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A system for exploring open issues in VR-based education

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Abstract

Virtual reality has been shown to be an effective way of teaching difficult concepts to learners. However, a number of important questions related to learning, immersion, collaboration and realism remain to be answered before truly efficient virtual learning environments can be designed. We present CyberMath, an extendable avatar-based shared virtual environment for teaching and exploration of non-trivial mathematics that allows further study of these issues.

Keywords: Virtual reality; Education; Collaborative virtual environments

1. Introduction

Virtual reality (VR) systems have the potential to allow learners to discover and experience objects and phenomena in ways that they cannot do in real life. Since the early 1990s, a large number of educational VR applications have been developed. These include tools for teaching physics [1], algebra [2], color science [3], cultural heritage objects [4] and the greenhouse effect [5].

There is convincing evidence that one can learn from educational VR systems [6]. However, a number of unresolved issues regarding the efficiency of such systems still remain.

2. Formal training vs. free-choice learning

Recent research indicates that the mechanisms of learning that take place in traditional museums are very different from those that arise in formal training. What museum visitors learn is not only influenced by their previous knowledge, interests, beliefs and feelings, but also depends on the interaction with other visitors and docents and on the physical characteristics of the museum environment itself. Because of the free-choice learning situations that arise in museums, one cannot assume that the learning process follows a totally prescribed and predictable course. Rather, visitors tend to remember very general things about an exhibition and random detailed information of particular exhibits. It is less common that visitors learn global concepts and overarching principles [7].

Most existing VR systems for education are based on the constructivist learning theory, which assumes that the learners construct their own understanding of what they study and that learning is a collaborative process. As a result, the design of these systems often encourages free-choice learning and discovery. However, the goal for the systems is very often to support or even replace traditional school education.

It may very well be that it is possible to use the free-choice theories that originate in museum research to understand the learning that takes place in educational VR systems. If so, the discrepancy between the goals of traditional school education and the unpredictable nature of museum and free-choice learning may help explain some of the reported failures of educational VR systems [8].

3. Immersive vs. non-immersive VR

Several different authors have shown that immersive VR, where the learner is in a CAVE or wears a head-

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mounted display, can be more efficient than monitor-based desktop VR [9]. Unfortunately, current immersive VR systems are expensive, fragile, and can be cumbersome to use. These drawbacks make them hard to utilize for larger groups of learners. It also means that they are hard to integrate into existing school environments where resources are limited. Desktop VR systems, however, can often run on standard PC hardware, equipment that is increasingly common in homes and in classrooms today. Also, learners using desktop VR systems are less likely to experience motion sickness and fatigue, factors that are known to inhibit learning [10]. It is unclear whether the advantages of desktop VR systems can make up for their lack of immersion.

4. Collaboration in educational VR systems

A number of different initial studies suggest that collaboration between learners in virtual environments have a positive educational effect [5,8,11,12]. However, little is known about how the presence of a teacher or facilitator influences learning in VR applications. It is likely that the learners will benefit from facilitator guidance, but it is also possible that a system that allows the teacher to take a more active role within the virtual environment would have a positive effect.

Avatar-based multi-user virtual environments can induce the formation of user communities. The increased level of anonymity and "safety" in such communities may encourage users that usually avoid experiential learning situations to participate in educational activities [13]. However, it can be more difficult to avoid digression in discussions when the participants are anonymous than when they are known to each other [14]. There are few available guidelines for handling large-scale participation in educational VR systems.

5. Visual realism in educational VR systems

A number of different studies have shown that visual realism in VR applications must be used with care [15]. It is not certain that an increased level of realism will improve learning since it may distract the learner from focusing on the subject that is to be learned. However, the motivational value of excessive visual realism is very high, something that the motion picture and computer games industries have been taking advantage of for decades. How to use realism in order to highlight key relations and concepts in educational VR applications is still an open question.

This paper presents CyberMath, a system in which all of these issues can be explored. To our knowledge, no previous educational VR system has all the features necessary for such studies. In addition, CyberMath is built to support the exploration of many mathematical subjects, ranging from elementary school content to post-graduate content.

6. System description

CyberMath is an avatar-based shared virtual environment. Its original implementation (illustrated in Fig. 1) was based on DIVE [16], which is a application development framework that has the ability to display interactive three-dimensional graphics as well as to distribute live audio between standard desktop PCs. However, we quickly discovered that DIVE has a number of drawbacks. Our main concerns lie with its limited visual quality, fixed feature set, low execution speed and lack of security features. Also, DIVE is somewhat crash prone and hard to configure and set up.

