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HOCHSCHULE DARMSTADT
UNIVERSITY OF APPLIED SCIENCES

Bachelor Thesis

Expanded Realities

Development of an interactive AR assistance to expand cooperative learning environments

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Study program: Expanded Realities
Print Date: 17.01.2023

Preamble

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Deutsche Zusammenfassung

Einführung

Virtuelle Welten werden immer wichtiger in einer digitalen Gesellschaft, mit zahlreichen Anwendungsmöglichkeiten in den verschiedensten Bereichen. Bildung ist einer dieser Bereiche. Das Problem ist, dass individuelle Lernmaterialien notwendig sind, diese jedoch teuer und zeitaufwendig in der Erstellung sind. Zudem schließen manche neue Technologien, wie VR, reale Lernmaterialien aus. Dies führt zu einer noch größeren Anzahl an benötigten, virtuellen Materialien. Ziel ist es, einen Weg zu finden, traditionelle Lernumgebungen und deren Materialien zu erweitern und Lehrenden sowie Lernenden eine Möglichkeit zu geben, schnell und einfach neue individualisierte Lerninhalte zu erstellen.

Die Recherche bezüglich des Lernens hat ergeben, dass mehrere Faktoren eine wichtige Rolle spielen. Ein wichtiger Punkt ist die Motivation. Diese wirkt sich maßgeblich auf den Lernprozess aus und kann diesen unterstützen, jedoch auch einschränken. Das Ziel sollte es sein, intrinsische Motivation beim Nutzer zu erreichen, sodass Lernen nicht für eine Belohnung, sondern um des Wissengewinns wegen stattfindet. Das ist zunehmend wichtig, wenn man sich kreierendes Lernen anschaut. Hierzu beschreibt die Lerntheorie des Konstruktivismus Lernen als einen aktiven Prozess, bei dem Nutzer Informationen mit subjektivem Vorwissen verknüpfen, um so ihr Wissen zu konstruieren. Das macht Lernen zu einem subjektiven Prozess, der durch kollaborative Elemente unterstützt werden kann. Eine Lernumgebung spielt hierbei eine große Rolle, da diese eine aktiven, kollaborativen und kontextbezogenen Prozess ermöglichen kann.

An diese Punkte können nun neue, immersive Medien, wie Augmented Reality (AR), anknüpfen. Vorteile entstehen durch ihre Kombination aus einfacher Handhabung, wie bei physischen Bausteinen, und virtuellen Vereinfachungen, wie duplizieren und umwandeln der Bausteine.

Konzept

Eine AR Anwendung, laufend auf einer Quest 2 (HMD), bietet die besten Möglichkeiten für Nutzer, um intuitiv Lernmöglichkeiten zu erstellen und eine Erweiterung der Lernumgebungen zu erreichen. Nutzer können, mithilfe von virtuellen 3D Bausteinen, Inhalte erstellen. Diese können dann mit zusätzlichen Informationen erweitert werden, wie Textelementen oder Verbindungslinien. Zudem findet alles in einer geteilten Onlineumgebung statt, sodass andere Nutzer mitgestalten und sich austauschen können. Nutzer verfügen auch über sekundäre Fähigkeiten, die es ihnen erlauben, erstellte Objekte einzufärben, sie zu löschen oder in ihrer Bibliothek zu speichern. Zudem ist die Anwendung darauf ausgelegt, Lernumgebungen sämtlicher Art zu unterstützen, das heißt, Nutzer sind in der Lage ungehindert zu kommunizieren und andere physische Lernmaterialien zu verwenden.

Die Anwendung ist designed, um Nutzer jeglicher Art zu unterstützen. Das heißt, alle Lehrenden und Lernenden können ab einem Alter von 13 Jahren (Vorgabe des Headset Herstellers), ohne benötigtes Vorwissen, mit Hilfe der Anwendung neue Lerninhalte erstellen.

Anwendung

Erstellt wurde ein Prototyp mit Hilfe der Unity Game-Engine und dem Oculus SDK. Der aktuelle Prototyp verfügt über eine volle Baufunktionsweise, mit drei verschiedenen Bausteinen (Würfel, Kugel, Zylinder) und zwei erweiterten Präsentationsmöglichkeiten. Diese erlauben es, Verbindungslinien zu ziehen und Textboxen zu setzen. An sekundären Möglichkeiten verfügt der Nutzer über den Pinsel, um Objekte zu färben, das Löschen und die Bibliothek, mit deren Hilfe Nutzer aufgelistete Lernmaterialien platzieren können.

Am Ende wurde noch eine Nutzereinführung erstellt, welche es neuen Nutzern erlaubt alle Funktionen zu testen und zu erlernen.

Im finalen Prototypen nicht repräsentiert sind die erweiterten online Kollaborationsmöglichkeiten, da diese im gesetzten Rahmen, aufgrund von technischen Schwierigkeiten, nicht eingebaut werden konnten.

Benutzer Test

Der finale Prototyp wurde im Rahmen eines Nutzertests auf die Probe gestellt. Hierzu wurden 21 Tester verschiedenen Geschlechts und im Alter von 20-26 Jahren, mit variierendem Vorwissen, als Tester herangezogen. Diese haben zunächst die Einführung absolviert, danach eine Aufgabe von einem physischen Blatt Papier erhalten (ohne das Headset abzusetzen) und final eine freie Bauaufgabe durchgeführt. Nach Abschluss dessen wurde mit jedem Tester eine qualitative Befragung, durchgeführt. (Empirische Datenerfassung mittels Fragebogen und Interview).

Dabei wurde ersichtlich, dass alle Nutzer in der Lage waren, die Aufgaben zu bewältigen und dass alle in unter 10 Minuten in der Lage waren, eigenständig Lerninhalte zu erstellen. Zudem hat die Befragung ergeben, dass die Nutzer die Anwendung als hilfreich, sowohl für die Arbeit mit physischen Lernmaterialien, als auch für das freie Erstellen von Lernmaterialien, empfanden. Die von den Nutzern erstellten Lerninhalte zeigten zudem die vielfältigen Ideen für Anwendungsmöglichkeiten und das Potenzial für individuelle Lernmöglichkeiten.

Ergebnis

Zusammengefasst zeigt die Anwendung, dass das intuitive Erstellen von Lerninhalten auch ohne Vorwissen möglich ist. Zudem zeigt die Implementierung mit der Quest 2 eine realistische Anwendungsmöglichkeit für den Bildungssektor, da diese mit einem Preis von ungefähr 450 Euro eine preiswerte Möglichkeit gegenüber anderen AR HMDs darstellt. Eine weitere Entwicklung würde sich auf die Online-Kollaborations-möglichkeiten fokussieren, da diese noch mehr Lernpotentiale ermöglichen. Weiteres Nutzertesten bleibt erforderlich, um in realen Lernumgebungen zu testen, wie funktional die Anwendung für den Lernprozess ist.

Abstract

We see an increasing focus on Expanded Reality (XR) systems with Virtual Reality (VR) and Augmented (AR) capabilities. These systems provide an affordable solution and novel ways of interacting with virtual content infused into someone's surroundings. Simultaneously we can see growing demand for digital, learning-oriented applications. Studies indicate that AR helps in learning processes by contextualizing information and creating highly adaptive environments.

Presented in this Bachelor thesis is the concept for an AR tool to support learning environments. The tool will enable users to create 3D learning materials whenever they are needed or take one out of their library of creations to explain or explore them collaboratively. The building process should be easy, intuitive, and fast, allowing for a low entry level and upward potential to create content ranging from simple blockouts to complex objects or full-on learning worlds. Beyond the creation, the tool also offers presenting and interaction capabilities through individualized learning materials. Users can move or rotate them, group objects into one learning material, add text notes to clarify functionality or add descriptions, and create connections between different materials or sections. All this while working in a shared world, where users can collaborate, add remarks, interact with creations or suggest changes and additions.

The created prototype of the AR tool allows users to build custom learning materials to support their learning topic. These virtual materials are then contextualized through the information of the physical surroundings, actively incorporating the users' physical learning environment and materials within the tool.

This thesis highlights the benefits of AR assisting in learning environments. The evaluation process indicated that the created tool achieved a low-entry level building solution, enabling users to exploratively create individualized learning materials incorporated into their learning environment. All with the Quest 2 as an affordable hardware solution for the educational setting.

Bachelor Project task description

Description of the motivation

The current industry is building immersive systems with an increasing focus on XR. Many of them provide VR and AR capabilities with passthrough camera systems. These systems present novel ways of interacting with virtual content infused into someone's surroundings and can offer affordable commercial solutions. Simultaneously we can see growing demand for digital, learning-oriented applications. It's important to explore these possibilities to understand potential use cases for expanding traditional learning environments. Studies have indicated that AR helps in learning processes by contextualizing information and creating highly adaptive environments. Virtual content creation offers countless opportunities for adaptive learning materials beyond physical materials.

Specifying the goal, and describing the task

To create an AR assistance that is able to support learning environments with different needs an adaptive tool is needed, which supports creative processes and collaborative work. First research is to be conducted that focuses on principles for creative tools. What is needed to bring the individual ideas to life, what learning practices support virtual environments with that purpose and how are users able to interact with virtual material within their surroundings? Furthermore, a deeper look into collaborative learning, principles, practical integration and explorative learning processes is needed. Finally technical research regarding Unity implementation under the aspects of AR capabilities, user interaction, user menu and guidance, multiplayer capabilities, and visual representation of virtual contents in AR is to be conducted.

On the basis of this research, an extended concept will be developed with a focus on AR user interactions and assisting tools for learning environments. Important is the ease-of-use of the building tool, to provide the users with a simple, fast, and precise enough system which allows for simultaneous user interactions. Under the aspect of learning environments, the system should offer real-time multi-user interaction with synchronized building and the possibility to interact with physical and virtual material.

This concept is to be implemented as a prototype with the Minimal Viable Product (MVP) including a block-based building tool with simple cubes augmented into the physical surroundings and support learning environments. Finally, an evaluation of the implementation under the question of how well users are able to prototype learning materials and expand their physical learning environment should be carried out.

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Glossary

Immersive media

XR	Expanded Reality
AR	Augmented Reality
MR	Mixed Reality
VR	Virtual Reality
HMD	Head Mounted Display
UI	User Interface
UX	User Experience
3D	Three-dimensional

Development

SDK	Software Development Kit
MVP	Minimal Viable Product

Introduction

Motivation

With Virtual Reality (VR) entering mass media (e.g., television, newspapers) and the world becoming more and more virtualized, new ways of interacting and creating virtual content are needed. This virtualization can be seen in all aspects of our lives, like becoming a digital introduction to a new workplace, socializing with friends over long distances in VR chatrooms, getting chirological treatment supported by AR, or just through entertainment like playing immersive video games on a PlayStation VR. These new technologies offer novel ways of interacting with vitality and can support many industries and important aspects of society like medicine or education. To benefit from these virtual worlds, they first need to be filled with objects and content. As with real tools and surroundings, this virtual content often needs to be tailored specifically to the intended purpose. With learning being a core fundament for every aspect of our society, this is especially a problem in the educational sector. Here individualized content is essential to support the learning process properly and achieve the intended learning goals. The **Problem of creating individualized virtual learning materials is that it requires professionals, is expensive and is time-consuming.** Beyond that new **virtual learning solutions (like VR)** often **exclude physical learning materials** which leads to even more content that needs to be digitized. This is where Augmented Reality (AR) can provide an alternative, by supplementing reality rather than replacing it. This opens up new possibilities for integrating virtual content into physical environments, to support processes like learning and utilizing AR capabilities to improve upon them. The **goal is to find a way to expand traditional learning environments and allow learners and teachers to create the virtual material they need in a fast and easy-to-learn way**.

The spectrum of Expanded Realities (XR)

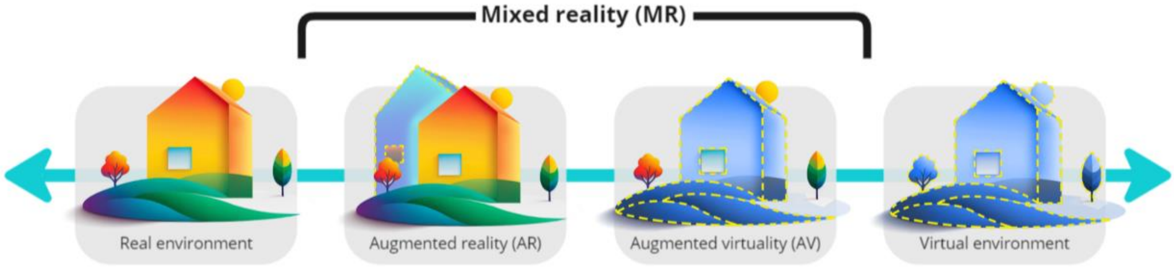

Figure 1: Reality-virtuality continuum, Illustrates the spectrum from a Real to Virtual environment

The most commonly used definition of AR is after Azuma in the year 1997.

"*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* (VR) *completely replacing it.*" [1]

Here AR is very strictly defined as a technology that expands the real world and is through this distinguished from VR. Because these technologies often have similar properties Milgram et al. brought up in 1995 the Reality-*virtuality continuum* [2] (Figure 1). This defines the technology on a spectrum from a *Real* to a fully *Virtual environment* where all systems place, rather than strictly defined borders. They highlight the term Mixed Reality (MR) to define XR technology between fully real and fully virtual environments, including Augmented Reality and Augmented Virtuality (virtuality augmented with real objects). This is becoming more and more important as many state-of-the-art systems have both AR and VR capabilities and are moving along the spectrum, rather than being clearly defined to one functionality. To avoid confusion about the level of AR this thesis avoids using the term MR to describe systems, as otherwise, many current XR systems would just classify as MR. To make the degree of AR clear, all systems are labelled with different levels of reality and virtuality.

