Collaborative Augmented Reality in Education

Hannes Kaufmann
Institute of Software Technology and Interactive Systems
Vienna University of Technology
Favoritenstrasse 9-11/188
1040 Wien, Austria
+43 1 58801 18860
kaufmann@ims.tuwien.ac.at

ABSTRACT

Technological advances enable the use of innovative learning tools for education. This work gives a brief insight into the potential and challenges of using collaborative Augmented Reality (AR) in education within the greater context of immersive virtual learning environments. As an example the experiences made during the development of a collaborative AR application specifically designed for mathematics and geometry education called Construct3D are summarized. Construct3D is based on the mobile collaborative AR system “Studierstube”. We describe our efforts in developing a system for the improvement of spatial abilities and maximization of transfer of learning. Means of application and integration in mathematics and geometry education at high school as well as university level are being discussed. Anecdotal evidence supports our claim that Construct3D is easy to learn, encourages experimentation with geometric constructions and improves spatial skills.

Keywords

Collaborative Augmented Reality, VR learning, mathematics education, geometry education, spatial intelligence.

1. INTRODUCTION

Research in conceptual learning in immersive virtual environments is a relatively young field but growing rapidly. As suggested by several authors [9, 12, 15] Virtual Reality (VR) can contribute to raise interest and motivation in students with a high potential to enhance the learning experience. However, the practical potential of VR is still being explored and understanding how to use VR technology to support learning activities presents a substantial challenge for the designers and evaluators of this learning technology [5].

While the talk will also overview recent approaches to AR learning environments, this paper concentrates on the use of collaborative Augmented Reality for educational purposes. A good definition of Augmented Reality is given in the survey by Azuma [2]. According to this definition, Augmented Reality is a variation of Virtual Reality. VR technology completely immerses a user inside a synthetic environment. While immersed, the user cannot see the real world around him. In contrast, AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, AR supplements reality, rather than completely replacing it. Ideally, it would appear to the user that the virtual and real objects coexist in the same space.

2. COLLABORATION

One of the most important purposes of an educational environment is to promote social interaction among users located in the same physical space [12]. In collaborative Augmented Reality multiple users may access a shared space populated by virtual objects, while remaining grounded in the real world. This technique is particularly powerful for educational purposes when users are co-located and can use natural means of communication (speech, gestures etc.), but can also be mixed successfully with immersive VR or remote collaboration. Another psychological factor of importance is that some users feel unsafe if their view is “locked” in an immersive virtual world whereas AR allows them to “keep control”, to see the real world around them. Safety issues are important in collaborative mobile systems (for direct use in classrooms) where AR is obviously used to give mobile users the freedom of sight needed to move around. There is an interplay between emotions and learning [7], but how feelings such as insecurity and emotions in general influence learning is a matter of ongoing research. However developers have to consider above mentioned issues when building their ideal learning environment. Augmented Reality cannot be the ideal solution for all educational application needs but it is an option to consider. The technology used always has to depend on the pedagogical goals and needs of the educational application and the target audience.

3. DESIGNING EDUCATIONAL VR/AR APPLICATIONS

For the development of any educational application technological, domain specific, pedagogical and psychological aspects have to be considered. First and foremost an extendable (mobile collaborative) AR or VR system is needed as a platform to develop an application for real use in classrooms. There is no single technology that fits all needs. It is very important that user interfaces and display types fit the application and educational needs (e.g. an application teaching blind people geometric forms of famous architectural buildings should obviously use appropriate input and output devices). Application development requires professional skills in the application domain. Pedagogic and didactic skills are needed to adept the application to user requirements. If special skills should be trained or enhanced like spatial abilities in the case of the later mentioned Construct3D application, a number of psychological aspects must be considered. They influence content design, design of the user interface and concepts for evaluations.

As Mantovani [5] points out, the basic assumption that the learning process will take place naturally through the simple exploration and discovery of the Virtual Environment should be reviewed. Despite the value of exploratory learning, when the knowledge context is too unstructured, the learning process can become difficult. Constructivist theory provides a valid and reliable basis for a theory of learning in virtual environments [15]. As constructivism underlines, learning takes place when students can build conceptual models that are both consistent with what they already understand and with the new content. In order to ensure successful adaptation of old knowledge to new experience, flexible learning direction should be provided [5]. One possibility is to integrate known types of information and educational supports other than the 3D representation (such as audio and text annotations, images etc.). Another possibility is to carefully define specific tasks to the users/students through interaction with the teacher. We suggest the use of different learning modes in virtual environments from teacher-supported to autodidactic learning as described in section 6. Finally, VR environments can be tailored to individual learning and performance styles.

