General Training of Spatial Abilities by Geometry Education in Augmented Reality

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Overview

- **Motivation**
- **Construct3D –**
  AR Application for Geometry Education
- **Training Spatial Abilities**
  - Strategies

Motivation

Spatial abilities

- A prerequisite for solving 3D problems
- Many students have difficulties with spatial thinking

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Hypothesis:

- See 3D objects in 3D
- Interactively construct, modify, “touch” geometric objects
- Build mental models of geometric situations more easily

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Geometry Education

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Geometry Education in VR/AR

Hypothesis:

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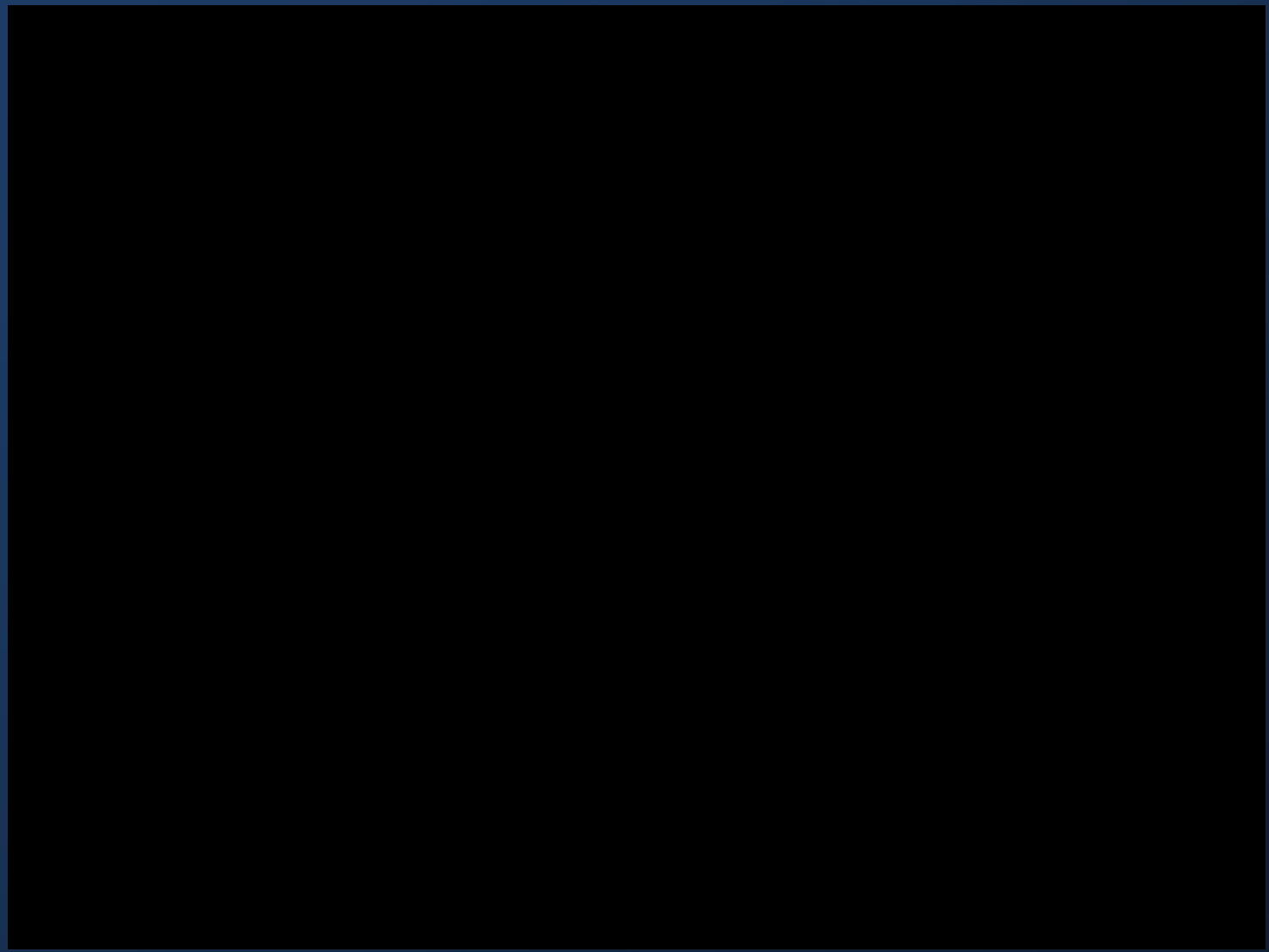
Goal

- **Develop an educational VR/AR application**
  - for constructing dynamic 3D geometry
  - Various fields of use:
    - High school & University education
    - Tool for studying VR Learning – pedagogy, didactics
- **Main purpose: Training spatial abilities**
  - on a general - not task specific - level

We created…

Construct3D

(Kaufmann H. et al., since 2000)



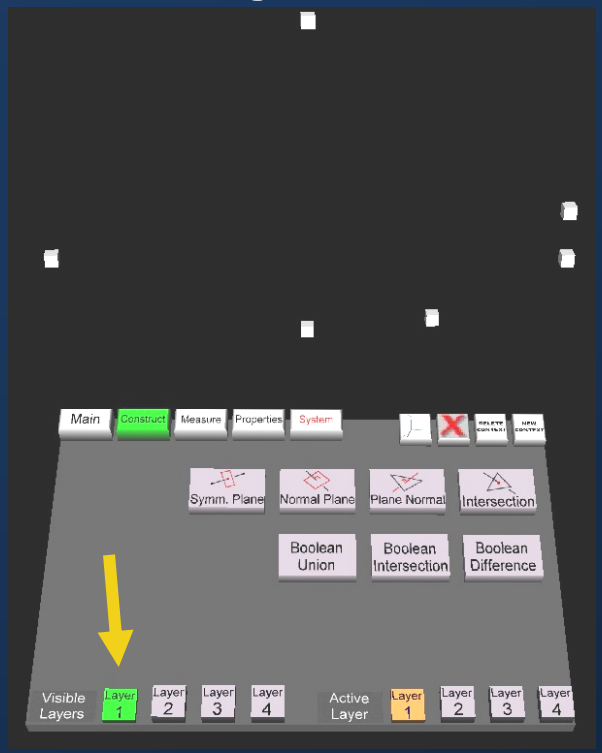
Features

- Basic objects: 2D primitives, 3D basic objects, curves, NURBS surfaces, surfaces of revolution
- Constructions: Surface normals, tangents and tangential planes, …
- Intersections: Boolean operations, intersection curves
- Measurements
- Transformations
- Dynamic modifications of points are possible at all times