Placement of the concept

For the context of this bachelor thesis, the concept presented is clearly placed in the spectrum of AR. The technical implementation will be placed between AR and VR. The reason being that the Quest 2 is actively implementing the real environment supplemented by the augmented virtual content (AR), but is as of now not capable of including landmarks (real surrounding objects) besides the floor level to simulate objects' interaction with the real surroundings.

Current systems - MR, AR, and XR

Recent years have shown big improvements for AR and XR systems, with Microsoft HoloLens actively in use in many industries, or Meta pushing the field of VR into mainstream media (e.g., television, newspaper). The massive growth has provided a variety of AR-capable device options ranging from consumer-grade devices like the Quest 2 to Industry professional devices like the Vario XR3. Many of these systems offer a combination of VR and AR interaction or separate modes for each. With phone-based AR still being the most prominently used solution, listed in table 1 are some of the alternatives to provide state-of-the-art AR in form of a Head Mounted Display (HMD).

Brand	**Device**	**Spectrum of AR**	**Pricing (Starting from)**
Meta	Quest 2	VR + AR Black & white passthrough	450$ (Launched 300$)
Meta	Quest Pro	VR + AR color passthrough	1800$
Pico	Neo 4	VR + AR color passthrough	399$
Microsoft	HoloLens 2	AR	3849$

Varjo	XR 3	VR + AR	6459$ + subscription

Table 1: Showing an overview of current AR HMDs and their price [3]

Learning

Dr. habil. Cora Titz describes in [4] the different aspects of learning and teaching. The following three paragraphs will provide an introduction to the basics of learning.

How do we learn?

[4] explains how we learn. Learning is not equal to knowledge acquisition. Learning is always a process of changing the state before learning.

Process of information

[4] states that to efficiently utilize information, our brain needs repetition. Many studies have shown that for long-term knowledge spaced out learning is more effective than concentrated learning. To increase learning gains, even more, the brain also needs to connect new information with pre-existing knowledge to create an elaborate net of information, which forms our knowledge.

Motivation in learning

[4] describes the motivation as follows. The motivation to learn can be intrinsic, which means the motivation comes from the thing itself (e.g., interest in technologies) or through the way of presenting learning material, so-called situative interest. The motivation can also be extrinsic, which means the motivation to learn comes from the awaited result (e.g., a reward) and not the learning itself. If the reward is omitted, the motivation is lowered or not existing anymore. Emotions can be activating (happiness, fear) and deactivating (boredom, hopelessness). When they work on activating, they encourage motivation and activate the learning process. When they work deactivating, they lead to a lack of motivation and therefore not activate the learning process.

Theories applying to AR

Presented are two learning theories applying to AR found on multiple occasions across the literature. The first is digital game-based education. Across researchers, *the consensus is that well-designed educational games promote learning gains and improve learners' interests, motivations, and engagements* [5, p. 1170] This supports them by developing new soft skills and deep knowledge and supports relevant skills like communication, collaboration, critical thinking, and creativity [5, p. 1170]. A downside to game-based education is that the motivation is extrinsic and comes from the game, this is often reward-based motivation, which only works if users get motivated from set rewards and stop the moment they don't receive the rewards anymore.

Another approach is the 'Multimedia Learning' theory [6]. It is based on three assumptions, the first one is that there are two separate channels for visual and auditory information. The second assumption is that the two channels can only absorb a limited amount of information at any given time. The final third assumption humans are active learners. These can then be applied to AR where due to its nature user can interact with visual (3D models), text-based (e.g. info panels), and auditory (e.g. ambient sounds) information. This can create an active learning environment where both channels can absorb information.

Constructivism

The learning theory of constructivism, described in [7], centers around the idea of learning by constructing knowledge. Key points to understand what's important to the theory are as follows: *Knowledge is constructed.* This means all learners start with a set of pre-existing knowledge and build in connection to this existing knowledge new one out of the learnings. *Learning is an active process.* Learners need to engage and actively be a part of the learning process to construct their knowledge, rather than passively receiving knowledge from a teacher. *Learning is contextual.* Information can not be retained through isolation. Learning is the process of connecting information, reflecting on existing knowledge, and subjective representation of information. *Learning is a social activity*. Interaction with others is essential to create an understanding of the information and helps us to reflect on our learnings. Finally, *Motivation is key to learning.* With learning as an active process, motivation is key to the creation of connections and engaging the learner in the learning process.

Learning environments

[8] defines that the term environment refers here to the location, context, and cultures in which learning happens. This includes physical environments like a studying room or outdoor environments but also refers to the characteristics of these environments e.g., how individuals interact and treat each other. Traditionally these aspects are mostly associated with physical environments but they can also apply to virtual spaces. In these cases, context and culture play a more important role and become deciding factors when classifying virtual learning environments. [9] continues to define that both physical and virtual learning environments can be categorized into a variety of types and can be differentiated by the intended purpose. Most relevant here is the classification between an active and a passive learning environment. Passive environments focus on enforcing knowledge through stage knowledge repetition. This means students learn through listening, writing, and repetition. Active ones encourage students' active participation to achieve the learning goal. This means students are a part of the learning by not just listening but actively exploring, thinking, and shaping their knowledge.

Concept of contextualization

When we talk about contextualization, we mean setting things into perspective and comparing them with outside sources. In the case of AR, multiple ways of contextualization can occur. One way AR contextualizes information is by setting virtual content into the context of the physical environment. The surrounding physical objects serve as a reference and help the user to better understand the virtual object, by size, materials, cultural identity, and more. Another way of contextualization in AR is through the multiple channels available. A 3D object can be further set into context by adding sounds and text, which supply the user with more information for example about the purpose of the object and its natural surroundings. This could help learners to get a deeper understanding, trigger emotions or connections, and therefore set the newly acquired information into the context of existing knowledge.

Building Blocks

Physical & virtual building

One of the most common traditional physical building blocks are Legos. The plastic bricks [10] with their iconic shape and the connection pins allow for a grid-like snapping between the points and enable users from children to 99 years old to create what they imagine. In the beginning, only a handful of brick shapes existed, and only over time, the number of different pieces grew. The building process is hereby easy to learn and hard to master. Untrained users are able to build a rough version of what they imagine and skilled users are able to create highly detailed and intricate designs. The brand has since grown its beginnings immensely and nowadays incorporates digital and VR Lego building tools as well as traditional sets.

Figure 2: Lego bricks [10]

Virtual building accelerated after the release of Minecraft in 2009. The open-end survival game with its iconic cube-based style offers players countless ways of building out what they imagined and even included logic blocks that over time enabled players to build out logic-driven machines and circuits. Once again the limits of the building blocks and cohesive style encouraged creative thinking and sparked the fascination of the players. This led to more and more players trying to bend the limiting rules by creatively using blocks in unintended ways or using the game as the foundation to create their own mini-games, adventure maps, or online worlds.

Finally, new technologies like VR & AR bring these two worlds closer together and combine the benefits of physical and virtual building. They achieve this by combining the intuitive building process of physical building blocks with the benefits of virtual building, like unlimited block supply, clone objects, and undue actions.

Industry usage

Especially in creative industries both physical and virtual building are in use. When prototyping ideas or level layouts for example the first thing created is a blockout (rough model to get an idea of the volume for later objects and elements). For this often physical blocks are still used to create this first draft due to their intuitive, easy-to-use nature and therefore rapid prototyping capabilities. But also new virtual modelling tools find more usage in the industry. Google created ‘Blocks’ [11] [12], because during their VR development for a productivity app, they noticed that the model creation process for their prototypes took a long time and required often multiple employees. With their VR tool, on the other hand, employees without modelling experience were able to create a prototyping-ready model or use their model to show designers what they had in mind, to speed up the modelling process.

Examples of VR prototyping tools

Google Blocks

[11] [12] describe Google Blocks as follows. It aims to allow users to create a quick and cohesive-looking low poly model in VR. Their creation is then shared in the Gallery (not available anymore). There it's free for everyone to download or remix (use, altered) to build new ones out of them. All are available under a free license system with only a displayed reference to the original creator.

Figure 3: User modeling in Google Blocks [11]

Inside the app, users utilize a limited tool set to shape and form their models and a color pallet with 32 pre-set colors to make each model coherent in style and appearance. The modeling process is easy to use and still allows users to use advanced techniques found in traditional modeling software (etc.) with features like tweaking polygons, and extrude or alter shapes along the way.

Gravity Sketch

In [13] Gravity Sketch is shown as a VR tool aimed to create professional-grade models with a targeted workflow of first sketching and then enhancing the sketch with 3D modeling [14]. It allows users to import or use preinstalled reference models to sketch and build on top and provides a full range of professional 3D Modeling tools. Besides the creation, it also features team-focused collaborative features, where designs can be reviewed and commented on in a virtual environment. Gravity sketch is used in big companies, for example in the automotive and technology industry.

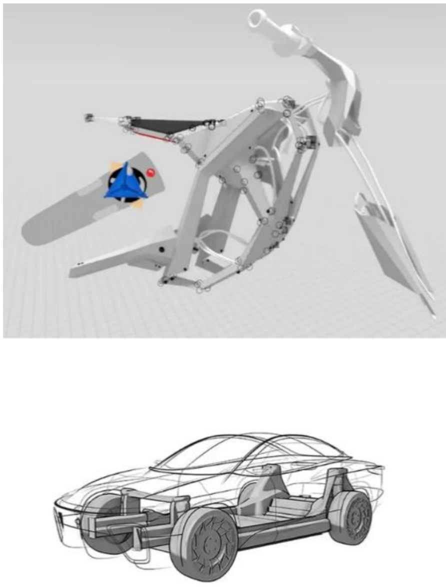

Figure 4: The modeling process in Gravity Sketch [14]

Arkio

Figure 5: Virtual user interaction in Arkio [15]

On their webpage [15] Arkio is described as targeted at architects and a fast solid modeling tool that allows for boolean operations, snapping, and sliding. It is aimed to deliver a similar experience to working with physical objects in architectural modeling. It allows for cross-platform collaboration with VR, MR, desktop, tablet, and phone support. Users can work together in a shared virtual space. For the workflow, Models can be imported from a variety of 3D tools including Revit, Rhin, and Unity. It also supports AR features where users can work on top of their physical surroundings and can create windows and doors into the virtual world.

Concept

Overview

The starting point for this concept was an AR tool that assists users in their physical learning environments. The first ideation process led to two fields of concepts for how to achieve this. One idea was a collaborative AR space where users can shape and visualize their ideas, and the other an adaptive learning environment that uses AR to infuse the physical surroundings with topic-specific information. Through further iteration, the concept evolved into a shared collaborative space with fast prototyping capabilities. This final concept showed bigger potential, because it was less explored, offered wider implementation possibilities, and big potential for further development capabilities.

The tool will enable users to create individualized 3D learning materials whenever they are needed and explore them collaboratively. The building process should be easy, intuitive, and fast, allowing for a low entry level and upward potential to create content. The complexity can range from simple blockout to complex objects, or full learning worlds. Beyond the creation, the tool also offers presenting and interaction capabilities with these learning materials. Users can take previously created learning material out of their library of creations to explain or share their creations with others. They can move or rotate them, group separate objects into one learning material, add text notes or descriptions to clarify functionality, and create connection lines between different material sections. All this while working in a shared world, where users can collaborate, add remarks, interact with creations, and make suggestions for changes and additions.

Setup

Most commonly when talking about AR, especially in the aspect of education, we see the use of smartphone-based AR. It is the most affordable solution if all students already have a device at hand that is capable of running the AR application. It has nevertheless its downsides, the biggest one being the lack of immersion and limited interaction capabilities. This concept is to be implemented into an HMD-based AR solution to create deeper immersion and intuitive hands-free visualization of AR content. This should allow users to create more precise models and interact with each other unobscured. The technology of choice is the Meta Quest 2 (formally Oculus Quest 2) with its pass-through and hand-tracking capabilities to offer an affordable state-of-the-art solution. This leaves no other hardware requirements. The tool is programmed with the Unity game engine, the Oculus integration SDK for interactions, and photon Pun2 for networking.

Figure 6: Concept of collaborative user creation of learning material

To get the tool assistance in a learning environment, only the HMD is required. With the tool users are able to build out the content needed while still seeing and interacting with their physical learning environment. This provides them the freedom to shape the learning process and retain interaction with other users and most importantly with other learning materials in the environment.

Sound

When working with immersive media one of the key aspects is sound. Besides the visual stimulation, sound offers a second channel to convey important information and provide the user feedback on their actions. With this second channel, we can then convey passive information, like ambient sounds or sounds that add additional information regarding the functionality of an object. Therefore, the inclusion of an immersive sound concept (figure 7, [16]) is essential. In the case of this concept, sounds would play a major role in giving users feedback on their actions. This could be implemented with a sound when pressing a button, selecting a color, or once a building block is placed. Beyond that sound could also be added as an active feature to support users in shaping the learning material. This could be implemented with a system that allows users to upload specific sounds and then let them place audio sources with these sounds. The sound could support their learning materials or help to create immersive learning environments.


Figure 7: 3D sound immersion of the user [16]

Application structure

The tool consists of main modes and secondary tools. The main modes and their functionality are connected to one hand (right hand/controller) and the secondary tools on the other hand (left hand/controller). This gives them a distinct place and should help users to learn the features of the tool.