In the following sections we will describe how the above mentioned guidelines have been implemented within our collaborative AR application for mathematics and geometry education.

EXAMPLE CASE: CONSTRUCT3D

Figure 1: Collaborative work of students within the Augmented Reality application Construct3D. In this example the students inscribe a sphere in a cone.

4. MOTIVATION

Spatial abilities present an important component of human intelligence. The term spatial abilities covers five components, spatial perception, spatial visualization, mental rotations, spatial relations and spatial orientation [4]. Generally, the main goal of geometry education is to improve these spatial skills. In a long term study by Gittler and Glück [3], the positive effects of geometry education on the improvement of spatial intelligence have been verified. Various other studies [8, 11] conclude that spatial abilities can also be improved by virtual reality (VR) technology. However, little to no work has been done towards systematic development of VR applications for practical education purposes in this field.

To fill the gap of next-generation virtual reality interfaces for mathematics and geometry education we are developing a three dimensional geometry construction tool called Construct3D [6] that can be used in high school and university education. Our system uses Augmented Reality [2] to provide a natural setting for face-to-face collaboration of teachers and students. The main advantage of using AR is that students actually see three dimensional objects which until now they had to calculate and construct with traditional (mostly pen and paper) methods. Our thesis is that by working directly in 3D space, complex spatial problems and spatial relationships can be better and faster comprehended than with traditional methods.

It is important to note that while geometry education software shares many aspects with conventional 3D computer-aided design (CAD) software at a first glance, its aims and goals are fundamentally different. Geometry education software is not intended for generating polished results, but puts an emphasis on the construction process itself. While relatively simple geometric primitives and operations will suffice for the intended audience of age 10 to 20, the user interface must be both intuitive and instructive in terms of the provided visualizations and tools. Commercial CAD software offers an overwhelming variety of complex features and often has a step learning curve. In contrast, geometry educators are interested in simple construction tools that expose the underlying process in a comprehensive way.

Our accompanying video demonstration shows the prototype of such an AR-based geometry education tool. We present the interaction and menu system followed by an introduction of how to work with Construct3D in a single user as well as collaborative setup. The video concludes with an overview of the hardware in our stationary lab setup providing a testbed for future evaluations.

5. APPLICATION DESIGN

Construct3D is based on the *Studierstube* system described by Schmalstieg et al. [13]. *Studierstube* uses augmented reality to allow multiple users to share a virtual space. We use see-through HMDs capable of overlaying computer-generated images onto the real world, thereby achieving a combination of virtual and real world, allowing natural communication among users. The latest version of *Studierstube* allows the mix and match of heterogeneous output devices such as personal HMDs, virtual workbenches, conventional monitors, and input through a variety of tracking devices. All these devices appear to act as interfaces to a single distributed system.

The current version of Construct3D offers a basic set of functions for the construction of primitives such as points, lines, planes, cubes, spheres, cylinders and cones. Construction functions include intersections, Boolean operations, normal lines and planes, symmetry operations, and taking measurements. Currently additional functions such as special and general curves (circles, conic sections, B-Spline curves) and surfaces (quadrics, NURBS surfaces) are being implemented by using the ACIS toolkit [1].

Construct3D promotes and supports exploratory behavior through dynamic geometry, i. e., all geometric entities can be continuously modified by the user, and dependent entities retain their geometric relationships. For example, moving a point lying on a sphere results in the change of the sphere's radius.

All construction steps are carried out via direct manipulation in 3D using a stylus tracked with six degrees of freedom. AR affords that users see their own body and hand as well as the effects of their actions while working, so the construction process physically involves the students and resembles handcraft more than traditional computer operation. We believe this being a key factor in the potential success of using AR for teaching geometry which we plan to evaluate in the future.

Necessary system operations such as selection of primitive type, load, delete, undo etc. are mapped to a hand-held tracked panel, the personal interaction panel (PIP) [14]. The PIP 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 allow the props to be used as multi-functional tools. A recent speaker-independent speech interface allows the control of all interface elements (widgets) via speech commands. This improves the speed and efficiency of working.