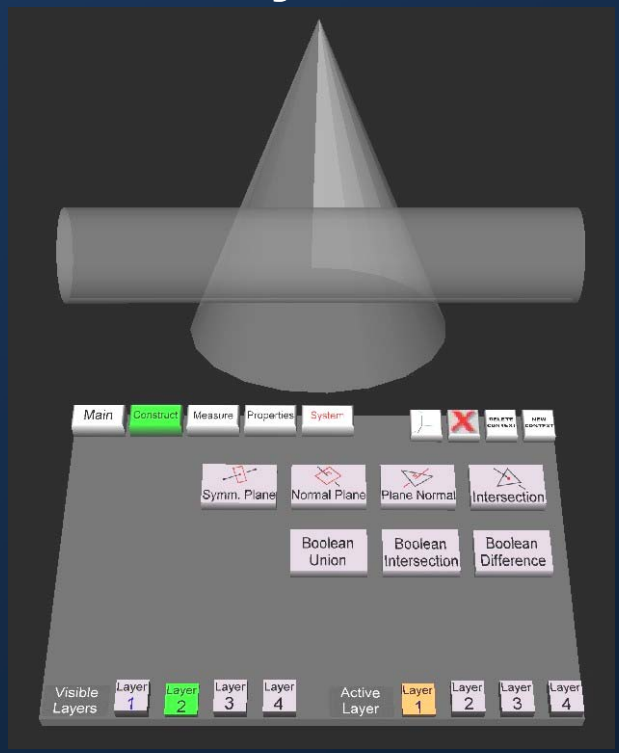
Layer Concept

- **Layers: working in “sub-spaces”**
  Example: Boolean Operation

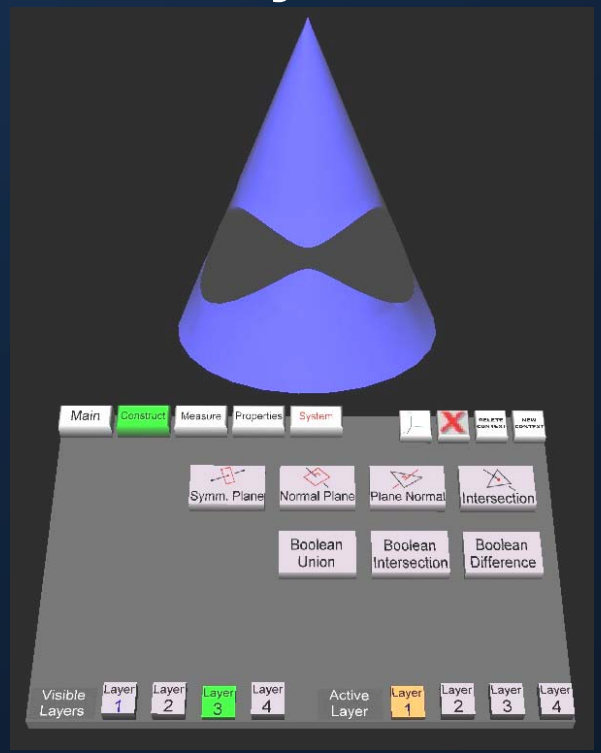
Layer 1



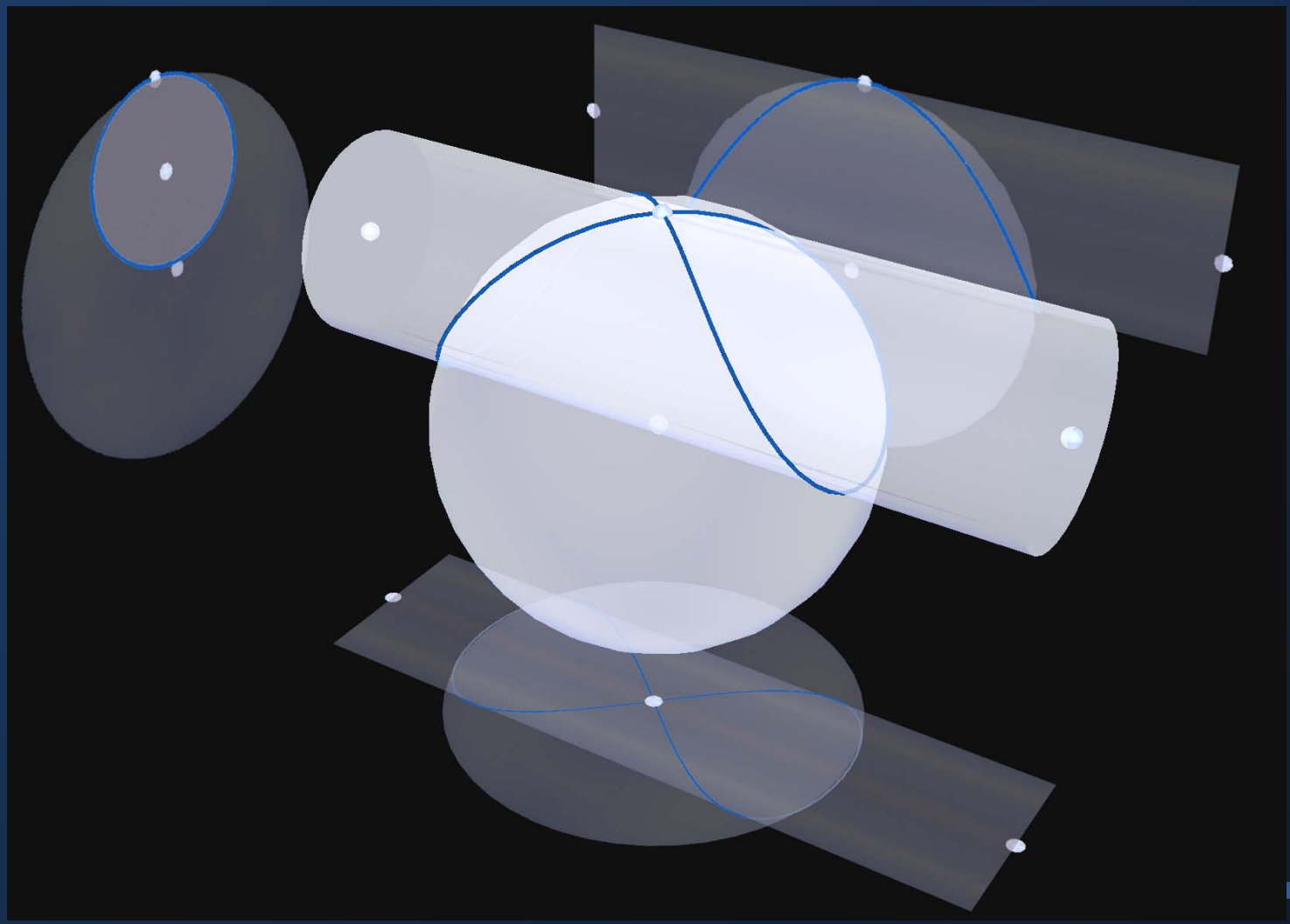
Layer 2



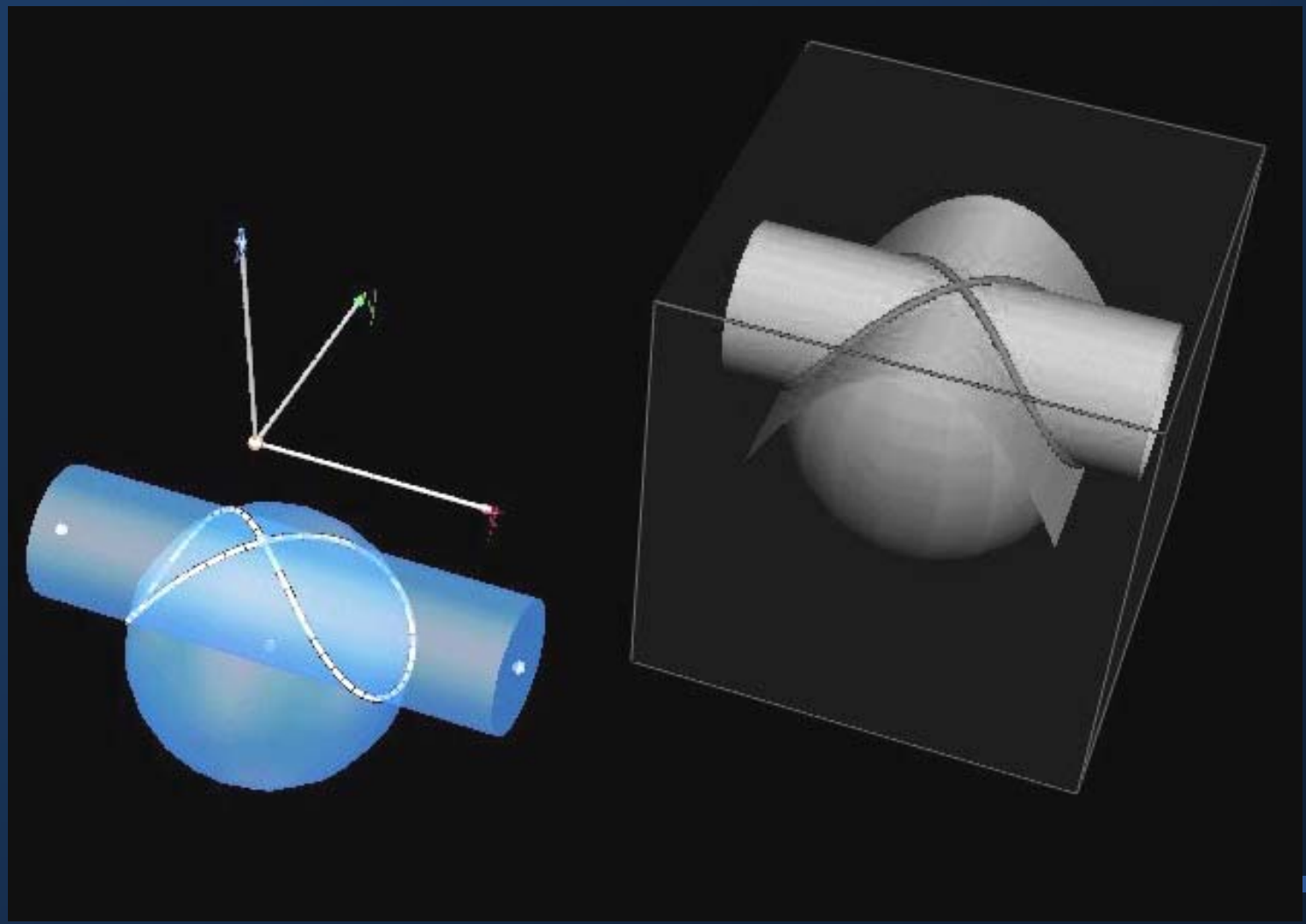
Layer 3



Normal views



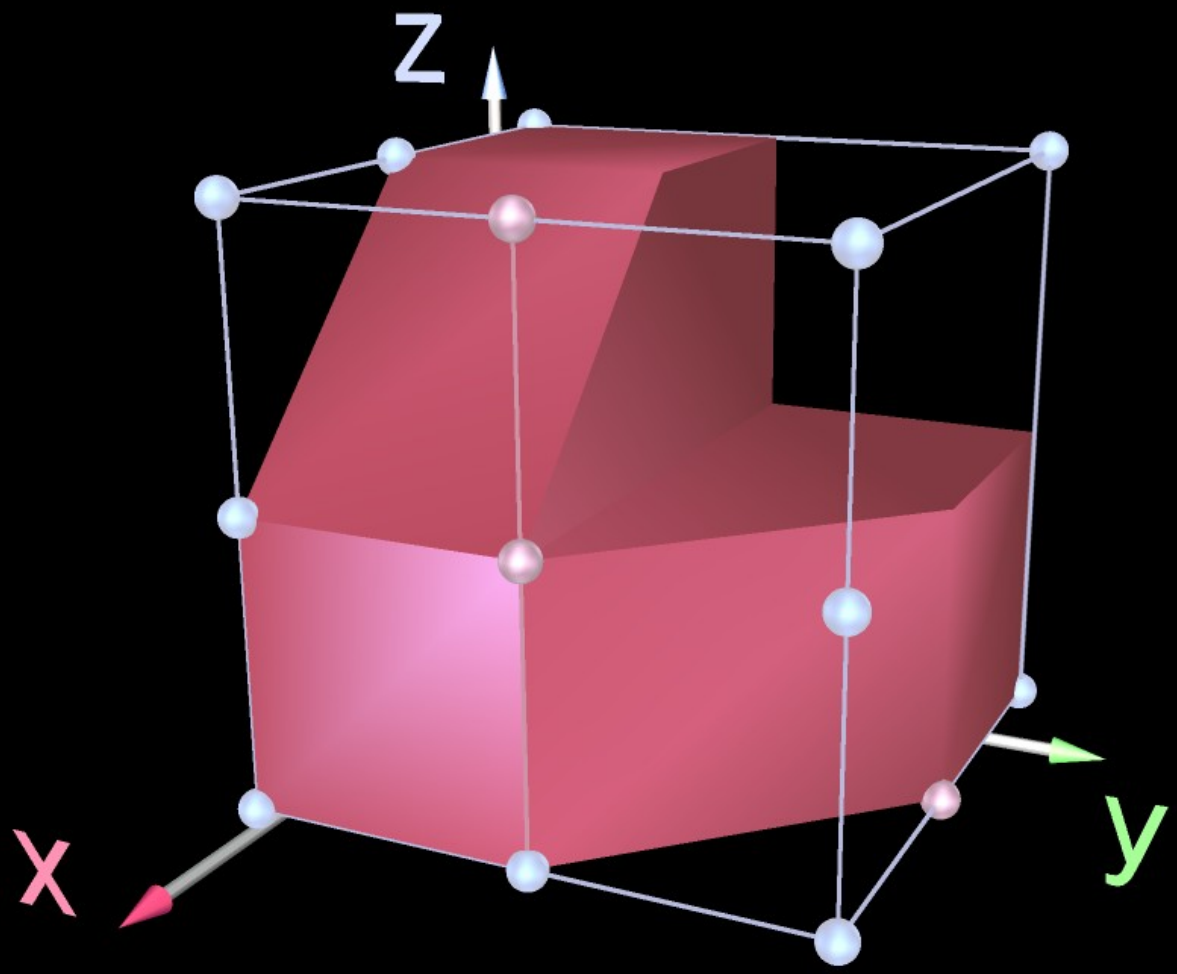