The tool will consist of three main mechanics that separate functions and interactions. This helps to guide users and limit options to only the necessary ones depending on the use case. These modes form the main functionality of building learning material, presenting learning material, and interacting with shared learning materials. The secondary tools consist of additional functionalities like deleting, undoing actions, changing color, a library of creations, cloning objects, and object grouping. These support the main mechanics and can be used simultaneously.

Building

This mode is the primary way of creating and manipulating the learning material. It allows users to select a desired starting shape and create a block by placing the shape in their surroundings. By holding the button it allows them to place a scaled version, ranging from the initial place point to the controller/hand position. This allows for a fast and fluid way of placing geometry and already tailoring it to the intended purpose and the physical learning space. When a shape is not fitting to the intent or needs to be adjusted by position or rotation, users can then grab the block (with a button press or hand grab gesture) and adjust the placement. With these core interactions, users can blockout learning material fast and easily and create complex objects out of multiple blocks. When leaving this mode all blocks get grouped to form a combined object, the new learning material.

Presenting

The purpose of this mode is to allow a user to present learning material to others. This can be newly created material or creations from the library. Users can then add connections to certain parts of the object to visualize their thinking process or show relations between material. They also have the option to create additional notes to add descriptions or explanations. Finally, they can create a focus area which is a holographic 3D space that can be dragged out to focus other users' attention on one specific area of the object. This should help with the guidance of attention, similar to a laser pointer in traditional learning environments.

Collaboration and interaction

Finally other users can interact with others in a variety of ways. Most importantly they can use the build mode to add suggested parts to a model or build other learning material if wanted. This serves the purpose of opening up for collaborative thinking, better creations together, and new possible ways for interpreting learning materials. It also opens up the possibility for other ways of interaction, like a task for the other users to recreate a certain aspect or reimagine it. Next, they can interact passively through gestures, Thumbs up and down. This could be detected via hand-tracking and can be used for quick feedback or to vote about topics. This could support a traditional teaching setup.

Secondary tools

First with the paintbrush tool, blocks can be recolored to separate aspects or give further information about the material. If an object is not wanted anymore, it can be erased with the delete tool. The library tool provides the users with an inventory. Here users can save their creations and load them into the world to present them to others.

Target group

The tool is designed to be easy to use and still offer complex creation and interaction capabilities. It's therefore not targeted at a specific age or educational user group. The target audience consists of all learners and teachers. No specific pre-existing knowledge about AR or VR is required. The tool operation would only be accelerated by pre-existing HMD usage experience. The minimum age to use a Quest 2 is defined by Meta as follows:

"Designed for ages 13+ Meta VR systems are not toys and must not be used by children under 13. Younger children have greater risks of injury and adverse effects than older users. While we know that children under 13 may want to use Meta VR systems, we do not permit them to create accounts or use Meta VR systems. Adults should monitor the time their teens 13+ spend using the headset. " [17]

User journey

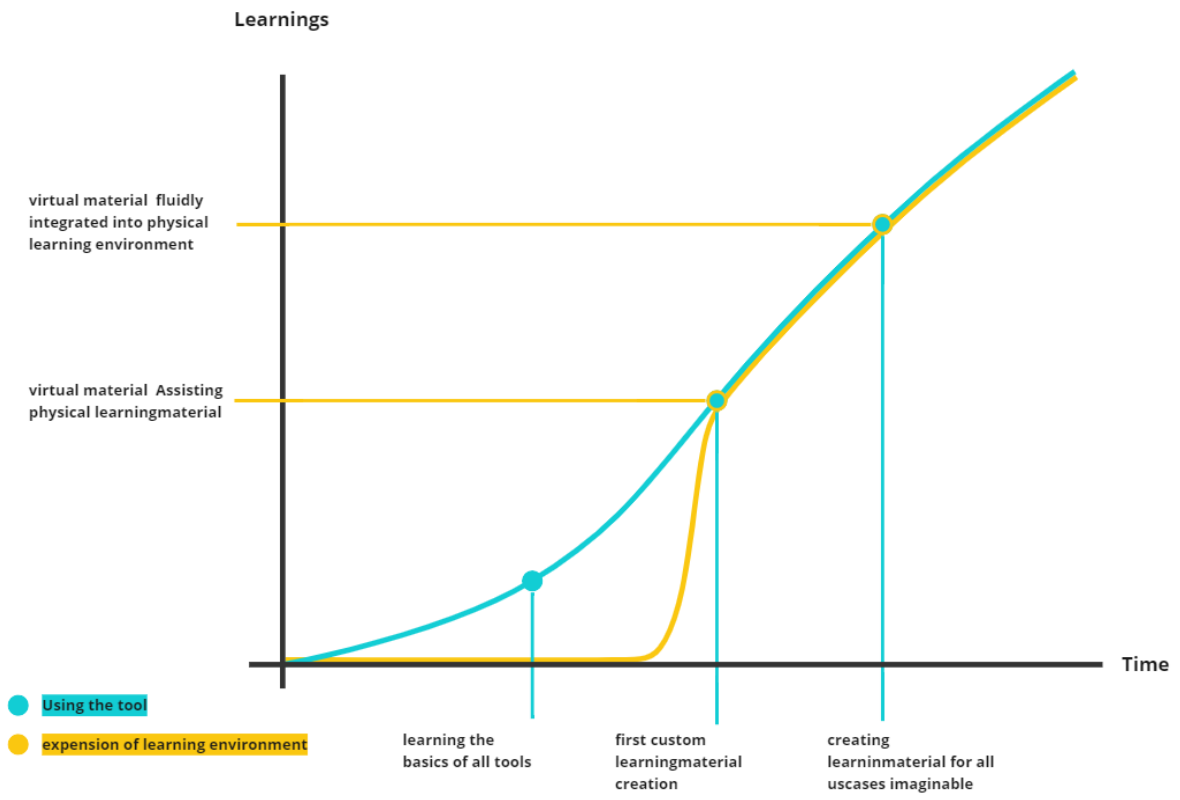

Figure 8: User journey, illustrating the learnings over time

This user journey aims to show the different learnings users can achieve with the tool. Instead of showing engagement over time, the figure 8 shows the learnings over time. Represented are two learning curves. The blue curve shows the user learning the tool itself. Along the line, three milestones are highlighted. The first marks the point once the user has finished the introduction and learned the basics of the tool. This marks the entry-level required to operate the tool. From there on users' progress with practicing the tool operation and memorizing the controls, this leads to the second milestone, their first custom learning material. This is the changing point, from here on users stop learning the tool and start learning with the tool and by continuing to reach the final milestone a constant creation of new learning materials.

Along the blue curve sits the yellow one, which illustrates the parallel expansion of the learning environment. In the beginning, until after the first milestone, no expansion is possible, because users first need to learn how to use the tool. Once this step is complete and users begin to create their first learning materials, then the learning environment can start benefiting from it and users can begin incorporating physical material into the process. The final step to expand the learning environment is the fluid integration of the virtual content. When incorporating both, creating new and connecting to previous, then the most learning can be achieved.

Learning concept

The tool reinforces learning through the process of creating learning materials, presenting the material, and interacting with other users. This forms a nonlinear setup, which encourages the users to explore learning possibilities and to expand their horizon. The process of building learning material allows users to create subjective representations to construct their knowledge. The new material is through AR contextually anchored in reality, allowing users to directly reflect and compare it with previous knowledge to their perspective of their surroundings. This creates an active learning process based on intrinsic motivation that is further deepened through collaborative exchange. The presenting and interaction capabilities further expand this exchange by encouraging users to exchange information about the material, add additional text or draw connections to explain their thinking behind certain aspects. This allows for integration into a wide variety of learning environments. In practice, this could support traditional learning environments with for example one or a small group of users (teachers) giving out tasks or presenting learning materials and a second group of users (learners) answering the task with 3D creations or interacting with provided learning material. Alternatively, the tool could also be used unrestrictedly to assist learners directly in collaborative learning e.g., between students working together in a non-hierarchic learning environment or in group work to create necessary material, to help them explain topics, or to expand information from other (physical) learning materials.

The Use-Case

Overall the tool is designed to assist any specific situation or field of learning. The purpose is that by utilizing creative processes users are able to build material that represents their subjective interpretation of the information to support their specific learning needs. This individualized learning material thus enables deeper learning and can be potentially applied to a variety of current or future use cases (similar to individually created notes).

Example Use-Case: chemistry

To provide an overview of how the tool could assist one common learning topic the example of chemistry is presented here with the field of molecule reactions.

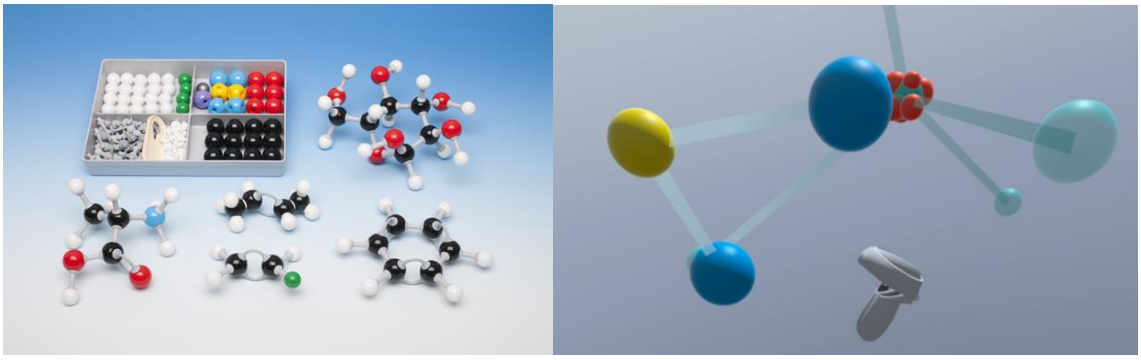

Figure 9: Traditional molecule-build set vs XR molecule building concept

In a regular chemics high school class, around 20 students' study. As one of the bases of understanding chemical reactions, students learn how to write a reaction equation. This equation shows how many elements are needed to perform a basic reaction. They are supported by their learning materials, consisting of individual materials (books, worksheets) and shared materials like whiteboards, smartboards, or a model building box (Figure 9. When dealing with complex reactions of molecule structures, often the only way is to try to understand the three-dimensional structure of a molecule. A molecule model building box can help to visualize the process when being unsure of how a reaction happens and what connections are available on a molecule. This leaves all students with one option which enables a deeper understanding of the three-dimensional reaction process, the physical molecule-build set.

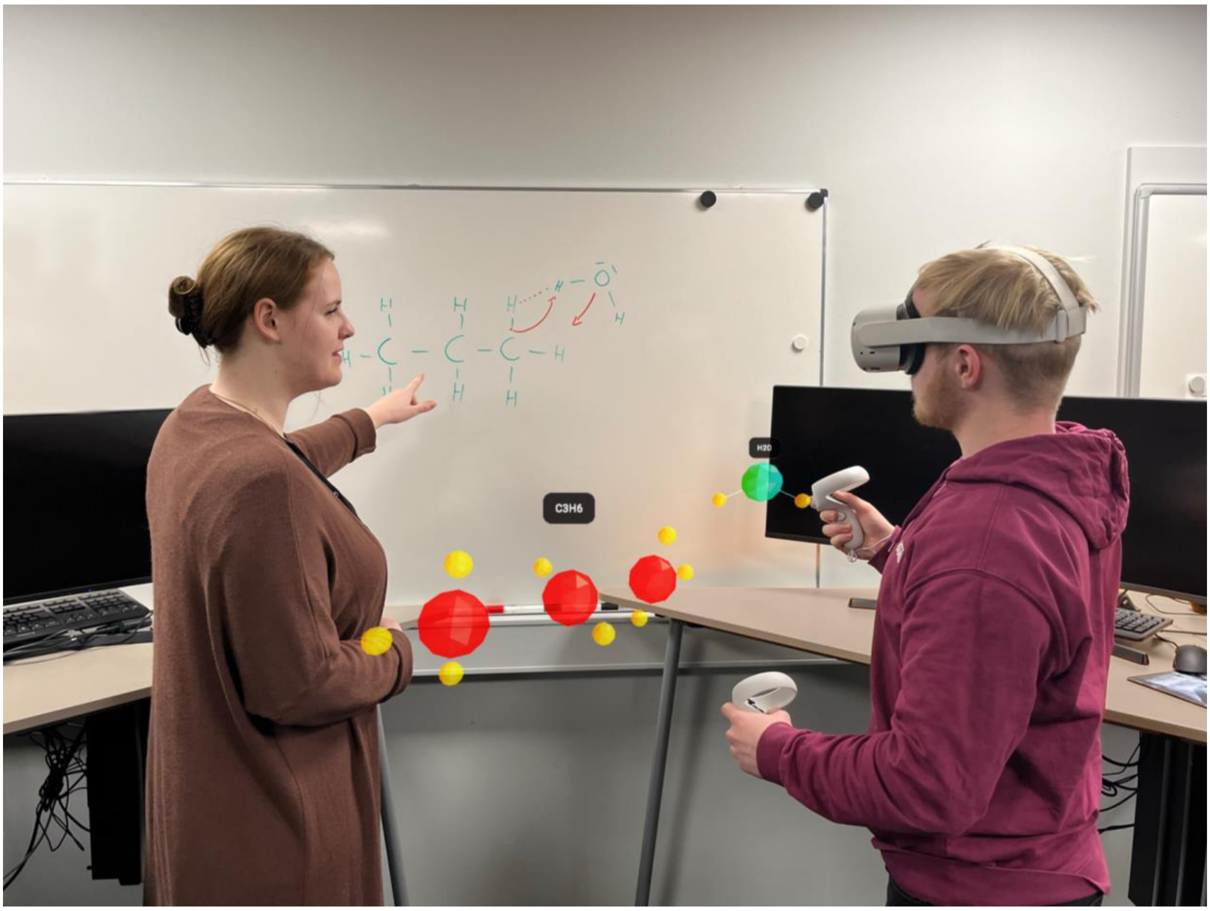

Figure 10: Shows an example of how an interaction with the presented tool for chemistry could look like.