As a result, we chose to re-implement CyberMath using VRJuggler [17] together with a number of C++ graphics and networking utility libraries that are under development at the Royal Institute of Technology. This setup supports a number of hardware configurations, ranging from desktop PCs with standard consumer-grade graphics cards to CAVE environments, which will allow us to study how different levels of immersion influence the learning process.

CyberMath is built as an exploratorium that contains a number of exhibitions (Fig. 1). This allows "docents" or facilitators to guide the visitors through the exhibitions at pre-arranged times, but also allows the visitors to peruse the environment at their leisure, alone or together with others. Since CyberMath can distribute information across networks, learners from different physical locations can visit the environment simultaneously.

Multiple visitors can simultaneously manipulate an exhibition object in CyberMath. In order to reduce confusion, it is important to make explicit the presence of each visitor in the virtual environment. In addition, we believe that visualizing user presence and allowing these visualizations to transfer emotional content (such as facial expressions) increases the potential for person-to-person collaboration and interaction. The way visitors control their avatars in CyberMath is similar to many popular computer games. Since many learners are familiar with these games (especially younger learners), our hope is that this will shorten the time required to master the controls.

When a visitor points to an object in the environment using the computer mouse, his/her avatar will indicate this through a "laser pointer"—a red line from the eye of the avatar through the indicated point on the object.

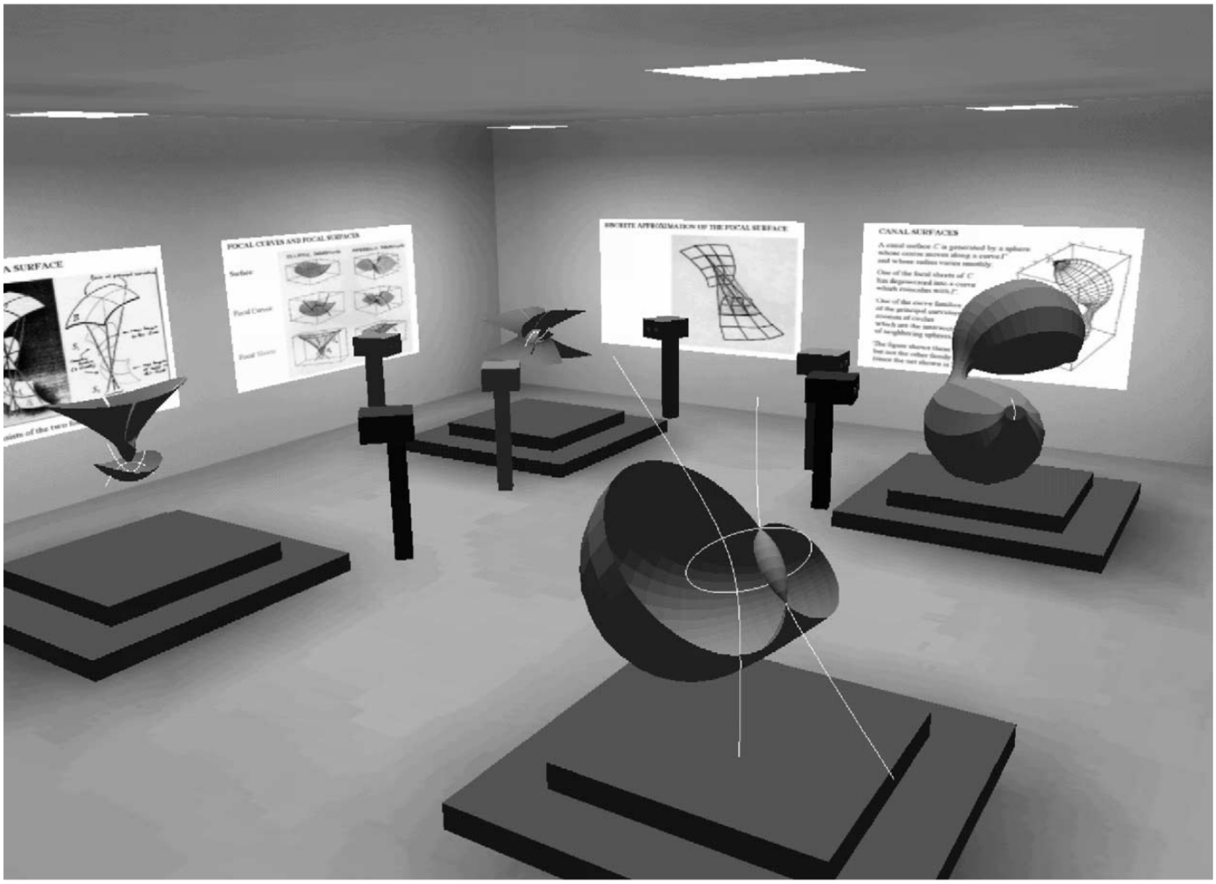

Fig. 1. A CyberMath exhibition (DIVE version).