VRML Import & Export



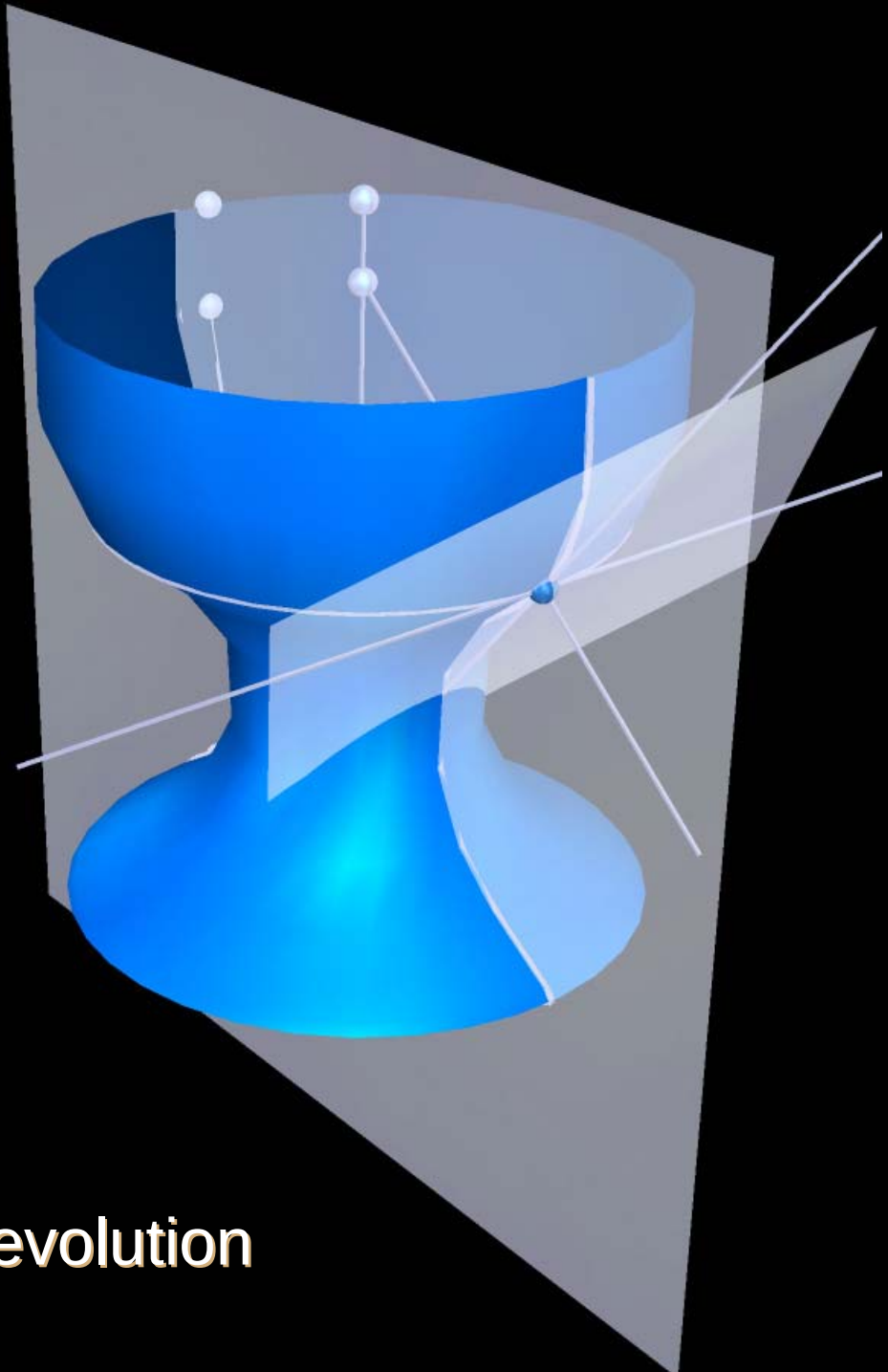
Additional Features

- Global undo and redo
- Preview
- Distributed Construct3D

Content
&
Learning Tasks

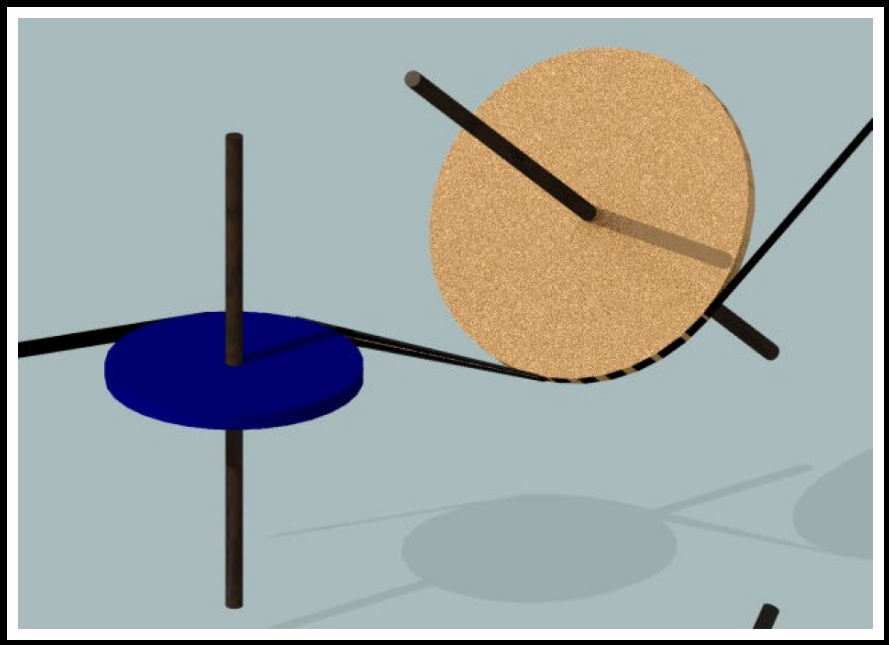


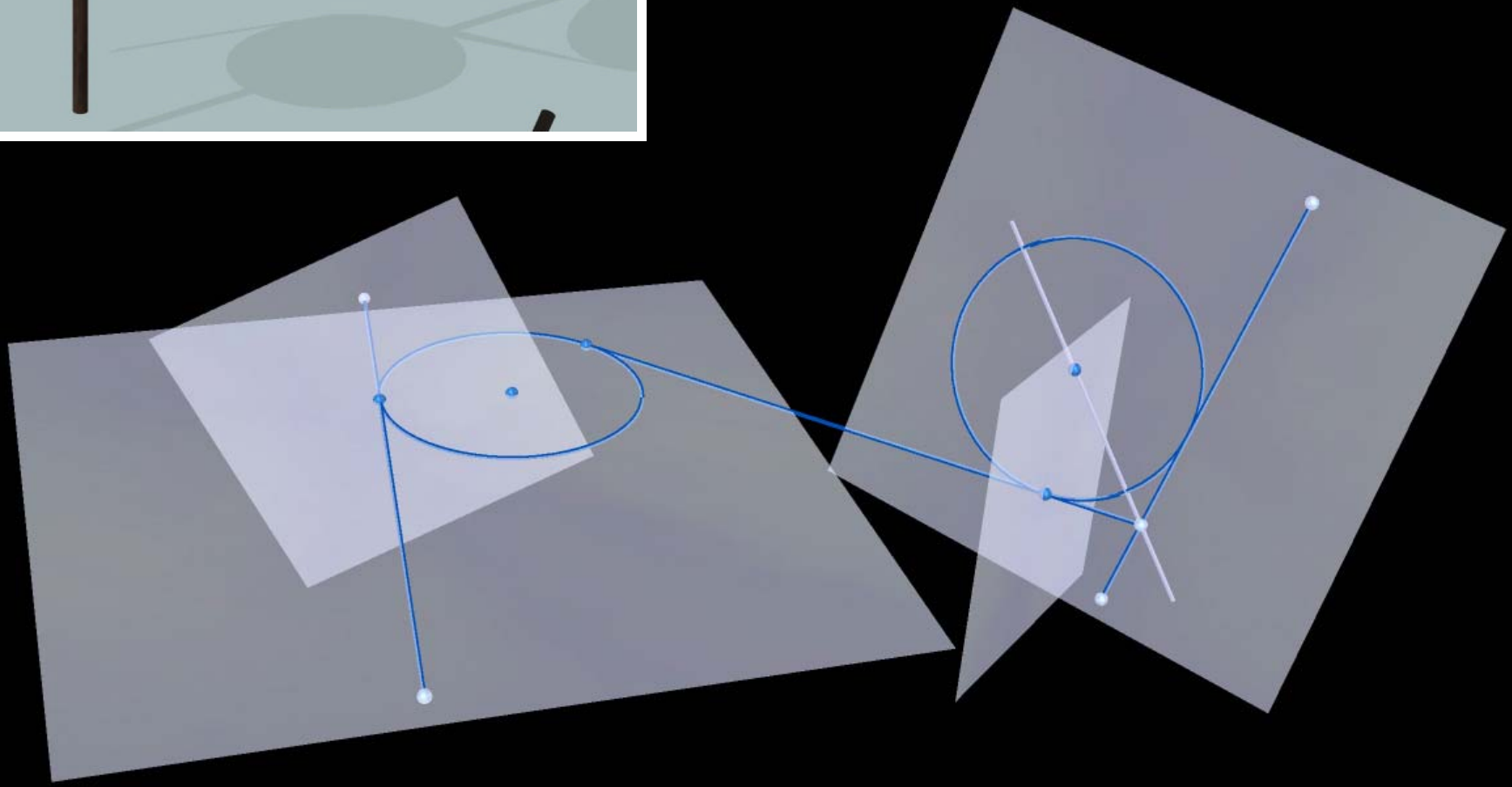
Tschupik Cubes

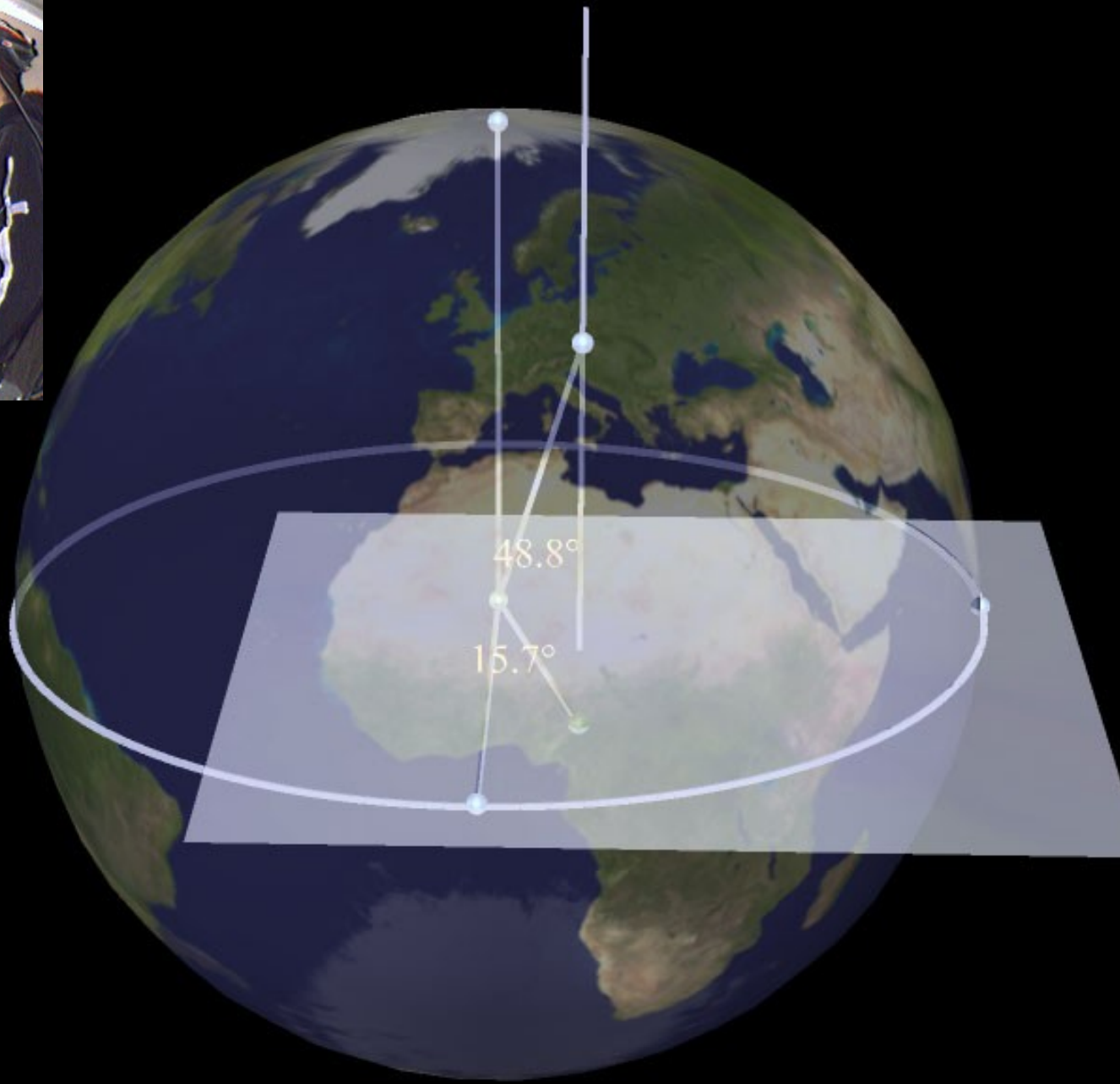


Surface of Revolution

