Virtual Reality as an Innovative Setting for Simulations in Education

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Abstract

The increasingly widespread use of simulations in education underlines the fact that these teaching tools compared to other methods or media allow students to approach and experience new topics in a more realistic way. This realism enhances their learning and understanding of complex subjects. So far it has been difficult to interactively simulate three-dimensional dynamic learning content. In this field, the continuing development of Virtual Reality (VR) offers new opportunities for educators to convey a wide variety of subjects. It is the aim of this paper to characterize the nature of Virtual Reality as an educational setting for simulations, and to show that *Studierstube,* our multi-user collaborative Virtual Environment, comprises the necessary features for applying VR-techniques to educational purposes. We further discuss the general applicability of VR to various fields of education and demonstrate its specific application as a tool for teaching elementary three-dimensional geometry.

KEYWORDS: Simulation, Virtual Reality, Augmented Reality, Geometry Education

EDUCATIONAL BENEFITS OF SIMULATIONS

The application of gaming and simulation techniques to education and training is a comparatively recent but promising development. Although the first applications of games and simulations in the field of military training date back to the end of the eighteenth century, it was only in the mid-1950s that the use of complex teaching methods such as games, simulations and case studies was successfully introduced into business management training. Further developments of these techniques as educational tools allowed their application in the social sciences in the 1960s and then, starting in the 1970s, they spread to an ever-increasing range of other disciplines at all levels of education. Aided and stimulated by the didactic opportunities that computer technologies offer, the use of games and simulations within education is still growing rapidly.

A generally accepted definition of simulations is that given by Guetzkow [1962 and 1963] who characterizes a simulation to be an operating representation of central features of reality. A simulation must therefore represent a (conceivably) real situation and must be dynamic. For Raser [1976]

simulations are dynamic models, a model being a representation of the structures and relations within a system [also see Wallquist, 1990].

Simulations have distinctive features that have proved especially useful for educational purposes for the following reasons [Ellington/Gordon/Fowlie, 1998; Raser, 1976]:

REDUCED COMPLEXITY AND ACCENTUATION

Contrary to real life situations simulations can be tailored according to the desired educational objectives. A simulation can include all features educators consider necessary and have all aspects left out that are found irrelevant or distracting. Complexity is reduced, at the same time important aspects can be accentuated. Constraints of real life settings can be avoided: in many cases real situations and settings are too complicated, too dangerous or too expensive or even impossible to create whereas Therefore, a lot of simulation techniques are used to supplement and/or substitute conventional laboratory work in chemistry, biology, physics or technology: Simulations allow experiments in human genetics, in reactor physics or population dynamics, just to name a few examples. Raser [1976] summarizes the reasons for using simulations that are mainly due to the aspects of reduction and accentuation: Some features of a system only become visible in a simulation. Some processes in the simulations can be run several times whereas in reality it would be impossible to reproduce a certain state or to repeatedly run a certain process. In many cases it is less expensive and less dangerous to build a simulation than to use the real system. A future pilot who still makes mistakes when flying will better learn about his weaknesses in a flight simulator than by causing a plane crash [also see Lehmann, 1976].

FLEXIBILITY

Due to the features of reduced complexity and accentuation, simulations are highly versatile and flexible. Therefore, a variety of levels of complexity and of difficulty can be achieved according to the cognitive and/or affective objectives that are to be attained.

Additionally, simulations can either be run by one person or simultaneously by a number of persons. Not only should students hence be able to acquire factual as well as procedural knowledge but also to develop interdisciplinary (transferable process) skills such as decision-making, problem-solving, divergent thinking, interpersonal and communication skills.

STIMULATION OF INTEREST AND MOTIVATION

Simulations are student-centered teaching methods, requiring the students' involvement and active participation in the simulation process to operate the system. Many students find this kind of learning to be more interesting and motivating than having conventional classroom teaching. Evaluations of student-centered teaching methods have shown that student motivation and interest are significantly stimulated. How much students actually learn depends of course not only on the quality of the teaching method itself but also on their prior knowledge, their general and specific abilities and on instructional quality, i.e. the way the method is implemented for teaching by the teacher [Miles et al., 1986; Boocock/Coleman, 1976; Randel et al, 1992].