Each avatar also has a sound indicator that is activated when its corresponding visitor speaks into the computer microphone. Exhibited objects can be manipulated by using the computer mouse. Action buttons situated next to interactive exhibitions control animations and the visual representation of the objects in the exhibit.

All objects in CyberMath, including the user avatars, can be visualized at a number of different levels of realism, ranging from uniformly colored surfaces to radiosity lighting. This makes it possible to investigate how realism affects learning in virtual environments.

We have built a Mathematica-to-CyberMath conversion utility that can be used to convert standard three-dimensional Mathematica objects and animations to the CyberMath file format. It is then straightforward to add C++ code to turn the converted Mathematica objects into interactive CyberMath exhibitions. This makes it possible to support rapid-turnaround teacher-driven development of new CyberMath exhibitions in the same fashion as in the QuickWorlds project [18].

The original DIVE version of CyberMath had the ability to associate URLs with exhibition objects, so that when a visitor clicked on an object, a corresponding URL was opened in a www browser. This made it easy to offer additional information about the exhibited objects (such as mathematical formulae and links to other relevant www pages). We are currently implementing this in the new CyberMath version.

A number of example exhibition areas in the exploratorium have been completed.

7. Interactive transformations

With this exhibit, learners can explore the effect of any R^3-R^3 transformation on different mathematical entities such as points, lines, planes and spheres (illustrated in Fig. 2). First, the learner selects a transformation by entering it on the blackboard behind the exhibit. This involves clicking on the blackboard and typing the desired expression on the computer keyboard. Then, a geometric entity is chosen by clicking on one of the buttons on the front side of the exhibit. The points on the entity are transformed in real-time by the transformation on the blackboard and the result is immediately shown in the coordinate system on the