6. LEARNING MODES

As mentioned in section 3, despite the undoubtful value of the exploratory learning provided, when the knowledge context is too unstructured, the learning process can become very difficult. In order to adapt each example to the students' needs, we will provide modes for teacher-supported and autodidactic learning in our tutorials:

1. *Teacher mode*: A teacher performs the whole construction and explains all steps. He has the possibility to use pre-constructed steps of the tutorial to switch back and forth in order to show various states of the construction. He teaches one or more students.
2. *Normal tutorial*: The whole construction or steps of it are "played" including explanations and after the whole construction or after predefined steps students have to repeat them. They are guided by a teacher.
3. *Auto-tutorial*: Students go through the tutorial themselves, listening to pre-recorded explanations of the steps. The instructions can be given by recorded speech or our text-to-speech system. They have to understand the construction and should be encouraged to repeat it.
4. *Exam mode*: Students must do the whole construction by themselves. At the end there should be a check button where the pre-recorded solution can be checked with the constructed solution.

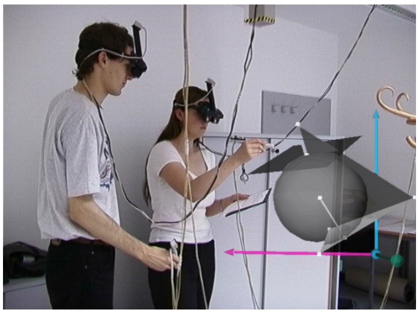

Figure 2: A tutor assists a student while working on the model.

In this context it is important to note that we believe that Construct3D can and will never substitute a teacher or classroom education as it is known today. It is designed to be a valuable addition, offering new chances and possibilities in mathematics and geometry education.

7. EVALUATIONS

In order to better understand the educational efficacy of VR/AR in learning, extensive evaluations are necessary. Most evaluations so far concentrated on usability issues of the application rather than its efficacy for supporting learning. Roussos et al. [12] describe a general evaluation framework that emcompasses, rather than restricts the multiple dimensions of the issues that need to be examined in virtual learning environments. Taking into account the multidimensionality of learning as well as virtual reality as a field, a number of technical, orientational, affective, cognitive, pedagogical and other aspects were included in the evaluation.

- The *technical aspect* examines usability issues, regarding interface, physical problems, and system hardware and software.
- The *orientation aspect* focuses on the relationship of the user and the virtual environment; it includes navigation, spatial orientation, presence and immersion, and feedback issues.
- The *affective parameter* evaluates the user's engagement, likes and dislikes, and confidence in the virtual environment.
- The *cognitive aspect* identifies any improvement of the subject's internal concepts through this learning experience.
- Finally, the *pedagogical aspect* concerns the teaching approach: how to gain knowledge effectively about the environment and the concepts that are being taught.

As far as the methodological approach is concerned, integration of quantitative and qualitative methodologies seems the best way to face and to catch this complexity [5]. Riva and Galimberti [10] presented a complex model of data analysis which supports the value of the mixed use of quantitative and qualitative tools.

Concerning Construct3D we plan to do extensive evaluations of this type in upcoming research projects but have not done so yet. The key hypothesis - that actually seeing things in 3D and interacting with them can enhance a student's understanding of three-dimensional geometry - were supported by observations made at trial runs with real students. In our first evaluation [6] with 14 students we got very positive and encouraging results and some problems were pointed out.

At this stage Construct3D is not used by students on a regular basis in mathematics and geometry education. While developing Construct3D we are regularly visited by teachers, students, colleagues and friends who evaluate the system and give feedback on its quality. This helps to constantly improve the application and adept it to the students' needs.

Figure 3: Presentation of Construct3D at a science fair in the Vienna Museum of Technology.

8. FUTURE WORK

Much work remains to be done. In particular, a comprehensive evaluation of the practical value of an education tool such as ours will require the development of substantial educational content that is put to real use in classroom. We are currently at the stage where we have working tools available, but need to apply them now to real educational work. For the beginning we plan to create tutorials for vector algebra, conic sections and Boolean operations. We believe that despite the exciting possibilities of new media, educational content creation for an interactive system is at least as difficult as authoring good textbooks, and will require a substantial amount of time and work. Finally, the true value of the new tool in classroom use needs to be verified through controlled evaluation.

9. CONCLUSION

Due to advances in the development of pedagogical concepts, applications and technology, and a simultaneous decline in hardware costs, the use of small scale or mobile immersive virtual or augmented reality systems could become feasible for educational institutions within this decade (assuming ongoing development at the same rate). Nevertheless, the potential of each VR/AR feature needs careful reflection in order to be actually translated into educational efficacy. The matter is not questioning whether or not VR/AR is useful to enhance learning. The matter is understanding how to effectively exploit its potential.

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