Simulations can be used for a wide variety of educational purposes. Though they usually offer no advantage over conventional face-to-face teaching ("chalk and talk") as to conveying basic facts and principles of a subject, they are particularly appropriate to demonstrate applications of these facts and principles. They mainly allow to provide illustrative examples which may also be dynamic and three-dimensional ones that can hardly be included in a conventional textbook.

On the other hand, the distinctive features of simulations imply problems and weaknesses that are typical of more complex teaching methods [Ellington/Gordon/Fowlie 1998]:

Due to their complexity the application of simulations might cause organizational problems by being too time-consuming and hence not fitting into the curriculum. Moreover, they might also require special facilities and equipment.

Some teachers might only choose simulations as teaching tools because they consider them time fillers or diversions. But just because simulations have the potential to foster learning and enhance understanding this does not necessarily mean that every use of simulation techniques will automatically be

educationally effective regardless of the teacher's efforts to introduce the students into and guiding them through the learning process. Many teachers neglect the fact that students are likely to not derive any benefit from dealing with the simulation process if they lack the support from their teachers they need to understand the system and use it effectively.

Within their model of classification of cases, games and simulations, Ellington, Gordon and Fowlie [1998] classify Virtual Reality (VR) situations and settings as simulations. The increasingly important use of computers as a tool, a medium or as learning content in education offers new opportunities to educators and challenge them at the same time. Teachers are expected to use computer technologies for their teaching in a meaningful and skilful way. The following paragraphs aim to introduce VR and especially *Studierstube,* our multi-user collaborative Virtual Environment, as a medium to effectively generate interactive simulations of three-dimensional dynamic learning content that have been difficult to develop for educational purposes thus far.

STUDIERSTUBE AS AN INNOVATIVE EDUCATIONAL SETTING FOR SIMULATIONS

Real-time 3D display, highly interactive setting, and sophisticated 3D interaction are characteristic properties of *Virtual Environments* (VE). Studierstube, our implementation of a collaborative VE, extends these features by introduction of individual views and viewpoints, personal interfaces, and collaboration techniques. We apply *Augmented Reality* (AR), the less obtrusive cousin of Virtual Reality that enables computer generated images to be overlaid over reality using semi-transparent *head-mounted displays* (HMDs). This does not only allow direct social user interaction without mediating layers of software but also the possibility of including objects of the real environment – tables, mirrors, architectural models etc. – into the interaction concept.

FIGURE 1:
WORKING IN CONSTRUCT3D. THE TUTOR ASSISTS THE STUDENT WHILE WORKING ON THE MODEL. (IMAGE COMPOSITION)
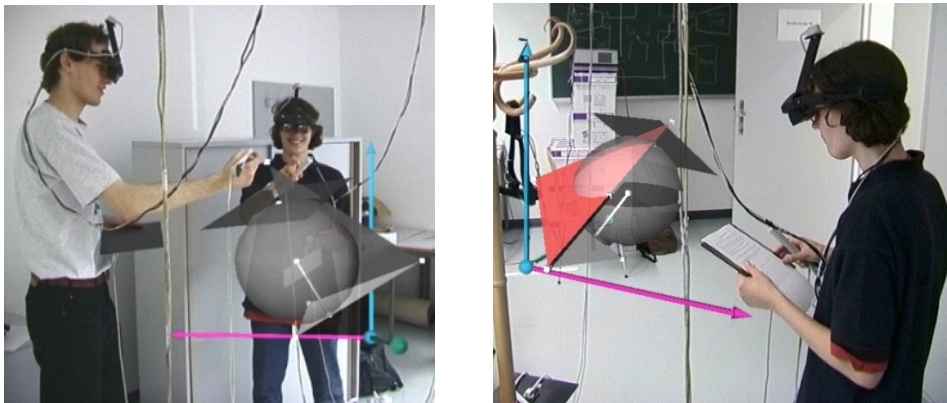
Studierstube is intended to be a collaborative AR user interface in which a variety of tasks can be performed. Such a user-interface is opposed to a dedicated application that is designed for only a single purpose, a concept dominant in today's VR installations. From the very beginning of the development of Studierstube it has been considered not only an environment for scientific use but also an appropriate setting for applications in the field of education [Schmalstieg at al., 1996]. Many distinctive features of Studierstube's hardware setup and underlying software concepts support teaching processes:

- Collaboration
  Studierstube supports *local collaboration*, multiple users may interact with any number of applications and with each other during a session. *Remote collaboration* of multiple groups of users via Internet connections will support distance education situations.

