
LEARNING OBJECTS FOR EDUCATION WITH AUGMENTED REALITY

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Abstract

To fill the gap of next-generation user interfaces for mathematics and geometry education Construct3D is presented, a three-dimensional dynamic geometry construction tool that can be used in high school and university education. This system uses Augmented Reality (AR) 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 they until now had to calculate and construct with traditional (mostly pen and paper) methods (Figure 1). By working directly in 3D space, complex spatial problems and spatial relationships may be comprehended better and faster than with traditional methods. This paper summarizes the development of learning objects and content specifically designed for teaching dynamic 3D geometry in Augmented Reality. It concentrates on pedagogical findings while working with teachers and students in more than 500 teaching lessons.

Introduction

Spatial abilities present an important component of human intelligence. Many studies have shown that spatial abilities can be improved by well-designed trainings [1, 2]. Geometry education has proven as one powerful means of improving these skills [3]; recently, a number of training studies have shown the usefulness of virtual reality (VR) in training spatial ability [4, 5]. Augmented Reality [6] is a variation of Virtual Reality (VR). VR technology completely immerses a user inside a synthetic environment. While immersed, the user cannot see the surrounding real world. 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. In terms of used technology, AR can be said to require the following three characteristics (1) combines real and virtual (2) interactive in real time (3) registered in 3D.

According to pedagogical theories [7], collaboration is a fundamental social process that supports learners' development of capabilities. In a collaborative AR environment multiple users may access a shared space populated by virtual objects, while remaining grounded in the real world. This approach 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 [8] or remote collaboration [9]. Supporting natural collaboration in the mathematics domain opens new possibilities to the educational process.



Figure 1: Students are working with Construct3D in 3D space. Left: The image shows how users perceive the virtual world and objects. Right: Views of spectators watching engaged students from outside the virtual world.

Construct3D

Software Design

Construct3D [10] is based on the Studierstube Augmented Reality system [11]. It supports generation of and operation on these basic geometric object types: Points (either freely positioned in space or fixed on curves and surfaces), lines, planes, circles, ellipses, cuboids, spheres, cylinders, cones, B-Spline curves with an unlimited number of control points and variable degree, interpolated B-Spline curves, NURBS surfaces up to 8x8 control points and variable degree, interpolated NURBS surfaces and surfaces of revolution (rotational sweep surfaces). Regarding geometric operations we implemented Boolean operations (intersection, union, difference); intersections between all types of 2D and 3D objects resulting in intersection points and curves; planar slicing of objects; rotational sweep around an axis and many more. Translations, rotations and mirroring of objects are supported as well.

At its start Construct3D initializes a 3D window and the user interface. The menu system is mapped to a hand-held tracked panel called the personal interaction panel (PIP) [12]. The PIP allows the straightforward integration of conventional 2D interface elements like buttons, sliders, dials etc. as well as novel 3D interaction widgets (Figure 2 right). Passive 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. All construction steps are carried out via direct manipulation in 3D using a stylus tracked with six degrees of freedom. In order to generate a new point the user clicks with his pen exactly at the location in 3D space where the point should appear. Users can easily switch between point mode (for setting new points) and selection mode (for selecting 3D objects).

A fundamental property of dynamic geometry software is that dynamic behavior of a construction can be explored by interactively moving individual defining elements such as corner points of a rigid body. For example: moving a point lying on a sphere results in the change of the sphere's radius. It can be seen what parts of a construction change and which remain the same. The histories of constructions as well as dependencies between geometric objects are maintained. Experiencing what happens under movement allows better insight into a particular construction and geometry in general.

Collaborative, Educational Augmented Reality Setups

The standard setup used for Construct3D supports two collaborating users wearing stereoscopic see-through head mounted displays (Sony Glasstron HMDs) providing a shared virtual space. The users interact with the system using pen and pad props (Figure 2 left). Both users see the same virtual objects as well as each others' pens and menu systems which allows a student or teacher to help the other user, if necessary. The big advantage of this setup is that it allows users to actively "walk around" geometric objects which are fixed in space. Excited students sometimes lie down on the floor to view objects from below or step on a chair to look down from above. This is a unique feature of an HMD setup which cannot be provided by monitor or projection screen based hardware configurations.