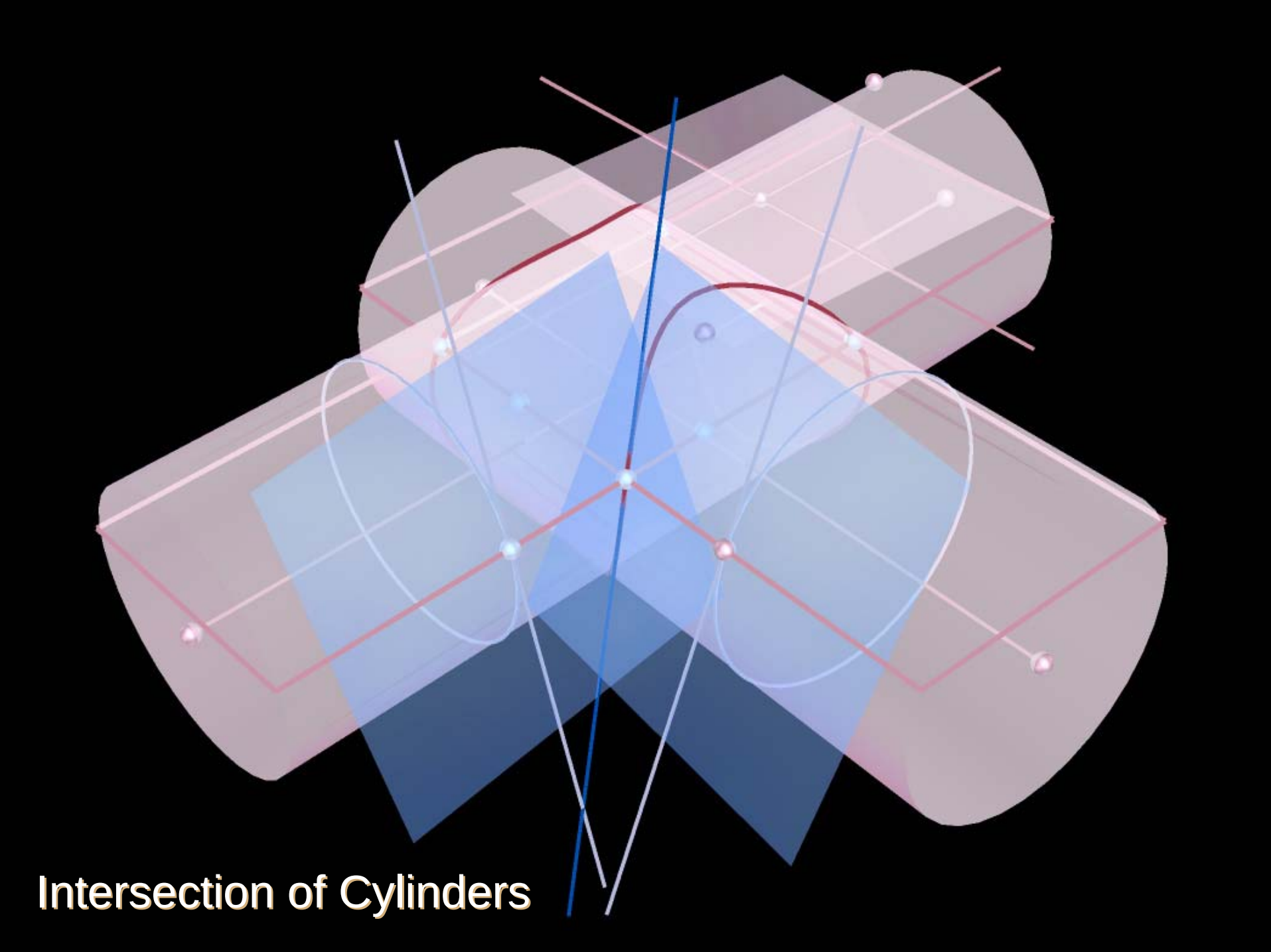
Deflection Sheave

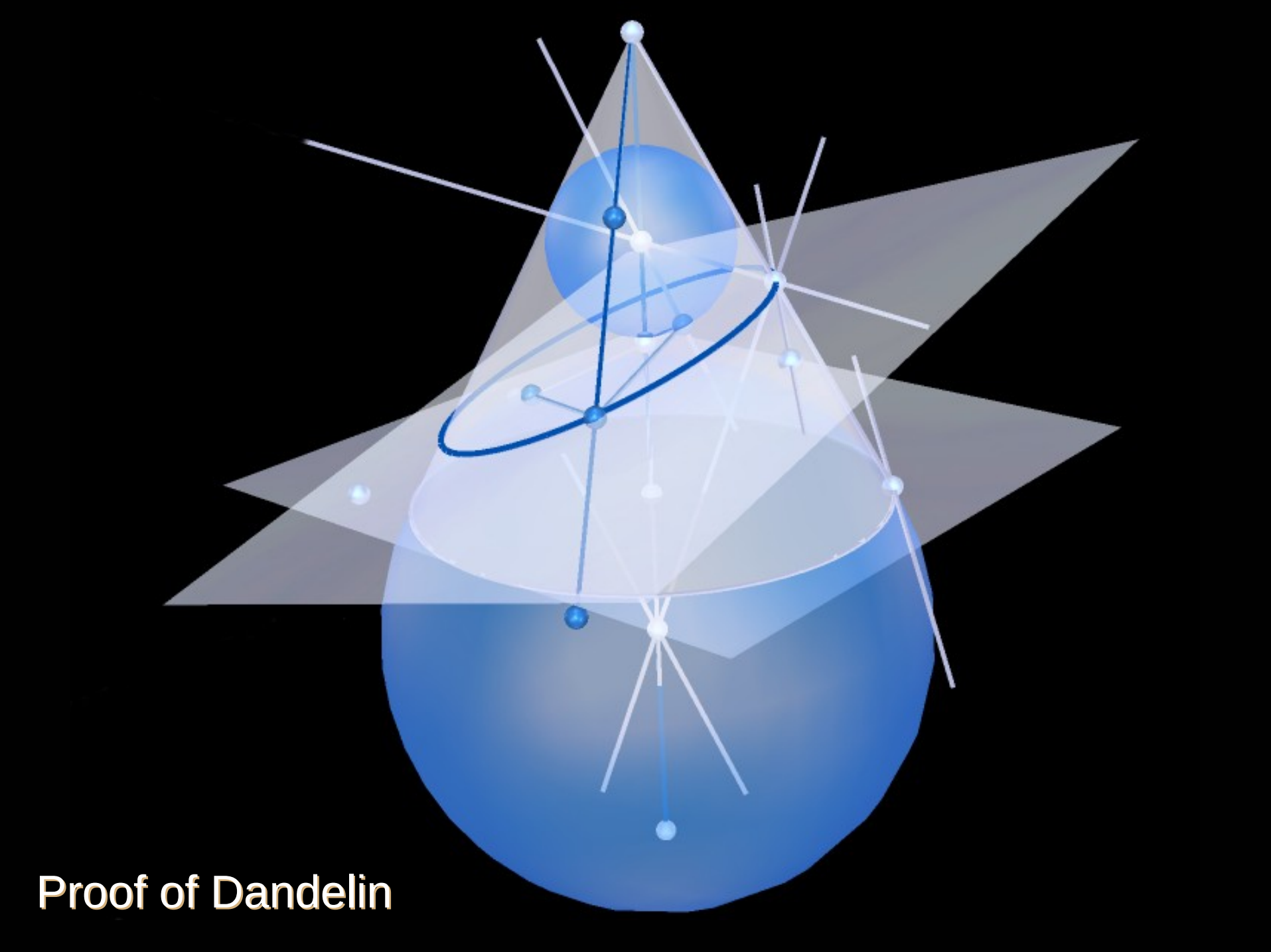






Adjusting Satellite Dish


Intersection of Cylinders


Proof of Dandelin

Key Strengths

- Dynamic 3D geometry - nearly haptic interaction with geometric objects
- Students can walk around objects. Active **relationship between body – object**