- Augmentation
  Since we display the computer generated images as *augmentation* of reality, participants can still use conventional teaching aides, like books and black- or whiteboards. In a local setup, where all users are in the same room, there is no need for the introduction of *avatars,* representations of the users` bodies in the Virtual Environment, since the users are able to see each other directly through the HMDs.

- Customized Views
  As described above, each user wears an individual HMD, which displays images rendered only for this user's viewpoint. Since the images have to be generated „customized" for each user, it presents no major problem to integrate this „customization" into the semantics of the system: each user is provided with a particular view of a virtual world according to his/her status in the situation. For example students may see the teacher's presentation, but not the teacher's notes, or a teacher may switch off certain aspects of the students' display, like political borders or country names on a virtual globe. An important aspect is privacy for students during a test: the teacher may see the students' work, but the students may not see each other's work.

- General Framework
  Studierstube does not represent a specialized application of Virtual Reality interaction techniques, but a *framework* in which many different applications may perform concurrently or exclusively [Fuhrmann and Schmalstieg, 1999]. The *content* of Studierstube depends on the different applications, only the *interaction paradigms* implicit in Studierstube's underlying software and hardware structure remains the same. This mirrors modern graphical user interfaces: What an application does is independent of the interface similarities (mouse, windows, menus).

The unique properties of Virtual Environments render them very suitable for a variety of different application areas one of which is the field of education: Three-dimensional input and output, real-time animation, simulation, and visualization are useful features for many but not all teaching goals and efforts. Studierstube promises to be a highly effective teaching method for all subjects whose content of learning includes spatial relationships, complex three-dimensional structures, dynamic models or simulations of physical processes [Fuhrmann et al., 1998]. In these cases students can acquire and apply knowledge in a more realistic way than they could have done with any other method or media. Studierstube's collaborative aspects can enhance cooperative work such as creative problem solving processes.

This does not imply that VEs should replace all other teaching methods or media, but it is considered to supplement them in an effective and meaningful way by contributing to the students' understanding and learning. By letting the students directly manipulate and experiment within the virtual world, a higher level of elaboration is reached than just by reading a book or listening to the teacher. Today's technology has not yet reached the point where all teaching processes may take place in a Virtual Environment, but considering the experiences that we have made so far with the development and use of Studierstube we have no doubts that Virtual Reality's enormous potential to foster learning and understanding will finally – as technology progresses – lead to a widespread use for educational purposes.

Table 1 proposes appropriate application examples to illustrate Studierstube's applicability to different teaching specific subjects.

TABLE 1
APPLICATION EXAMPLES FOR STUDIERSTUBE

Subjects	Examples	Applicability
Geography	virtual globe, geological visualizations, satellite data	good
Physics	simulation of relativistic effects, kinematics, dynamics	
Astronomy	planetary motions, virtual planetarium	
Biology	medical visualization, virtual microscope, virtual dissection	
Chemistry	molecular simulations	
History	visualization of ancient cities, games and simulations	
Geometry	3D constructions	
Analysis	visualization of functions	
Architecture	virtual models, walkthroughs, construction and planning	
Economics	simulation of economic systems by collaborative games	average
Languages		poor
Symbolic math		
Literature		

As the table shows, natural sciences dominate the spectrum of applicable topics. These are subjects which naturally lend themselves to demonstrations and experiments, and have traditionally been supported by such. Studierstube extends the possibilities by simulating settings which otherwise would be dangerous, too expensive or even physically impossible to implement. Even conventionally three-dimensional implementable props – orreries, molecular construction kits, globes – can be more conveniently implemented in VR and thereby freed from physical limitations.