The AR tool on the other hand enables all students to visualize complex structures while learning how they are set up, what rules apply and how reactions between them happen. This can be achieved in a variety of ways.

Learners

- Use the building tool to create a 3D representation of the different atoms and molecules
- Import structure provided or recently created
- Use the line functionality to create connections where a reaction could occur check if all open electrons are paired properly

- Add text descriptions, names, or specialties to deepen the understanding of the reaction or place remarks for future usage

Teachers

- Enhance physical learning material with 3D, to give learners a better overview of the structure of elements and molecules
- Task students with 3D creation of molecule reactions and more
- Monitor and assist learners within a shared AR space

Benefits

- Unlimited amount of building blocks, collaborative work, instant recreation
- Provide learners with a better 3D understanding and interaction of molecules and reactions
- Test their knowledge
- Create their personals library that helps their needs specifically

Other use cases

The implementation possibilities are ranging from practical usage (e.g., woodwork virtual volume study) to building-related (e.g. architecture classes) till abstract usage (e.g. geometrical forms for mathematics).

Implementation

External SDKs & plugins

1 oculus interaction SDK

2 photon pun 2

Development structure

The production can be separated into 3 phases. First the Unity project setup, then the development of the MVP with the core functionality (building system), and finally the finished prototype used for the user testing.

Setup

Unity project

Started with a Unity [18] 3D core 2021.3 project, switched the platform to android and tweaked the settings to support Quest Passthrough development (ILCPP, ARM64, android v29, gsl3)

Import: Packages required are Oculus Integration (OVR) [19], after the import select OpenXR as backend and setup Oculus developer hub and oculus app outside of Unity.

OVR camera & interaction

The 'OVRCameraRig' forms the base for the HMD data collection and input/output handling. For interactions, a mix of 'OVRInteraction' with a poke interactor and the 'ObjectManipulator' script was used. Both can be found in the OVR example scenes.

Figure 11: OVRCameraRig prefab inside of Unity

Passthrough

The AR capabilities first need to be enabled inside the 'OVRManager' settings, by checking the "Enable Passthrough" boxes. Then through adding the 'OVRPassthroghLayer' component on the 'OVRCameraRig' the composition and style can be setup. Passthrough is set to underlay to augment the virtual content on top of the real environment.

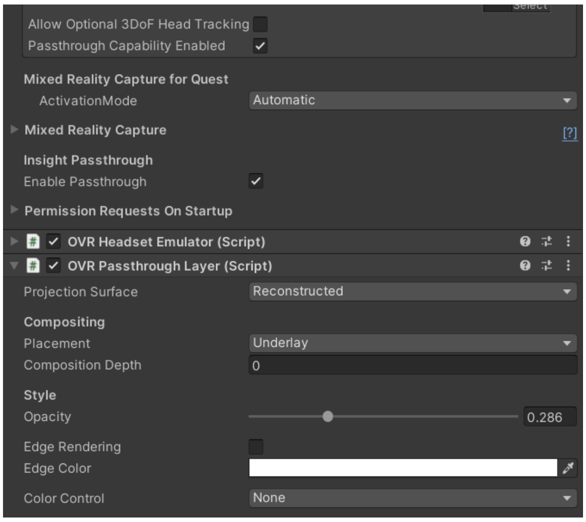

Figure 12: OVR Manager and OVRPassthroghLayer components to setup Passthrough support.

Multiplayer integration

To create real-time collaboration 'Photon pun 2' [20] was planned. A network manager handles the room creation, join, and online player instantiation. To be shared over the network, all tools and actions need to receive a photon view and photon transform view component. Instantiated objects need to be placed in the Resources folder, located in the assets. Due to the complications with the OVR SDK, with multiple interactions facing difficulties and needing custom solutions, a complete synchronized multiplayer was not possible to be implemented in the current version of the Prototype.

MVP - Core functionality

As the core of the concept the first step for the technical implementation was the building functionality. These get enabled through the 'BuildingMode' script. Building works by instantiating a prefab of the chosen building block and activating the scaling.

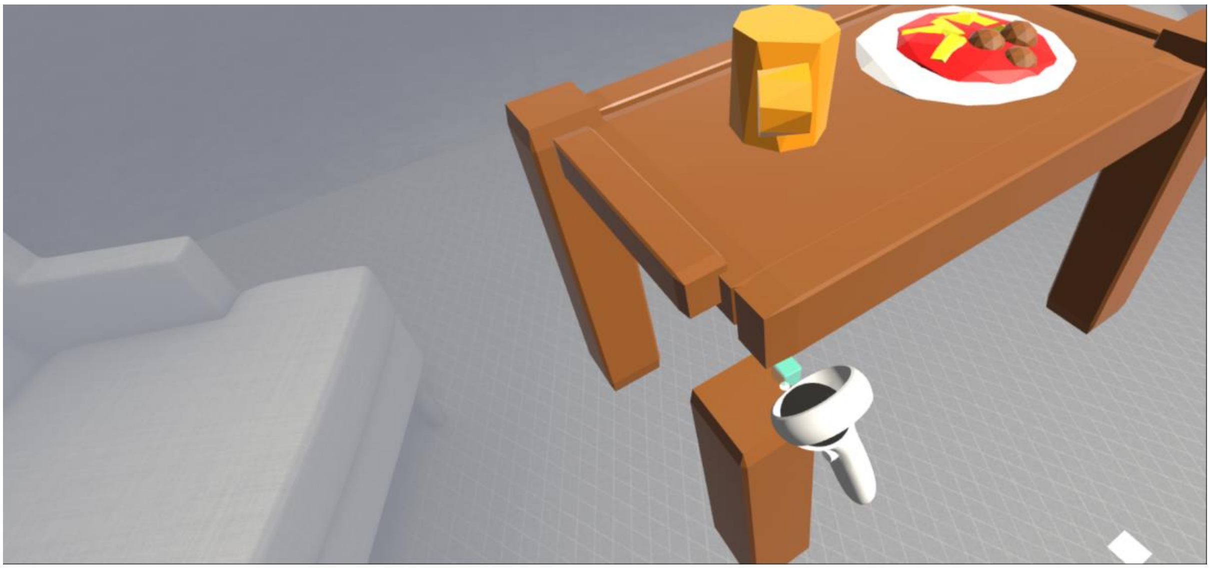

Figure 13: Building with the AR tool
(Virtual demo environment because Meta doesn't allow AR recording on the Quest 2)

The first iteration was a basic scaling function which gets the vector from the instantiated object to the 'placePoint' connected to the controller. This vector then describes the desired scale for each axis and can be applied to the local scale of the object. This provides an easy solution for placing and dragging objects but has the downside of enabling the user to scale objects negatively. This worked for the moment and was fixed at a later state by the advanced scaling function. The differentiating factor is from where the object scales. Rather than scaling from the left bottom corner of the object, the new function gets the center position between the spawn point and the controller and moves the object to that point. After that it subtracts the spawn position from the controller position, to get the scale-defining vector. With the use of Unitys 'Mathf.Abs' function, we get the absolute values of that vector and can apply it to the local scale of the object. This prevents negative scaling and invalid mesh creation.

```
Unity-Skript (2 Objektverweise) | 0 Verweise
public class BuildingMode : MonoBehaviour
{
    variables
    Unity-Nachricht | 0 Verweise
    private void Start()...

    Unity-Nachricht | 0 Verweise
    void Update()
    {
        #region change Buildingblock
        //change buildingBlock
        if (OVRInput.GetDown(switchPrimitiveButton))
        {
            if (currentPrimitive == (primitives.Length - 1))
                currentPrimitive = 0;
            else
                currentPrimitive++;
        }
        //preview enable
        foreach (GameObject go in primitivesPreview)
            go.SetActive(false);
        primitivesPreview[currentPrimitive].SetActive(true);

        spawnGo = primitives[currentPrimitive];
        #endregion

        #region Bilding
        //spawn current buildingblock
        if (OVRInput.GetDown(buildButton))
        {
            //spawn and parent building block
            localGO = Instantiate(spawnGo, placePoint.position, Quaternion.identity);

            Renderer localGorend = localGO.GetComponentInChildren<Renderer>();
            localGorend.material = colorManage.targetColor;
            instantiatePos = localGO.transform.position;

            localGO.transform.SetParent(parentGO.transform, false);
            active = true;
        }
```

Figure 14: BuildingMode script, showing the execution of changing out building blocks and instantiating a block

```
        //scale current buildingblock
        if (active)
        {
            if (localGO == null)
                return;
            scaleObjectSizeDependant();
        }
        //deactivate flag for scaling
        if (OVRInput.GetUp(buildButton))
        {
            active = false;
        }
        #endregion
    }

    0 Verweise
    void basicScaleObject()[...]
    0 Verweise
    void advancedScaleObject()[...]
    1 Verweis
    void scaleObjectSizeDependant()
    {
        Vector3 controllerPos = placePoint.transform.position;
        Vector3 spawnPos = instantiatePos;

        VectorGOtoHand = (controllerPos + spawnPos);
        localGO.transform.position = VectorGOtoHand * 0.5f;

        //scale from instanteate point to controller when bigger than minimal size
        VectorGOtoHand.x = (controllerPos.x - spawnPos.x);
        if (Mathf.Abs(VectorGOtoHand.x) <= minSzise.x) VectorGOtoHand.x = minSzise.x;
        VectorGOtoHand.y = (controllerPos.y - spawnPos.y);
        if (Mathf.Abs(VectorGOtoHand.y) <= minSzise.y) VectorGOtoHand.y = minSzise.y;
        VectorGOtoHand.z = (controllerPos.z - spawnPos.z);
        if (Mathf.Abs(VectorGOtoHand.z) <= minSzise.z) VectorGOtoHand.z = minSzise.z;

        Vector3 goScale = new Vector3(VectorGOtoHand.x, VectorGOtoHand.y, VectorGOtoHand.z);
        localGO.transform.localScale = goScale;
        Debug.Log("localGO.transform " + localGO.transform);
    }
```

Figure 15: BuildingMode script, showing how the scaling is handeled

Interaction methods

At this stage the building block was noninteractive, to change that a new building block Prefab (Name for a grouped object inside of Unity) was created on the base of a palm grab object. With the Grabbable component on the main object and a child object with the hand grab interactable and hand pose + box grab surface enabled grab capabilities supported for hand tracking and controller-based interaction.

Final prototype

Based on the MVP the final prototype improved on all functionalities. Beginning with the 'ModeManager', to manage all the different interactions and controls. It serves as the base and works by activating different mode profiles and tool profiles, therefore activating their interactions and controls. The array of modes includes the 'BuildingMode' and the 'PresentMode'. The array of tools includes the 'PaintBrush', the 'Delete' tool, and the 'Library'.

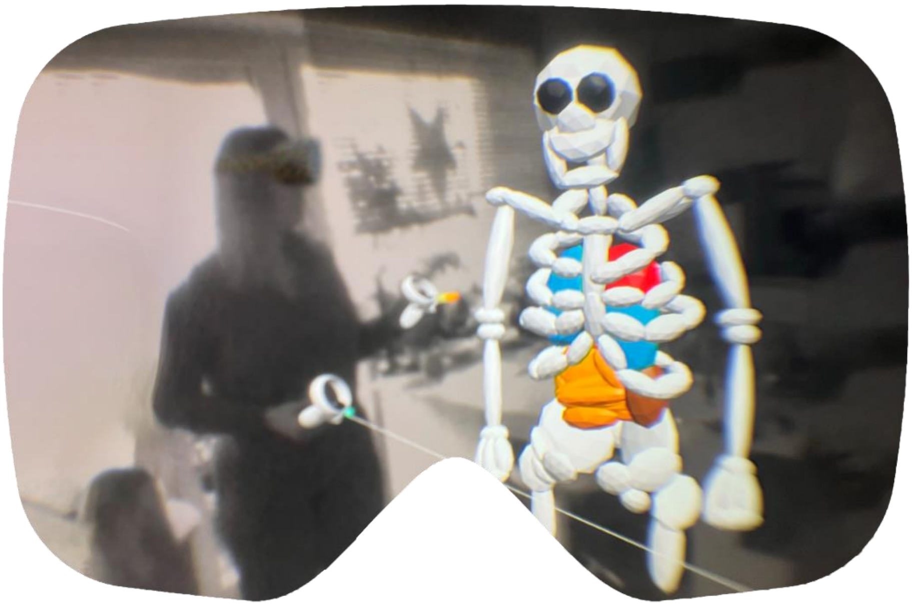

Figure 16: Perspective of a user wearing the Quest 2 and using the tool (captured through one lens of the HMD)

Present mode

The second mode is the present mode. The first functionality is the placement of connection lines. For the connection line, a script was used that gets the points on the line (min start and end point) and draws the line renderer according to these positions. The start and end points are both chilled to the line controller. The present mode manages the different actions and spawns a line on a button press. The user can then, by holding down the 'Trigger' button, set the position of the second (end) point. This allows for a fast and intuitive connection of objects. To actually connect the lines to the objects both points have a set of other scripts that parent them on touch with an interactable and hide the start and end points when not in the present mode.