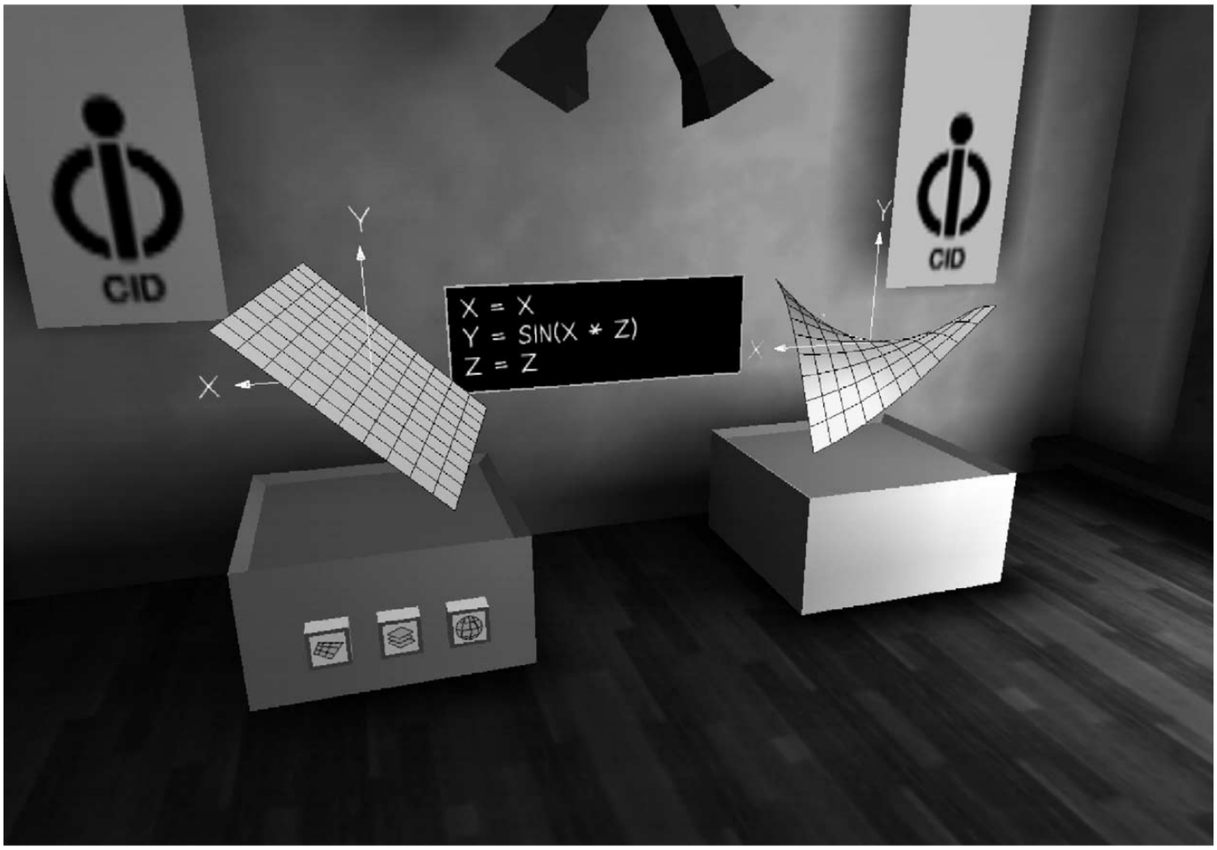

Fig. 2. The interactive transformation exhibit.

right. The learner can interactively rotate and translate manipulate the geometrical entities. This makes it possible to explore the transformation in a new way to get an intuitive sense for how it works, and it is also possible to interactively search for singularities and degenerate points in the transformed domain. We believe that this exhibit increases the cognitive contact with the mathematical ideas behind the transformation formulae.

8. Generalized cylinders

This exhibition illustrates how to increase the number of degrees of freedom in revolution surfaces through the use of differential geometry [19]. In particular, it shows a procedure that can be used to construct an orthogonal net across the surfaces for texture mapping. The exhibition includes a number of three-dimensional animations and wall posters. Differential geometry is usually taught at the post-graduate level (if at all). However, our initial usability tests indicate that CyberMath makes it possible to effectively introduce these concepts to undergraduate students.

8.1. Usability testing

We have completed two initial usability tests, one small test at our lab with three subjects and one larger test with 14 subjects. In the first test, the subjects were undergraduate students at the Royal Institute of Technology and in the second test, they were undergraduate students from the University of Uppsala, that is located to the north of the Stockholm region. A mathematics teacher from the Royal Institute of Technology (that is familiar with CyberMath) guided the subjects through the generalized cylinders exhibition hall. The teacher was in a separate physical location and all subjects were sitting at different workstations in one room. After the guided tour, they answered a written questionnaire. The questions were divided into four themes:

- effectiveness of the human/computer interface (navigation, sound quality, orientation of avatars, etc.),
- perceived level of immersion and awareness of other users in the virtual environment,
- level of collaboration (teacher–learner and learner–learner),

- transfer of content, feasibility of CyberMath as teaching tool.

The results show average ratings for the first three of these themes and a somewhat above average ratings for the fourth. These results are hardly conclusive, but they suggest that even though improvements in user interface and environment design are necessary, CyberMath has the potential of becoming a powerful tool for exploring mathematics.

We are planning a series of focused studies of CyberMath at the Royal Institute of Technology. These studies will focus on four main areas:

- *Educational aspects:* Can the theory and techniques that deal with free-choice learning be applied to educational VR systems? Is it possible to utilize the research on museum exhibition design to improve the effectiveness of virtual learning environments?
- *Immersion:* To what extent do different levels of immersion (desktop monitor, wall projection, head-mounted display, CAVE) influence the long-term retainment of knowledge acquired through virtual environments?
- *Collaboration and teaching strategies:* How does the possibility of large-scale participation influence the teaching and learning processes? To what extent must teachers adapt their teaching style in collaborative virtual environments?
- *Realism:* Can the increased motivational value of a realistic environment compensate for the lack of immersion in desktop-based systems? What level of realism is most efficient for different set of tasks? Is it possible to produce a set of general guidelines for using visual realism in virtual environments for education?

Our hope is that these tests will produce new insights into how to design efficient VR systems for education. We are also planning to build a number of new exhibition areas, including one that presents elementary three-dimensional geometry and one that introduces geometric algebra [20]. We will also use results from research on awareness and accommodation in virtual environments to further guide the design of these exhibition areas [21].

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