Most of these applications are self-evident, but some topics need more elaboration. Teaching and learning historical and prehistorical matters can be enhanced and supported by virtual reconstructions of artefacts and buildings. As to the field of economics, Studierstube enables students to directly manipulate parameters of economic models or to cooperate in simulations in which each student adopts the perspective of a particular economic entity like consumers, state, businesses or a whole country. Here the advantage of an VE opposed to conventional methods – books, presentations, discussions – would be high, since complex interdependencies can be experienced directly, but a similar concept could probably be implemented using a network of desktop computers. Studierstube would in this case only provide convenient ways to visualize economic variables and interact with other students.

Topics which do not directly benefit from the advantages of a VE have the common factor of symbolic manipulation: teaching languages, abstract concepts like algebra or literature can not easily benefit from 3D interactions or simulations. While of course applications can be found, most of them can be implemented using conventional media like video or CD-ROMs.

The following paragraph is intended to illustrate the specific application of Studierstube to the field of geometry education, in this case to teaching elementary three-dimensional geometry.

ILLUSTRATIONS OF TEACHING SIMULATIONS IN VIRTUAL REALITY

We use the collaborative augmented reality system "Studierstube" [Schmalstieg et al. 1996; Szalavári et al. 1998; Fuhrmann / Schmalstieg, 1999]. As an augmented reality system, it allows an integration of the virtual world into the real world. Users can partly see the real world and interact with it – a feature that proved to be very useful for our application. In addition this VR system provides us with very useful built-in features such as multi-user capabilities and support of the Personal Interaction Panel (PIP). We added sound support to the "Studierstube".

We chose to use the Personal Interaction Panel, (Szalavári and Gervautz, 1997), a two-handed 3D interface composed of a position tracked pen and pad to control the application. It allows the straightforward integration of conventional 2D interface elements like buttons, sliders, dials etc. as well as novel 3D interaction widgets. The haptic feedback from the physical props guides the user when interacting with the PIP, while the overlaid graphics allows the props to be used as multi-functional tools (Figure 2). Every application displays its own interface in the form of a PIP "sheet", which appears on the PIP. The pen and pad are our primary interaction devices. The pen has two buttons, a front – also referred as the primary – button and a back or secondary button. We use both.

FIGURE 2:
**WORKING WITH THE PIP IN AUGMENTED REALITY.**
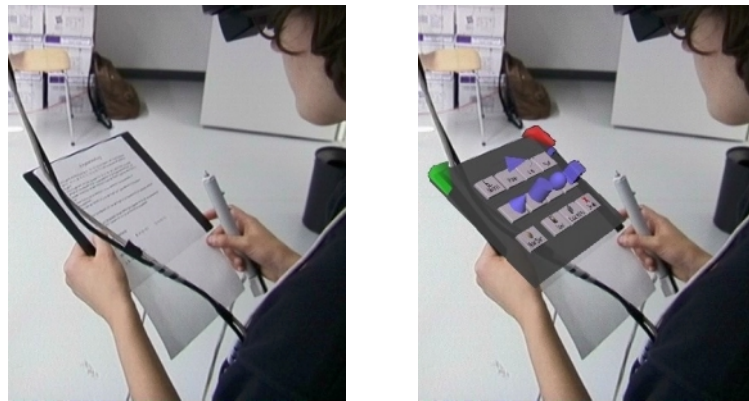
left: By looking out from underneath the head mounted display at the menu panel, the
          instructions on a sheet of paper can be read.
right: By looking through the HMD the menu system with 3D buttons can be seen.

USER INTERFACE

Our source of inspiration for designing a user interface for this HMD-based application is based on various ideas, problems and suggestions from such diverse areas as user interfaces, user centered design, usability engineering, human computer interaction in general [Szalavári / Gervautz, 1997; Mine et al. 1997; Baudisch, 1996; Pierce et al. 1997] as well as current software used for 3D modelling.

The PIP sheet of Construct3D represents the menu system. We try to keep the menu very simple. Large, textured 3D buttons are used with meaningful 3D icons floating above the buttons to allow easy and fast selection of the menu elements (Figure 3).