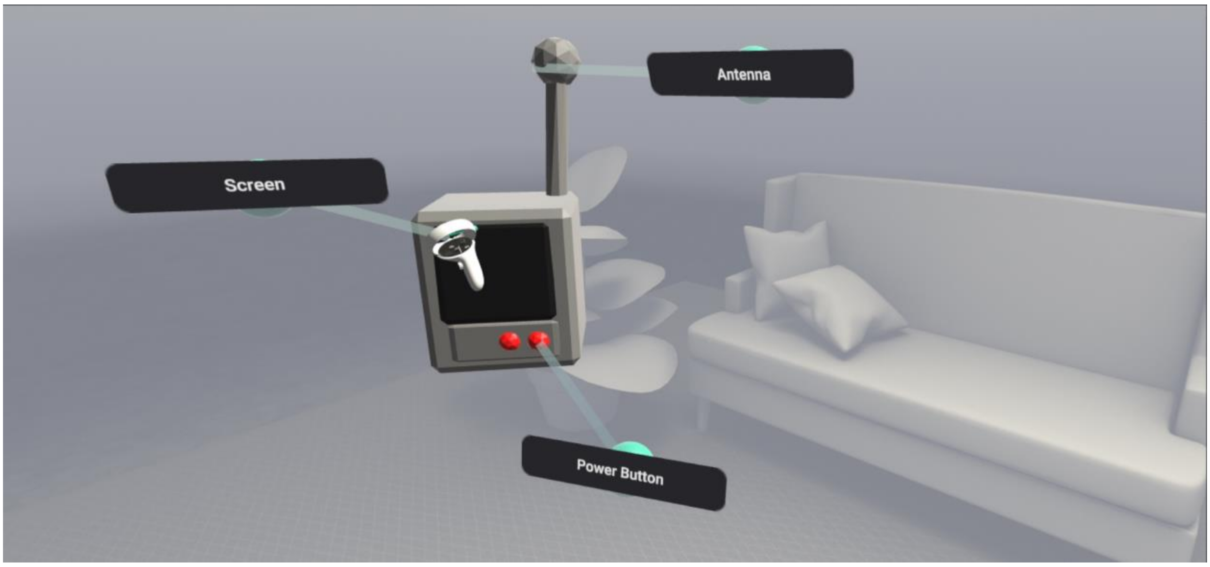

Figure 17: Adding connections and text in AR, with the Present Mode

(Virtual demo environment because Meta doesn't allow AR recording on the Quest 2)

As written information serves an important role in the educational concept, the second functionality of the present mode is the addition of text. By switching the functionality with the 'A' Button users can place a text field at their hand position. The field also has the functionality to always face the user, but in the first tests, multiple of the testers found the constant movement irritating. Because of that, the feature remained only executable from the editor. Another drawback during development was the lack of keyboard functionality in OVR. As a custom keyboard was too time intensive for this prototype the only other solution was to use a premade one. The asset store offers multiple options but the first test showed complications with the OVR setup and therefore was not implemented into the final prototype.

Secondary tools

The left controller serves as the base for all the secondary tools, these include the Paint brush, delete tool and library. Each tool is managed by a dedicated controller script and these get activated over the 'ModeManager' script.

Figure 18: Painting parts of the learning material in the AR tool

(Virtual demo environment because Meta doesn't allow AR recording on the Quest 2)

The 'Paintbrush' has a preview object, in this case, the brush, at the top of the controller and a clickable color palette to the side of the controller. The paint functionality works, by first checking if the object is allowed to be colored if so, getting the renderer from the object or a child object, and finally changing the material to the new targeted material. The target color can be set over a separate public function where the buttons of the color pallet subscribe to input the desired new material.

Figure 19: Delete unwanted pieces, in the AR tool

(Virtual demo environment because Meta doesn't allow AR recording on the Quest 2)

The 'Delete' tool has also a preview object at the top of the controller, modeled after a delete key of a keyboard. It works also with an 'OnTriggerEnter' function and checks if an object is either tagged as "intractable" or "PresentMaterial" to only destroy user-created objects on touch.

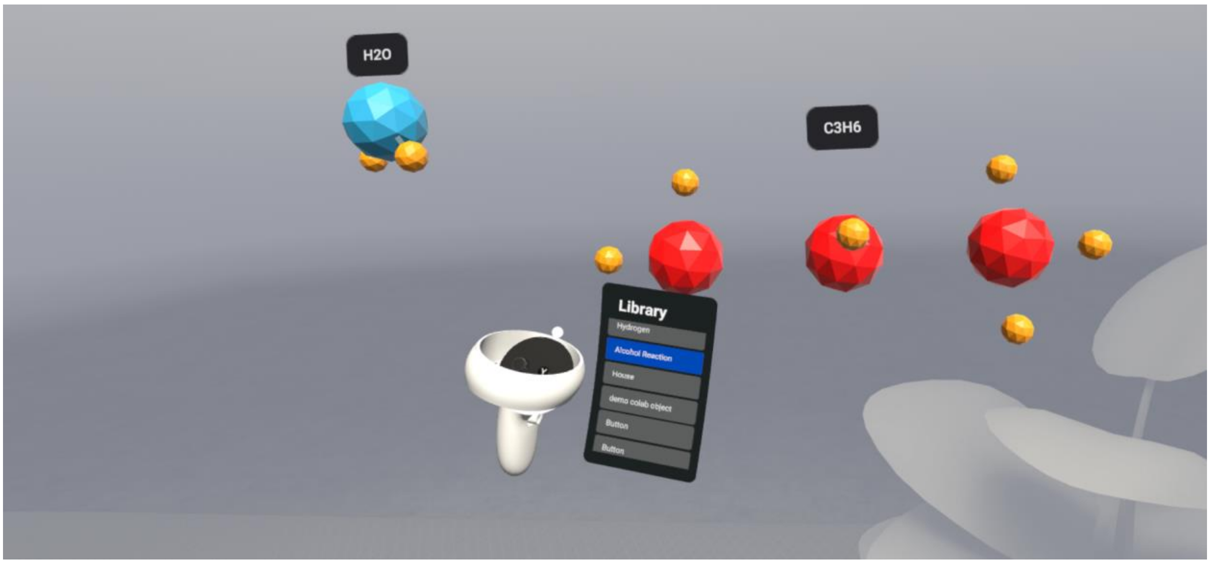

Figure 20: Place material from your library, with the AR tool

(Virtual demo environment because Meta doesn't allow AR recording on the Quest 2)

Finally, the 'Library' has a scrollable list module (OVR prebuild) attached to the side of the controller to have a better overview of the stored objects and still allow for a large and scaleable library of stored content. It works with a public class in which the buttons of the scrollable list can trigger and hand over the object to place. In the update of the class, the target object then gets displayed in front of the controller and placed once the (chosen) button is pressed.

Grab overhaul

To get more precise and intuitive grabbing of the OVR 'ObjectManipulator' script was implemented and edited. The building blocks got a final overhaul and now only needed a Grab object component and a box collider. The 'ObjectManipulator' works by getting values from the grab functions of the 'GrabObject' and getting the manipulation type. Then manipulating the currently grabbed object depending on the manipulation type. This allows for a fast and easy setup of new Building blocks and different manipulation types like distance grabbing, attaching to hand, or placing in hand.

UX design

User introduction

To achieve the goal of an easy-to-learn, intuitive tool users needed to be able to learn the mechanics of all tools and interactions available. As learned in the research multiple information channels (in this case text and visual) create deeper learning, therefore a mixture of written text instruction and a video showing the current interaction is used. The user introduction is presented on a virtual screen in front of the user which can be closed if users are already familiar with the tool or are done with the walk-through.

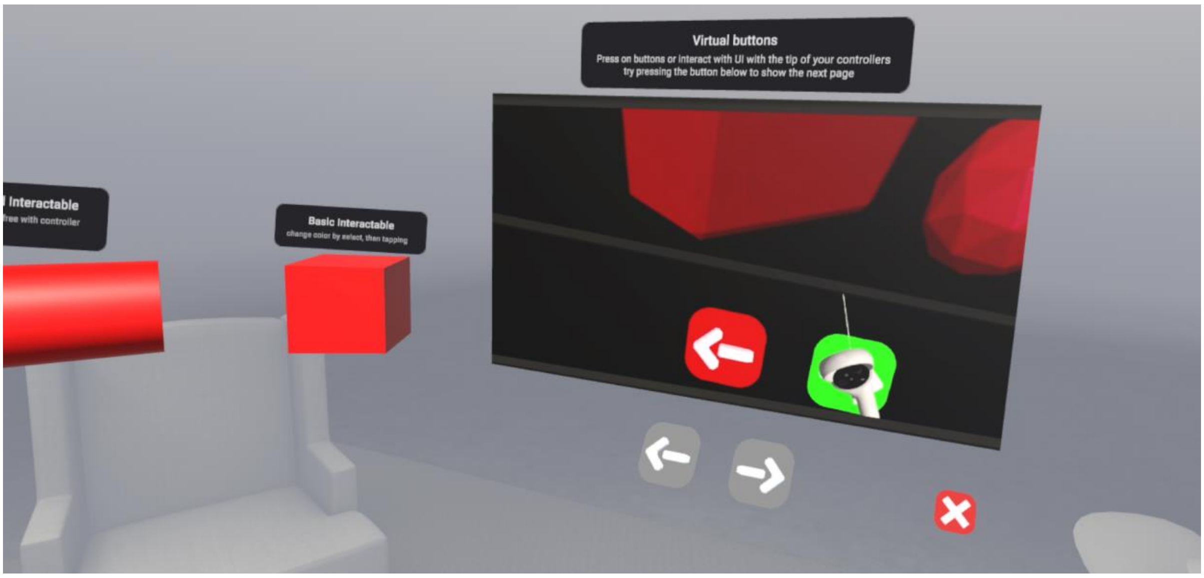

Figure 21: User introduction screen, with written instructions on top and a video underneath, showing the interaction visually

(Virtual demo environment because Meta doesn't allow AR recording on the Quest 2)

First, the users learn about physical button pressing to continue to the next page of the user introduction, this knowledge is reflected later, when users need physical buttons to use the color pallet or the library tool. From there on they learn how to interact with the virtual objects(grip) and how to use the main functionality (building & presenting). Finally, they learn how to use each secondary tool (Paintbrush, Delete, Library).

For the technical implementation, everything is controlled by the 'Userintroduction-Manager' script, which has a list for all the different pages (text files) and one with the according clips. It simply activates the current page and sets the according clip to play. The rest is managed over three functions the three buttons each subscribe to one of them. One function moves to the next page, one to the previous, and the final one closes the introduction.

Controller layout

A floating canvas with the full controller layout was also provided to quickly check button functionality if ever forgotten. The grab object component with the manipulation type set to UI was also utilized to move the canvas while grabbing in front of the user to enable full resolution and clear visibility and less demanding processing power while not in use.

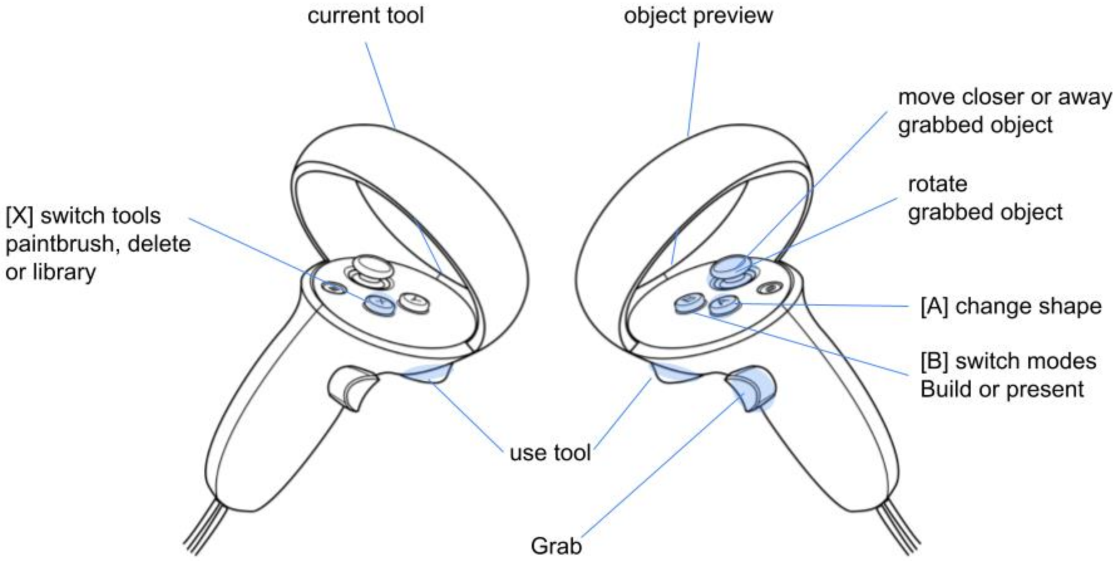

Figure 22: Controller layout for all interactions, present in the Prototype

Tool Design & 3D Models

To add fidelity to the project custom models were needed. I decided to use the opportunity of this graphical overhaul and create stylized models for the tools and primitives, to keep the clean and entry-friendly feeling.