- Strength to visualize abstract problems

→ Ideal content: Highly dynamic examples which encourage modifications and visualize abstract problems

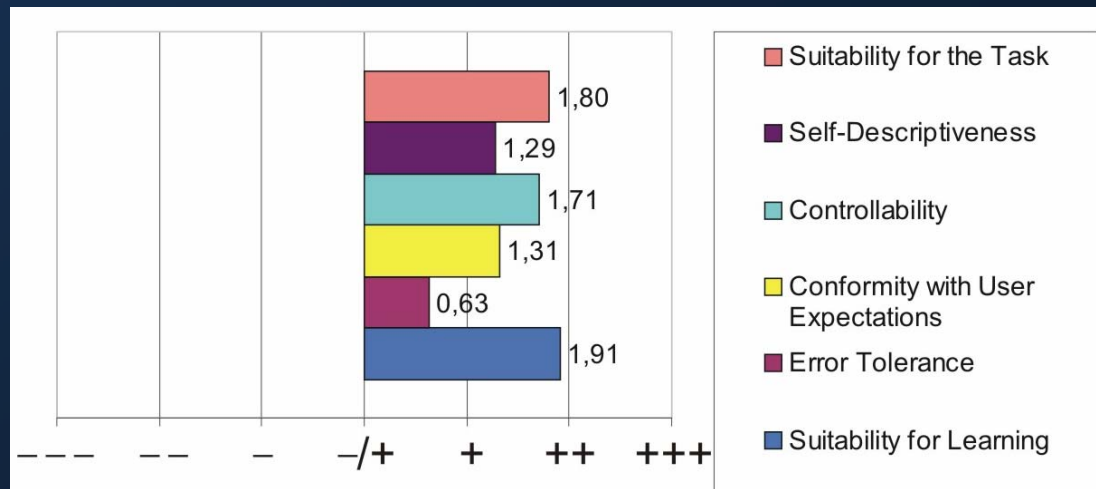
Usability Evaluations - Main Results

Construct3D

- easy to use, requires little time to learn
- encourages learners to try new functions
- can be used consistently
  - designed in a way that things you learned once are memorized well

ISONORM 9241/20

Usability questionnaire



Training Spatial Abilities

Team of Psychologists:
Prof. Judith Glück, Andreas Dünser, Karin Steinbügl

FWF project „Enhancing Spatial Abilities with Augmented Reality“

What we know…

- **Spatial abilities can be improved by Geometry Education**
- **Diverse improvements measured**
  - Assume general effects, esp. visualization skills
- **„Hands-on-practice“ has positive effects**

→ **Hypothesis: Interaction and „hands-on“ manipulation of 3D models in VR/AR improves central, general spatial abilities**

What we want to know...