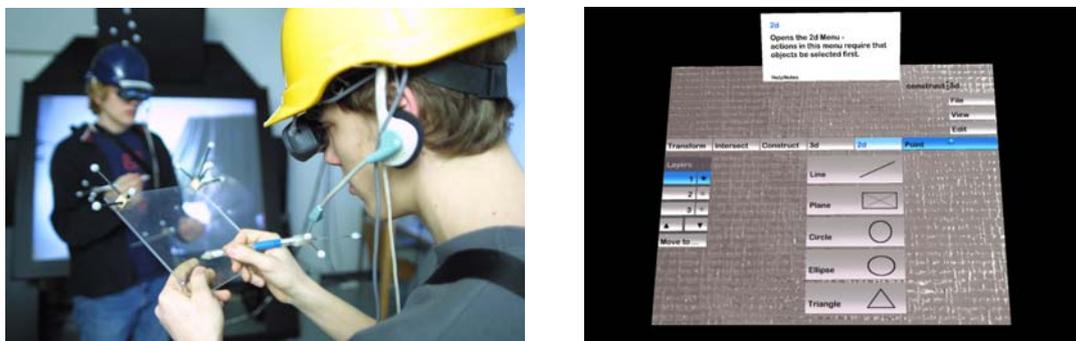


Figure 2: Left: Two students collaborate in our standard lab setup, wearing an HMD, holding a wireless pen and panel (PIP). All devices are optically tracked. Right: The menu system which is display on the panel.

Pedagogical Aspects

Pedagogic Theory

Constructivist theory provides a valid and reliable basis for a theory of learning in virtual environments [13, 14]. 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 [15]. 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 implemented support of different learning modes in virtual environments from teacher-supported to autodidactic learning (layer scheme described in [10]). Finally, VR environments can be tailored to individual learning and performance styles.

The core commitment of a constructivist position is that knowledge is not transmitted directly from one knower to another but is actively built up by the learner. Learning is considered to be an active process in which learners “construct” their own knowledge by testing ideas and approaches based on their prior knowledge and experience, applying these to a new situation, and integrating the new knowledge gained with pre-existing intellectual constructs. This is supported through relevant, engaging learning activities, which involve problem-solving and critical thinking.

We used activity theory [16] as a conceptual framework to design constructivist learning tasks. All e-learning content is highly dynamic and specifically targeted to the features of Construct3D. All examples represent real-life problems, encourage experimentation and the evaluation design actively involves learners. They are in accordance with the geometry curriculum of grade 12.

Teaching Experiences

In questionnaires and discussions teachers described three main strengths of Construct3D: (1) The ability to construct dynamic 3D geometry and nearly haptic interaction with geometric objects. (2) Students can walk around geometric objects, building an active relationship between body and object. (3) The application’s strength to visualize abstract problems.

In order to teach specific learning content, teachers usually pick the learning medium which is best suited for teaching the content. Since we know Construct3D’s strengths, it should mainly be integrated in geometry education for teaching content which requires 3D dynamic geometry or requires the visualization of abstract problems (as shown in the learning objects below). In addition these are exactly those areas that are hardly covered by other educational applications.

Construct3D has specific strengths and allows teaching principles by using 3D dynamic geometry that are hard or impossible to teach by any other means in traditional geometry education. Tasks that are well suited for Construct3D might be impossible to do in traditional courses and those ideal for paper&pencil work might be impractical to do in Construct3D. Because each medium is different, different content should be used to utilise the strengths of each.

The advantages of working in an immersive AR setup are manifold. Users see their own body and hand as well as the effects of their actions while working. The construction process physically involves students and resembles handcraft more than traditional computer operation. A spatial relationship between the user’s body and the geometric object in 3D space is established. We believe these are key factors in the potential success of using AR for teaching geometry.

We developed Construct3D to a point where it can be productively used for educational purposes. Due to a wide range of features useful content which utilizes dynamic functionality is easy to produce for teachers and students in a very short time. Our tool allows novel ways of teaching. Since development of our application is ongoing, we will see how teaching with this medium will change. Time will show how teachers will adapt content to the advanced features provided by our tool. Dynamic 3D construction and visualization capabilities are its fundamental strengths. Construct3D enables teaching

of new dynamic geometric content that is too difficult or impossible to draw with pencil on paper or with existing CAD programs.

Learning Objects

To illustrate the type of geometric examples and learning tasks that are ideal for teaching geometry with Construct3D we list actual educational tasks and learning objects that were previously used or will be used in evaluations. Students of age 16-18 who have geometry classes in high school work collaboratively with a teacher and another student in an HMD based setup as described above. Beforehand the problem description and a screenshot of the given elements that they will face later in the virtual world are given to the students. Web links are presented with additional information about the task; given images help to understand and translate the problem.

Flight route

The task is to construct the shortest flight route from Vienna to Sydney, which in ideal case is an orthodrome. The given virtual scene in Construct3D (Figure 3) shows a model of earth (with texture) to help pupils find the correct places on earth and to immerse them further into the problem.



Figure 3: Left: Vienna is marked on the globe. Right: Two students are collaborating to solve the problem.

Exploring the Shape of a Sunsail

Looking closer at a sunsail, raises the question of the geometric background of its shape. This task provides the possibility of perceiving a Hyperbolic Paraboloid (HP) in all its aspects: the construction, the generating lines, and how the surface gains its name.