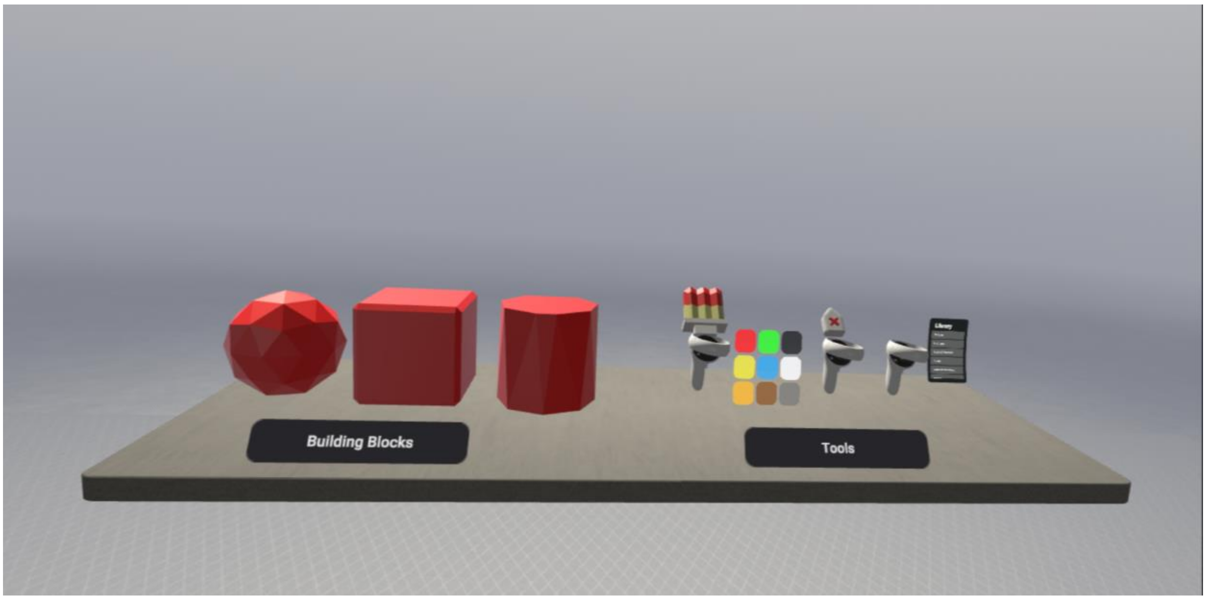

Figure 23: Representation of the three current building blocks available and the visual representation of the secondary tools

The paint tool is inspired by a paintbrush with the tip dipped into the current color, to give users intuitive and passive feedback over what color is currently selected and feedback on how the color will look on the objects. In the same spirit, the delete tool visual is inspired by the backspace icon (commonly used in programming). A red ex in the center of the arrow symbolizes the destruction and the overall visuals provide directional feedback on where the delete will happen, at the tip of the delete arrow. To keep the styling consistent the models for the different building blocks were designed in the same “low-poly” styling. The goal was to create interesting surfaces that users could use to easily give the appearance of more complex models and spark their creativity to use them in unintended ways.

The process was completed by saving each model as a ’blend’ file inside the Unity models folder to be able to change aspects of the model directly in Blender and automatically update changes in Unity. The old visual models got replaced with the new ones. Finally, through a few lines of code, the material of the paintbrush tip automatically changes to the current (target) color. A reference in the BuildingMode also gets the renderer of the instantiated building block and sets its color to the last selected one. This should speed up the creation aspect for the users by instantly creating the models with the same look as the last ones.

Evaluation

Method

Through a first questionnaire [21] general information was assessed. Candidates were then filtered into groups to eliminate biases and figure out who has already experience in teaching/presenting learning material and who is in the targeted demographic. On 20.12.2022 the user testing event happened and together with 10 other colleagues over the course of the whole day, the participants were tested. Due to the nature of such an event not all original participants attended and other testers visited instead. Finally tested were 21 participants with a relatively balanced mix of 7 females, 10 males, and 3 diverse, ages 20-26 years old, and VR experience from never experienced to expert VR users. To ensure inexperienced users were still inexperienced, users tested in a set order, this station was at position 2. Therefore all inexperienced testers had never or only once (station 1) used VR before.

Figure 24: Setup present at the user testing event

Setup

First testers put on the HMD, this process was assisted in ensuring correct setup and proper immersion. Then they were verbally instructed about what they see in front of them. “In the middle, you see the user introduction. To your right, you see a controller layout, in case you forget any controls, and to your left, you see some interactable objects. Now please follow the tasks presented in the user guide in front of you”. Once they completed the user introduction they were shown and handed a chemical reaction written on a piece of paper (Figure 25). Now they received the first task of recreating the chemical reaction or just the final molecule (H2O). After they had finished the task, they got the final task of letting their creativity free. ”Create what you always wanted to visualize in 3D, preferably something learning related, like something your learned recently or were you had struggles explaining with traditional learning materials“.

After finishing the testing all users filled out a second Questionnaire for qualitative analysis. Finally, all users were verbally asked to describe their experience with one word to get an honest and spontaneous reaction to their overall impression.

Figure 25: Scan of the chemistry task, written with permanent marker on a simple piece of paper

Outcomes

During all sections of the testing users' time needed was measured to find out the effectiveness of the user introduction and the overall intuitiveness of the tool. Detailed outcomes can be seen listed in a secondary document attached [21].

Questionaire

Testers had positive impressions of the tool with the majority stating it was highly effective in building out their personal creations and transferring physical learning material into 3D learning material. Rated on a scale from 1(low) to 5 (high).

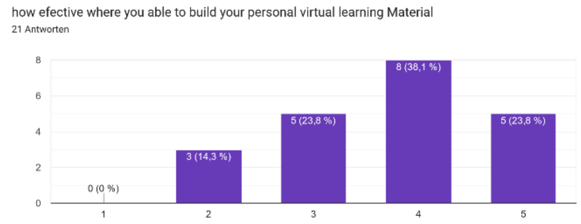

Figure 26: Results of the questionaire, about how effective the tool was for free creation

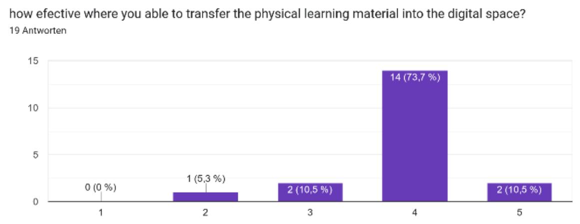

Figure 27: Results of the questionaire, about how effective it was to transfer written information while wearing the HMD

Other questions were more focused on Qualitative results. On the question "What did you find most helpful?", common answers were about the user introduction, the AR interaction with their surroundings, the 3D creation of material, and the overall self-expression capabilities. Under the question "What was missing and would help you to build your learning material?", common topics included the missing of text editing options, lack of object grouping capabilities, and a missing option for circular/ring-shaped building blocks. The final two questions were regarding the practical implementation of such a tool. The common answer for if they would prefer to use the tested tool was: Yes, but they would use both physical materials (pen & paper) and the tool in combination. The last question was "For what purpose or field of education would you use the tool?", common topics included the field of STEM learning (science, technology, engineering, arts, and mathematics) or in creative settings, for example, to create blockouts.

Outside observations and interviews

One goal, the users were unaware of, was to test how quickly and intuitive testers could learn the controls and utilize them to build out learning material. This was tested by measuring their time to complete the different sections and practically tested through the creation, both with the real-world task and free creation task.

Section	introduction	real-world chemics task	free creation	total
Time (average)	5-8 min	2-5 min	8-12 min	15-20min
completion	Yes	Yes	Yes	21/21 participants

Table 2: Showing time and completion for each section of the user test

The average time for the introduction shows that all participants were able to learn the features and apply them in less than 10 minutes. Achieving the goal of a low entry-level, easy-to-use, and beginner-friendly tool. Beyond that the free creation task shows that in another roughly 10 minutes participants ware already able to conceptualise and create elaborate 3D materials (Figure 28).

User creations in free building

Testers were tasked to let their creativity free, build something learning-related if possible or something they always wanted to see in 3D.

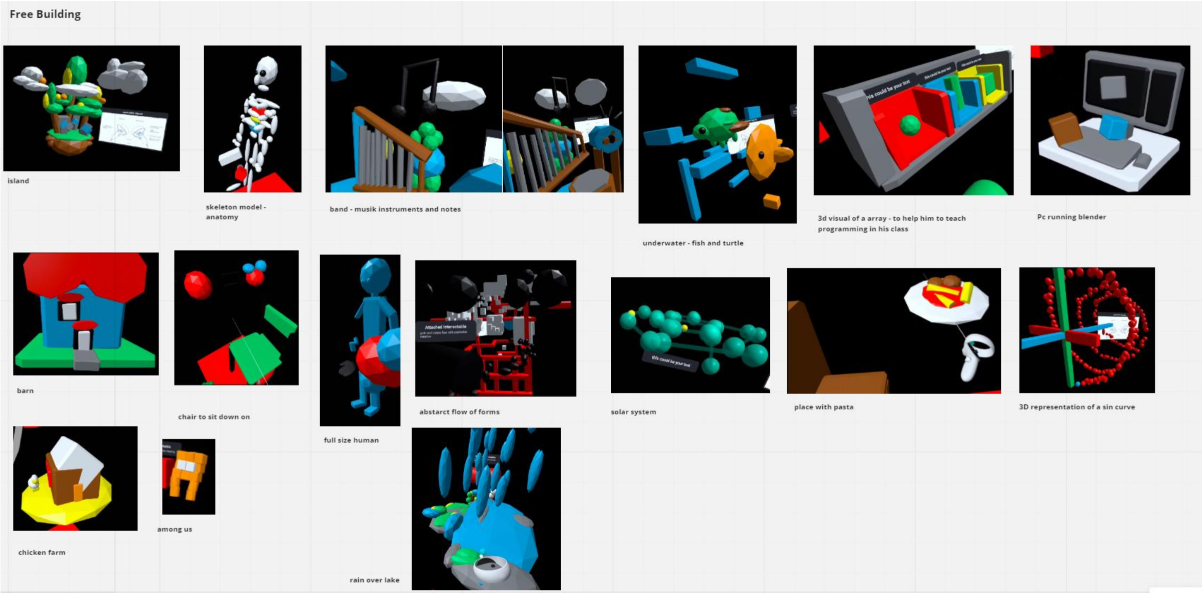

Figure 28: Creations from the user testers, created within the AR tool Creations from the user testers, created within the AR tool (Black background, because Meta doesn't allow AR recording on the Quest 2)

Figure 28 shows some of the creations to emphasize, how differently everyone created their learning material. With all being unique in style, execution, and creative usage of the building blocks. What is important to state here is that the participants had VR/AR experience ranging from never used before to experts. Still, all creations look coherent in style and execution. Another interesting aspect was the intended purpose for each material (asked in the interview). Here users reasoning ranged from simple creative exploration to complex purposes, like for explanation/visualization of an array for a beginner programming class or a 3D representation of a sine wave.

Biases

As described in the setup, each step tried to keep the biases as low as possible. But with all studies, some remain. The biggest one is the small participant number (21) and more than 90% of participants studying at our university. This means nearly all participants are interested in arts or technologies and actively in contact with Media. The second one comes from the nature of questionnaire testing. Leaving always uncertainty regarding the honest answering of participants. Both can be improved with future testing.

Conclusion

Achievements

The prototype showed that an AR learning material builder allows for the rapid creation of new material, expansion of physical learning material, and a fun & engaging way of interacting with virtual content. Besides that, the prototype achieved its biggest goal of a low-entry, easy-to-learn building tool. This was further indicated by user testing. This underlines the usefulness of AR and the effectiveness of current state-of-the-art systems in providing affordable (about 400$) HMD AR solutions. It is important to note that everything presented is just a prototype, but the groundwork is done with scalability in mind, so a full multiplayer implementation is well achievable with future development.

Relevance

This project shows that affordable HMD-based AR is possible and could be well integrated into learning environments. This is an important aspect for most traditional education facilities (e.g., schools, universities) because most HMD AR solutions focus on enterprise and industry usage, and therefore one of those systems is often not affordable in an educational setting. Regarding the learning capabilities and usefulness, the prototype also showed that such a tool doesn't need to replace the traditional learning materials because the passthrough allows users to incorporate them into their learning process. This was tested and validated with the evaluation where all participants were able to follow a task written on a piece of paper. Still, more testing is needed with a higher number of participants to validate the effectiveness of overall learnings.

Future

Further development would focus on the collaborative aspects of the concept. Fully incorporating user exchange with multiplayer capabilities. Once everything is synchronized in a shared world, the next step would be the completion of the other features, including save functionality inside the library, a virtual keyboard for the text notes, and more functionalities for the learning material creation. Further features are driven by user feedback and should include object grouping, cloning sections and more round/circular building blocks. Once all of this is implemented an in-depth user analysis with more participants inside a real learning environment (e.g. in a classroom) should be carried out. The focus should be on the possibilities of collaborative work, the effectiveness of created learning materials, and the overall effectiveness of the tool when implemented in a structured learning process (e.g. lecture). Newly gained knowledge from that process should then be used to expand on the concept to deepen collaborative qualities, learning material creation benefits and incorporation of physical materials inside the tool.

References & acknowledgments

Special acknowledgments go to

Max von Trümbach for Proofreading and as photo model

Thorsten Dubberke for Proofreading

Gesine Gerk as photo model

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SDKs & plugins

1. Oculus interaction SDK [19]
2. Photon pun 2 [20]

Bachelor user test result

Stats: 21 participants with a balanced mix of 7 females, 10 males, and 3 diverse ages 20-26 Years old and VR experience from never experienced to expert VR users.