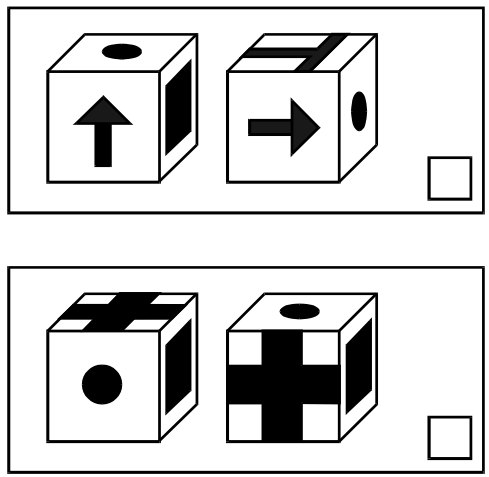
- Can we measure training effects?
- Which spatial skills are improved?
- Which strategies are used and can we enlarge the pool of strategies?
- Gender differences in training effects?
- Can gender specific strategies be changed?
- Inter-personal training differences?

Two Prestudies

- **First: 42 students (39 males, 3 females)**
  - MRT, MCT, PSVT:R, DAT:SR, WIT
- **Second: 79 students (35 m, 44 f)**
  - MRT, MCT, PSVT:R, DAT:SR, SOT, JLO, WIT
- **Age 16-19**
- **2 Austrian high schools**

Prestudy 1 – Findings

- **Tests (esp. PSVT:R, DAT:SR) can be solved with analytic strategies & reasoning & knowledge - not only „real spatial" holistic strategies**
  - Holistic strategies: Visualization; e.g. mental rotation of whole objects. Usually faster, better performance in some tests
  - Analytic strategies: decompose spatial tasks into smaller parts; verbalize
  - Example: Wayfinding



Thurstone (1937)

Prestudy 2 – Findings

- **Gender differences**
  - Males: Correlations between all spatial tests, logical reasoning (WIT) not correlated
  - Females: Significant correlations between all (incl. WIT)
  - Factor analysis: Different factor loadings

Males

	Component	
	1	2
PSVT:R score	**,661**	,196
MCT score	**,735**	-,141
MRT score	**,632**	,231
DAT score	**,836**	,083
WIT score	,187	**,888**
JLO score	**,826**	-,056

Females

	Component	
	1	2
PSVT:R score	**,689**	,363
MCT score	**,761**	,269
MRT score	,094	**,890**
DAT score	**,707**	,481
WIT score	**,736**	,392
JLO score	,211	**,682**

Prestudy 2 – Findings

- **Partial out logical reasoning (WIT)**
  - Males: no difference; **Females: All correlations** between spatial tests **disappear**

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Prestudy 2 – Findings

- **Partial out logical reasoning (WIT)**
  - Males: no difference; **Females: All correlations** between spatial tests **disappear**
- **Partial out elementary spatial functions (JLO)**
  - **Males: All correlations disappear**; Females: not much change

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Prestudy 2 – Findings

- **High spatial test performance related to**
  - Females: Good reasoning skills, logical thinking
  - Males: Speed and accuracy of basic spatial processes

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Evaluation Design

- **Pre- and posttests with 5 spatial ability tests (MRT, MCT, OPT, PSVT:R, DAT:SR)**
- **Strategy assessment**
- **Gender differences**
- **5 training groups with 250 students in total**
  - Construct3D group; Desktop CAD3D group
  - 2 standard school groups: Classical paper&pencil geometry, computer supported geometry educ.
  - Untrained control group

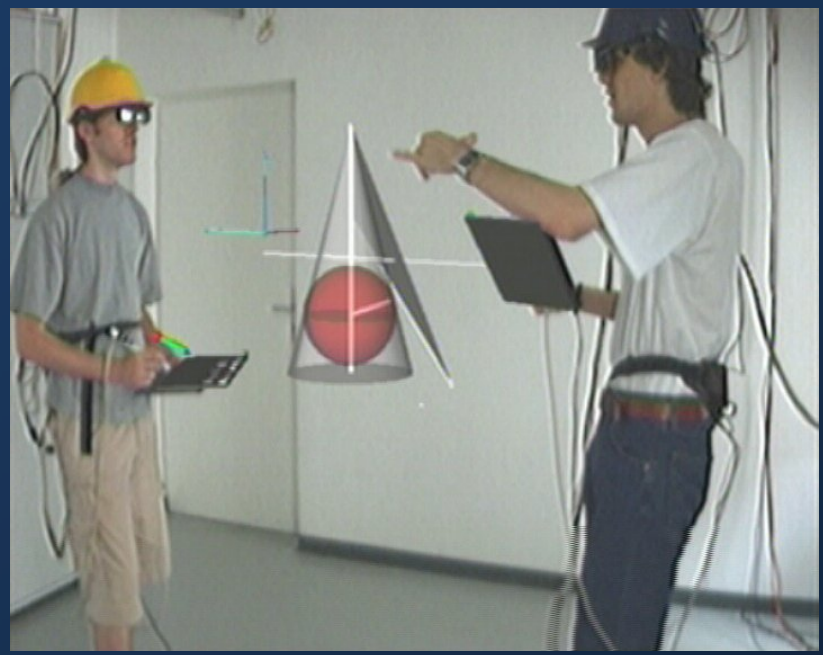
Possibilities & Chances

- **Construct3D: Platform for research on learning & training with new media (AR)**
- **Various fields of use:**
  - Tool for studying AR/VR Learning – pedagogy
  - Training spatial abilities on a general - not task specific – level
  - High school & University education
- **Dynamic 3D geometry**
  - Enables new ways of teaching geometry

Future Work

- **Bring technology to schools**
- **Pedagogical evaluation – learning transfer**
- **Work on spatial abilities:**
  - General training of spatial ability vs.
    Task specific training
  - Explorative interaction / Active construction sufficient?
  - Spatial understanding in VE better or equal to real environment? Is training in VE more efficient?

Thank you!



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http://www.ims.tuwien.ac.at/research/spatial_abilities/

Basic Immersive Multi-User Setup

- High quality optical tracking for 2-3 users
- User Interface: Personal Interaction Panel (PIP)
- Key features:
  - Students work directly on geometric objects
  - „walk around“ objects