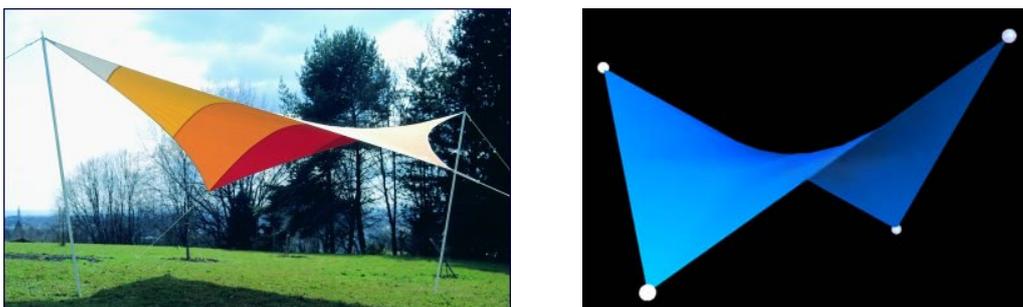


Figure 4: Left: A hyperbolic paraboloid in a real environment. Image courtesy by <http://www.cenotec.de/ind07erd.htm>. Right: A HP-surface constructed in Construct3D.

The hyperbolic paraboloid, as a particular ruled surface, is generated in Construct3D as a bilinear Bezier patch (Figure 4, right). Our purpose in examining bilinear patches is to examine and explain in a simple case how de Casteljau's algorithm works for surfaces. In addition the HP can be generated as a translational surface by moving a hyperboloid along a paraboloid (or the other way round). The students will learn and investigate this fact by dynamic movement of a plane intersecting the HP in a paraboloid or hyperboloid. This task discloses the mystery of how the surface gains its name.

Surfaces of revolution

Surfaces of rotational symmetry are omnipresent in everyday life. This should be an incitement to learn more about their structure. In this task the perpendicular axis of a surface of revolution is given.

Students have to rotate an arbitrary B-Spline curve around this axis. The result is a surface of revolution Φ (Figure 5). Construct3D provides the facility to modify the original B-Spline curve dynamically, which results in the modification of the surface of revolution in real time, too. This is a unique feature of Construct3D. The next step in construction is to pick an arbitrary point P on the surface of revolution Φ . P can be moved on the surface.

The tangential plane ε to Φ is spanned by a tangent to the meridian curve in an arbitrary point P and the tangent to the circle of latitude through P . When students now move P along the surface, the tangential plane ε , fixed in P moves, too. This enables the students to study the touching property of the tangential plane, and the intersection of Φ with ε .

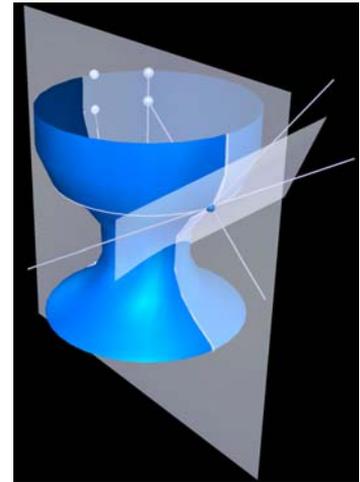


Figure 5: Surface of Revolution

An important topic in this task is the location of the surface normal in P , which is constructed as the surface normal to the tangential plane. Students are thrilled watching the surface normal intersect the axis of rotation while moving around P . This experience can not be replaced by constructing a surface of revolution with any CAD program.

Wheels of an Airplane

This problem deals with wheels of an airplane which are rotated into a shell in the hull of the airplane after its take off. A wheel in its initial and final position is given. Students have to construct the axis of rotation and the angle of rotation that rotates the wheel from its original position into the final position in the hull.

Center of Gravity of a Tetrahedron

Given is a regular tetrahedron by its vertices and edges. The construction of the center of gravity in a triangle is known. Motivated by depictive representations of the tetrahedron in Bottrop (<http://www.tetraeder.de/>) students have to analyse if such a center of gravity also exists in a regular tetrahedron (Figure 6). Then they have to manipulate the platonic body dynamically to see what happens with the center of gravity in the arbitrary case.



Figure 6: Left: The Bottrop Tetrahedron (Image by Torsten Znotka). Right: The center of gravity of a tetrahedron.

Future Work

Mid- to long-term plans are to extend the number of users (which is now limited to two) for being able to teach larger groups of students. We're developing a low cost optical tracking system to minimize the expenses for tracking, aiming at the integration of Construct3D and the concept of teaching geometry with Augmented Reality in high school and university education. In parallel we're collaborating with Austrian schools and external partners such as the Institute of Geometry at Vienna University of Technology.

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