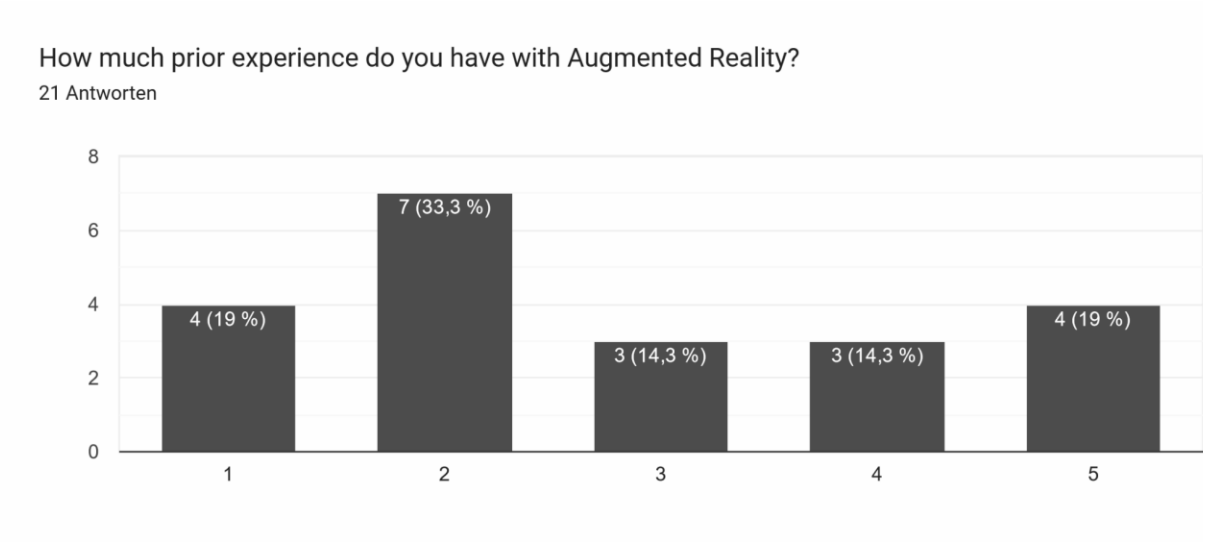
Both the original assessment questionnaire and the second one for the prototype testing are attached at the end of this document. Details regarding the outcomes of the Prototype testing are discussed in the following.

Prototype questionnaire

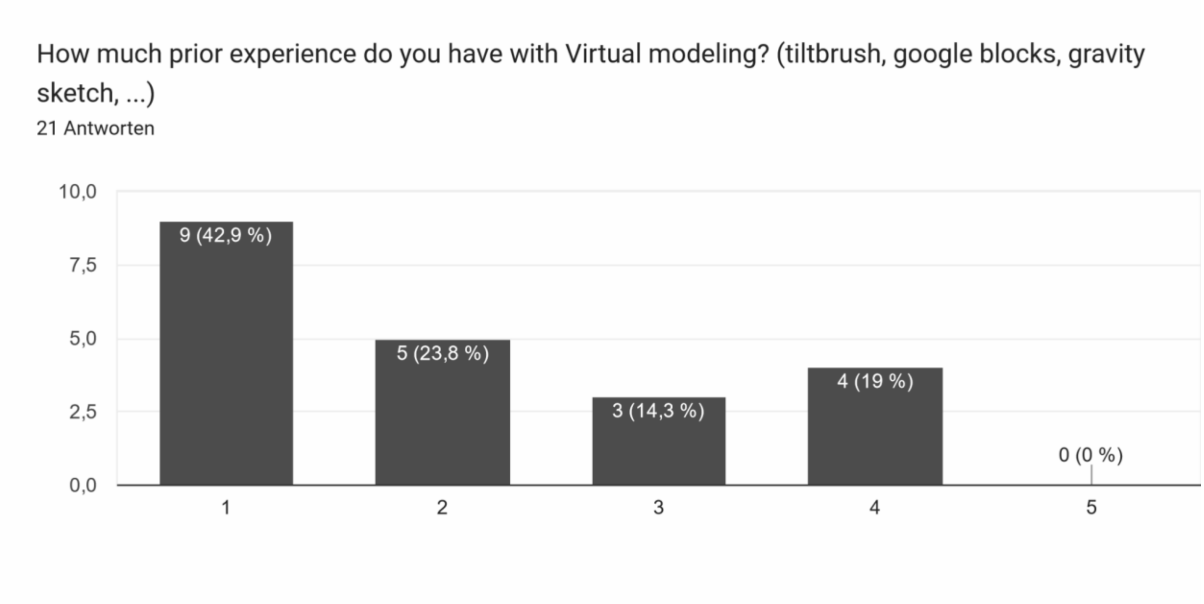
Previous knowledge

This section of the questionnaire was designed to assess prior experience to avoid biases e.g., in case positive feedback would have been only from experienced users.

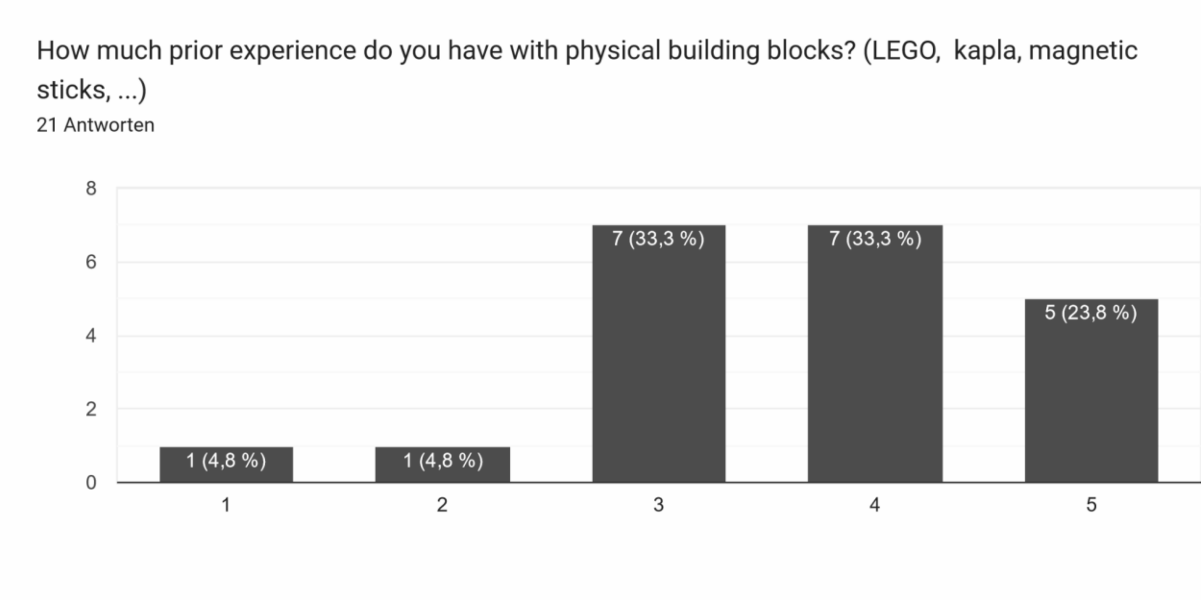
In general, all questions with a scale were rated from 1(low) to 5 (high).



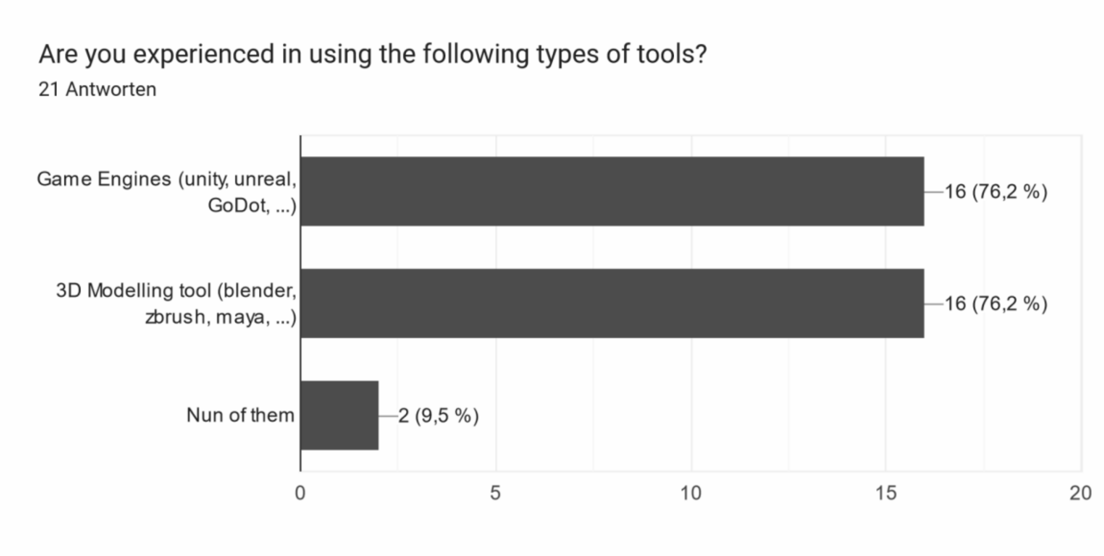
This question was a follow-up to the first questionnaire, where testers stated their experience with VR. In comparison to that, where testers had balanced experience, ranging from low to experts, most testers had little experience with AR. In the interview later no one stated that they had ever used head-mounted AR before.



Most testers had little previous experience with Virtual modeling tools.



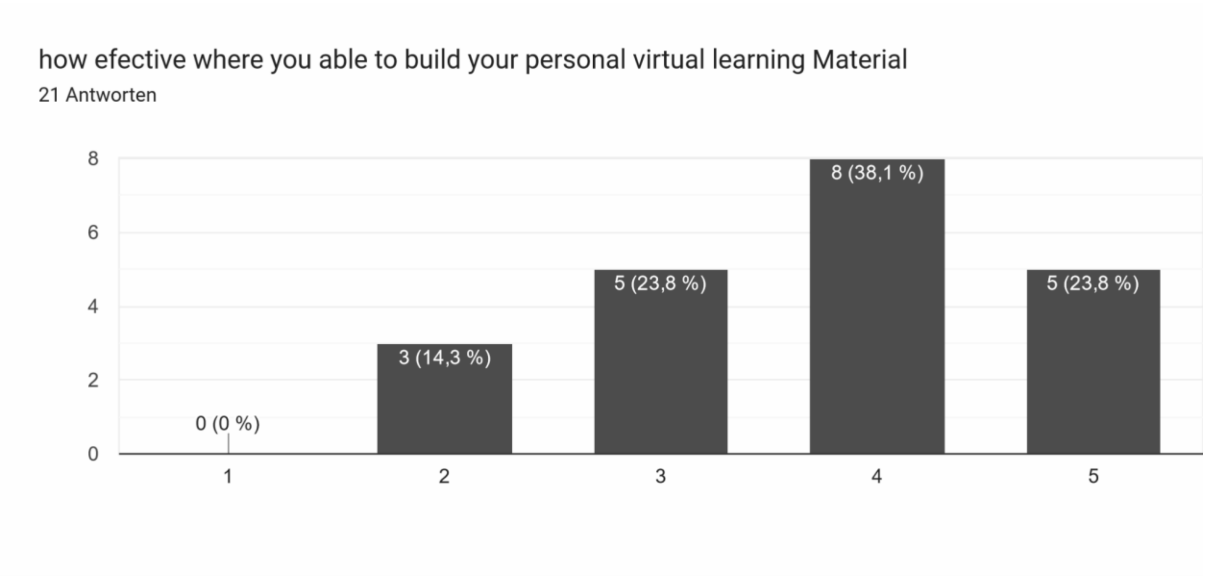
90% of testers had experience with traditional building blocks and more than 50% stated extensive experience with them. This shows that traditional building was an important aspect for most testers (mostly in childhood) and is relevant when transferring that knowledge to virtual building techniques.



About 80% of testers were experienced in using game engines and traditional 3D modeling software. This was assessed to be aware of biases, so most testers knew about digital modeling and had experience with other ways of interacting with virtual content (the outcome was to be expected due to the about 80% testers studying at h-da in the field of media).

AR Assistance testing

This section was all about the experience with the tested prototype.



two-thirds of testers felt the tool was (highly) effective for building out their personal learning material ideas.

What did you find most helpful?

Common topics include:

Instructions/tutorial, AR interaction with surroundings, 3D creation, and self-expression

All answers:

1. *instructions*
2. *being able to connect things*
3. *The possibility for self expression and also how clean the interactions felt.*
4. *The pass-through view. That way I didn't have to remove the headset to look at research paper.*
5. *3d objects and color*
6. *visual representation of the tools on your hands*
7. *nice tutorial and good tools*
8. *tutorial*
9. *the button instructions on the side helped me figure out what to do*
10. *shape tools*
11. *trying out the buttons by myself*

12. *being able to move stuff was nice. also being able to bring the controller scheme thing*
13. *Icons*
14. *Deleting tool*
15. *changing between different shapes*
16. *the fact that the tool was using AR with the headsets cams instead VR, like this i became less "disconnected from reality" while being in a virtual space. i could talk to and see people around me*
17. *color swap / brush was nice. Physical buttons had nice feedback*
18. *I am a visual learner soI ca see it being really helpful to students like me*
19. *that there where almost no bugs and that i could try everything out*
20. *Pass through*
21. *Being able to put models to anywhere in space*

What was missing and would help you to build your learning material?