FIGURE 3:
PIP SHEET AND MENU OF CONSTRUCT3D
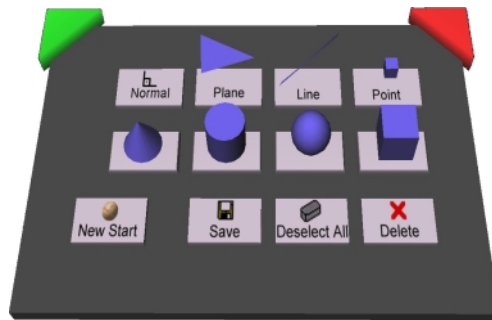
Menu selection is achieved by moving the pen over the appropriate 3D button until it is highlighted and clicking on the primary button of the pen (a highlighted 3D button can be seen in Figure 4). The menu button turns red when clicked and appears pressed down – a selection technique known to most users from 2D window interfaces.

The representation of the pen in the virtual world is a small green cylinder with a spherical red end and a conical blue tip as can be seen in Figure 4. Two functions are assigned to the two buttons of the pen and can be activated at any time during the construction process. By clicking the primary button the user places a point at the current position – a point is represented by a small cube instead of a sphere, to keep the number of polygons low for its presentation in the virtual world.

The secondary button selects the geometric element that is nearest to the current position of the pen. Once an element is selected it is highlighted in red (e.g. the cutting plane in Figure 3). In order to be able to select points on surfaces for instance, points have selection priority over other elements by default. Selecting a selected element again deselects it.

ORIENTATION AND NAVIGATION

When starting Construct3D the user faces a three dimensional coordinate system centered in its workspace, in the middle of the room. For easier orientation in the three dimensional coordinate system we attach a very simple "grid" to the tip of the pen [Baudisch, 1996]. This grid consists of three axis parallel lines, pointing from the current position to the foot in the corresponding coordinate planes xy, xz and yz.

In addition, the current coordinates in the given coordinate system are displayed left of the pen in centimeters with millimetre precision. Coordinates are written line by line, the text always faces the user. This enables construction of given points by their coordinates.

TOOLS AND FUNCTIONS

Seven basic objects can be constructed by clicking the appropriate 3D button on the PIP: point, line, plane, box, sphere, cone and cylinder (Figure 3). The four solids box, sphere, cone and cylinder are drawn semi-transparent in order to see objects inside and behind solids (e.g. in Figure 4 the axis and the point of the plane behind the cylinder).

FIGURE 4:
SAMPLE CONSTRUCTION AS SEEN BY A USER THROUGH THE HMD.
THE HIGHLIGHTED PLANE INTERSECTS THE SEMI-TRANSPARENT CYLINDER IN AN
ELLIPSE.
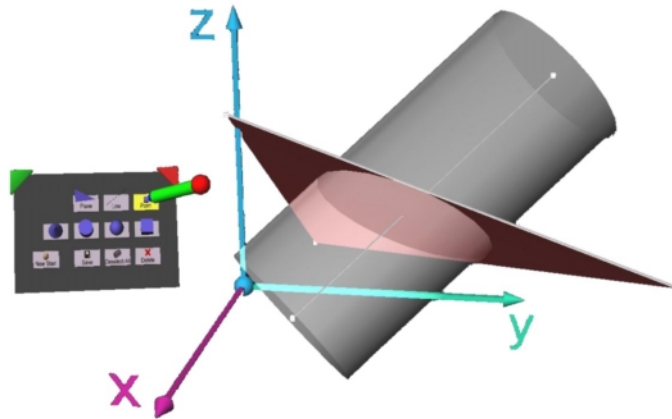
There are four other menu buttons. Clicking the "Delete" button deletes all selected objects, "Save" saves the whole scene as an Open Inventor file which can be loaded and manipulated afterwards with desktop tools. "New Start" deletes all objects and resets the environment to initial state. The "Deselect All" button deselects all selected objects. For every new construction new elements must be selected, therefore deselecting all elements at once is faster than deselecting objects one by one. We implemented a gestural action (as suggested by Mine et al. [1997]) to speed up and simplify this action. If all objects are outside a certain range of the pen and the user clicks the secondary button (selection button) all objects are deselected. The easiest gestural action related to this algorithm is to move the arm down, parallel to the body and press the secondary button.

