual Reality Software and Technology, VRST '06. pp. 277-286.

[Winn03] Winn, William: Learning in artificial environments: Embodiment, embeddedness and dynamic adaptation. In: Technology, Instruction, Cognition and Learning, 1 (2003). 87 - 114.

[X3D07] Web3D Consortium: Extensible 3D (X3D) ISO/IEC CD 19775-1r1:200x, 2007. http://www.web3d.org/x3d/specifications/ISO-IEC-19775-X3DAbstractSpecification_Revision1_to_Part1/

[Zach97] Zachmann, G.: Distortion Correction of Magnetic Fields for Position Tracking. In: Proc. of the 1997 Conf. on CG int., IEEE Computer Society. Washington, 1997, pp. 213-220.