Unless generating a point, base elements must be selected before a new shape can be constructed. A line requires two points as input elements. A plane can be generated by three points, one point and one line or two lines. If a user selects a line and a point and clicks on the plane button for example, the system recognizes the selected elements and calls the according procedure to draw a new plane.

A box requires the lower left and upper right corner as input. To construct a sphere the midpoint and one point on the sphere or the midpoint and two points indicating the radius of the sphere must be given. A cylinder can either be generated by two points (their connecting line representing the axis) and a point on the surface or by a line (the axis) and a point on the surface or by two lines, the first one being the axis, the second one being a tangent to the cylinder. A cone requires three input points: midpoint of the base circle, apex and a point on the cone. When more than one point is needed, the order of the selection is relevant.

The "Normal" menu button has been assigned construction of normal lines and normal planes to given elements. Input of a point not lying on a plane, sphere, cylinder and cone results in a line perpendicular to the selected surface. Selecting a point on the surface of a sphere, cylinder or cone results in a tangent plane.

The "Point" button is used for calculating intersection points. Intersections of line with line, plane, box, sphere, cylinder and cone are implemented.

AUDIO HELP SYSTEM

If the user selects a menu button without having selected the correct base elements, an audio help system, which otherwise remains in the background, gives feedback. A realistic, computer generated, female voice offers help such as "Please select axis and point on cylinder or a tangent" when trying to construct a cylinder.

EDUCATIONAL ANALYSIS

The crucial question is of course if the further development of VR as educational settings is a worthwhile endeavour from the pedagogical (especially didactic) perspective. From what research findings tell us about thinking and learning, what can we derive for instructional practices and educational environments such as Studierstube?

First of all, contemporary learning theories of cognitive sciences stress the importance of students' prior knowledge and preconceptions about a subject. This implies that teachers should identify, activate, and work with their students' initial understanding of a subject as well as provide them with the required basic knowledge they need to understand and correctly work with new information. Basically, students must have a deep foundation of knowledge, understand facts and procedures, and be able to organise their knowledge to develop competence in an area. Therefore, teachers should teach a subject matter "in depth", providing a firm foundation of factual ("knowing WHAT") and procedural knowledge ("knowing HOW"). This means that information should not only been given in a clear and understandable manner, but teachers should additionally illustrate the application of knowledge by providing a variety of examples. Research has shown that experts have fluent access to their knowledge, they have a better conceptual understanding which helps them select and learn relevant information and learn further related information. Meta-cognitive strategies like organising one's own knowledge can be taught but this kind of instruction must be incorporated into the specific subject matter of a variety of subject areas, meta-cognitive strategies are not generic across subjects [Fortmüller, 1991 and 1996; Pellegrino, 2000].

How can technology like the application of VR settings support a meaningful and effective learning process? Virtual Reality allows the teachers to create meaningful realistic problems they need to organise the establishment of new knowledge elements around. Especially for dynamic 3D-learning content it has been very difficult or even impossible so far to prepare problems that allow students to experience learning content in a realistic way and to apply their knowledge by exploring and experimenting with the components of the dynamic (virtual) system. The use of technology for teaching allows new levels of complexity: Students need not memorise isolated facts but they can use their newly acquired knowledge to fulfil authentic tasks. Technology brings complex but manageable problems into the instructional setting [Pellegrino, 2000].

But having complex and interesting problems is not enough. Instruction must provide scaffolds for solving meaningful problems and supporting learning with understanding such as modelling, coaching, or guiding through the learning process. In these cases, technology can provide resources to assist problem solutions, to give feedback on the quality of problem solutions, and to support reflection on the solved problem [Schneider, 1993 and 1996; Pellegrino, 2000].

In terms of social arrangements of instruction, technology like the VR setting of Studierstube promotes collaboration as well as independent learning. Collaboration is an important student interaction pattern that helps students develop indispensable interpersonal skills that are needed in every field of business and private life [Pellegrino, 2000].

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