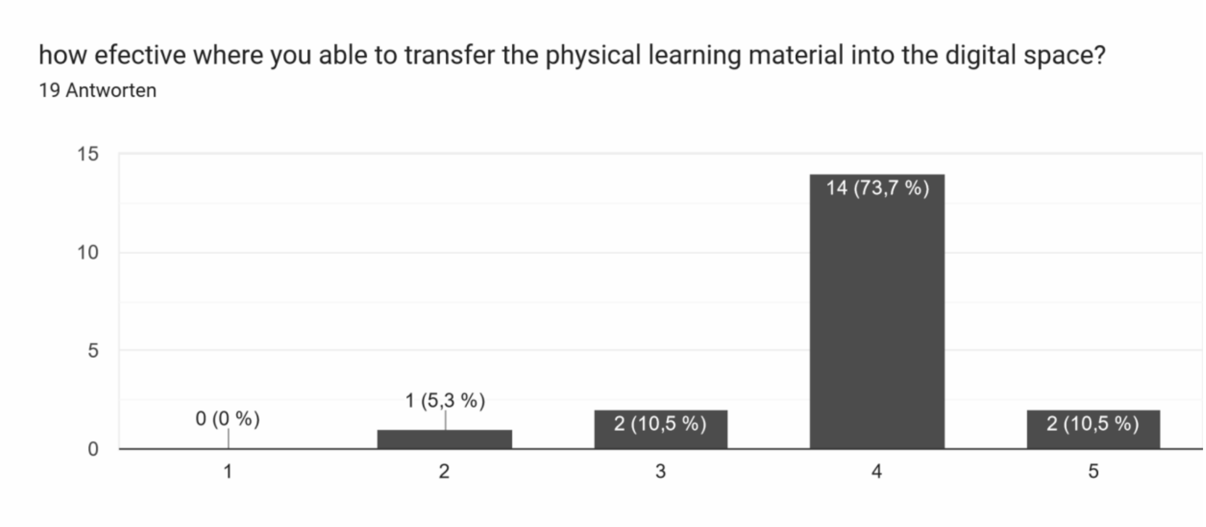
Common topics include:

Text editing, Object grouping, and circular building blocks

All answers:

1. *clearer indication for touch controls*
2. *I wanted to draw a circle or maybe make a ring shape*
3. *The ability to delete text fields, obviously. A way to select multiple objects at the same time to move them / grouping objects together.*
4. *-*
5. *text editing and scaling after placing objects*
6. *maybe a mode where no other function and only grabbing is active*
7. *move all touching objects at once*
8. *deletion of text, rotation of spheres, entering text*
9. *clearer instructions*
10. *more menues to control things insted of buttons*
11. *chemistry knowledge... I was a hauptschüler ;_;*
12. *being able to scale objects would be nice*
13. *Tabbing back via button*
14. *The option to rotate the cylinders and the spheres would have been helpful*
15. *Scaling and copying objects, undo button*

16. *function to rotate all objects. more models in selection. possibility to upload own 3d models. animation.*
17. *saving, duplicate, select multiple, resize, more shapes, color wheel,*
18. *up and down rotation but I had a lot of fun!*
19. *spirales?or connencting points with arcs or smth*
20. *editing tool and snapping tool and concave primitives*
21. *connecting pieces was a bit hard for me*



All testers could transfer a chemical reaction from a piece of paper into the virtual space and convert the information into 3D. 84% had the feeling that this transfer worked (extremely) well.

Do you prefer to use the tested tool to create your learning material? Or what would you prefer?

With these testers hat the most difficulties and some clarification to the extent of use would have been preferred by them. The goal was to figure out if testers would be interested in incorporating such a tool into their learning process, or if they prefer something else (e.g., only a laptop and a notepad)

Common answer:

Yes, both physical material and virtual with the tool.

All answers:

1. *i use both*
2. *I think it depends on the use case, this is good for engagement and for a visual topic*
3. *I could see myself using it for prototyping or for conveying 3D concepts to my peers, so yes, i do.*
4. *maybe yes*
5. *i think its a good way to visualize complex and theoretic topics like chemics*
6. *i would use this to work with*
7. *depends on what i plan to do with it, though generally i prefer Blender*
8. *i had some quick experience with other builders e.g. microsoft maquette where i prefered the user interface with quicker access to all the tools. the cycling through the many layers is not as intuitive, as lots of things are not "visible" (the buttons a, b, x, or y don't tell me that there is more behind)*
9. *-*
10. *yes it was helpful*
11. *idk*
12. *i like to take notes on paper but i can see a more advanced version of this becoming more common in the future*
13. *Prefer the tested tool*
14. *For simple visualization the tool is really helpful*
15. *not really*
16. *i would like to use the tested tool if it was more advanced in the possibilities you have to create things*
17. *really depends on the learning material you want to create. Open brush is already more advanced and open source so this could be a good starting point to adjust code to simplify for your needs.*
18. *Its super cool when youd get also a teacher explaining it while visulizing*
19. *yes would be hepful*
20. *I would like to experiment further with this tool to create teaching material*
21. *Yes, i do prefer to use the tested tool to create your learning material*

For what purpose or field of education would you use the tool?

Common topics include:

STEM learning, creative fields, blockouts

All answers:

1. *learning, exploration, architecture*
2. *chemics biology history*
3. *visual education for children*
4. *rough quick blockouts of 3d objects*
5. *various*
6. *game testing*
7. *design , ideation for projet .. blocking out*
8. *for arts*
9. *i think it could be a good introduction to AR in middle schools*
10. *Simple crafting in school*
11. *Chemistry & Biology*
12. *science lessons in school, especially physics (if gravity was implemented)*
13. *architecture*
14. *kindergarten, learn about shapes and how objects are made up, learn about combination within arts class for composition and form,*
15. *Math since it was always really hard for me to visulize*
16. *mathematics*
17. *Art creation, teaching for abstract concepts*
18. *Anatomy, Chemie, Biology and more*

Interview and outside observations

One goal, the users were unaware of, was to test how quickly and intuitive testers could learn the controls and utilize them to build out learning material. This was tested by measuring their time to complete the different sections and practically tested through the creation, both in the real world and free creation task.

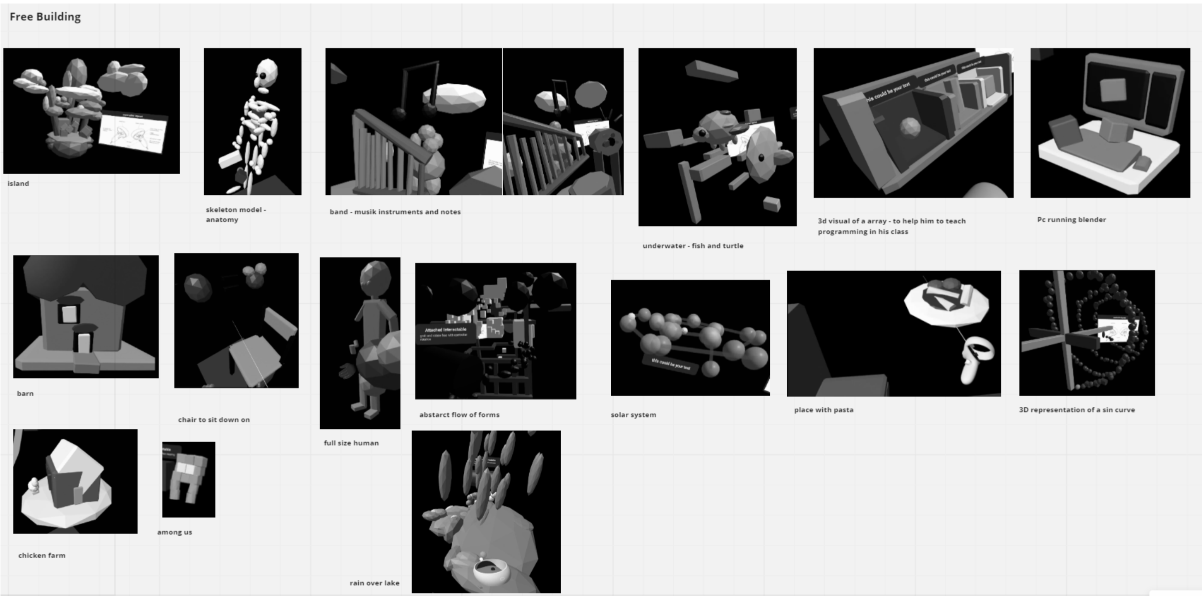
Section	introduction	real-world chemics task	free creation	total
Time (average)	5-8 min	2-5 min	8-12 min	15-20min
completion	Yes	Yes	Yes	21/21 participants

showing time and completion for each section of the user test

This shows that all participants were able to learn the features and apply them in less than 10 min. Achieving the goal of a low entry-level, easy-to-use, and beginner-friendly tool.

User creations in free building

Testers were tasked to let their creativity free, build something learning-related if possible or something they always wanted to see in 3D.



Creations from the user testers, created within the AR tool (background blacked out for privacy reasons)

The Figure above shows some of the creations to emphasize, how differently everyone created their learning material. With all being unique in style, execution, and creative usage of the building blocks. What is important to state here is that the participants had VR/AR experience ranging from never used before to experts. Still, all creations look coherent in style and execution. Another interesting aspect was the intended purpose for each material (asked in the interview). Here users reasoning ranged from simple creative exploration to complex purposes, like for explanation/visualization of an array for a beginner programming class or a 3D representation of a sine wave.

One-word description

After the testing all participants were personally asked to describe the experience with the first word that came to their mind. (to get spontaneous and honest answers).

Answers:

Fun, inspiring, intuitive, easy, cool (2x), creative (2x), Blocks (2x), complex, creating, nice, free.

spoken feedback

- too many buttons
- can't delete text
- hard to find the grip button
- physical pressing was unclear and hard to execute (color palette)
- sphere wired to scale
- unclear indications for the current tool

Biases

As described in the setup, each step tried to keep the biases as low as possible. But with all studies, some remain. The biggest one is the small participant number (21) and more than 90% of participants studying at our university. This means nearly all participants are interested in arts or technologies and actively in contact with media. A second important one comes from the nature of questionnaire testing. Leaving always uncertainty regarding the honest answering of participants. Both can be improved with future testing.

First Questionaire:

Bachelor User Test (1-2 min)

Hello there!
Thank you for being interested in our **user testing**. We are students from the 7th semester of Expanded Realities. This form helps us to find participants for our test groups which we conduct as part of our **bachelor theses.** The following questions are important for multiple test groups so some questions may not be related to other questions.

Snacks will be provided to all the testers on testing days!

All information gathered during the user tests is purely used to analyze our bachelor projects. **Your information will be handled discretely and will not be distributed to thirds.** If you have any questions, feel free to write to the email-address this questionnaire was delivered by or write us on Discord (2nd generation students).

Thank you!

At what days are you available for testing? (Multiple answers) *
Please select ALL days at which you are available. Testing will be done on the day(s) with the highest participation and you will be informed (by E-Mail) what day(s) are selected. The testing will take place at the Mediencampus Dieburg, Max Planck Straße 2. Tests will be conducted all day long and we appreciate any time you have, whether it is in the morning, the evening, or in between classes.

- ☐ 12.12.2022
- ☐ 13.12.2022
- ☐ 14.12.2022
- ☐ 15.12.2022
- ☐ 16.12.2022
- ☐ 17.12.2022
- ☐ 18.12.2022
- ☐ 19.12.2022
- ☐ 20.12.2022
- ☐ 21.12.2022
- ☐ 22.12.2022
- ☐ 23.12.2022

How old are you? *

Meine Antwort

What is your gender? *

- ○ Female
- ○ Male
- ○ Diverse
- ○ Prefer not to disclose

What is your current occupation? (Multiple answers) *

- ☐ Student (University or similar)
- ☐ Apprenticeship (Ausbildung)
- ☐ Teacher/Prof/Tutor
- ☐ Part-time job
- ☐ Full-time job
- ☐ Prefer not to disclose
- ☐ Sonstiges:

What is your most common mode of transportation? (Multiple answers) *

- ☐ By foot
- ☐ By bike
- ☐ By train/bus/tram
- ☐ By car
- ☐ Sonstiges:

How much experience do you have with Virtual Reality? *

	1	2	3	4	5	
No experience	○	○	○	○	○	A lot of experience

How much experience do you have with traditional video games (first person, third person games etc.)? *

	1	2	3	4	5	
No experience	○	○	○	○	○	A lot of experience

How much experience do you have with visual novels? *

	1	2	3	4	5	
No experience	○	○	○	○	○	A lot of experience

Have you frequently used any of the following types of tools? (Multiple answers) *

- ☐ Game Engines (Unity, Unreal, CryEngine, GameMaker, Armory3D, BuildBox, GoDot..)
- ☐ 3D Modelling Tools (Blender, Maya, GravitySketch, Tiltbrush, ZBrush, ...)
- ☐ Sandbox tools (Mozilla Hubs, Second Life, WorkAdventure, Vircadia, Horizon Worlds, RecRoom...)
- ☐ Graphics Editors (Adobe Photoshop, Adobe Illustrator, ProCreate, Photopea, PicsArt...)
- ☐ Interface Design Tools (Adobe XD, Figma, Sketch, InVision Studio, Axure, Craft, Framer X, Proto.io, Marvel, Origami Studio, Webflow, Flowmap, Balsamiq, ...)
- ☐ WebDesign tools (Wix, SquareSpace, Shopify, Canva, Tumblr...)
- ☐ no

Which 3D modelling tools have you used before? (Multiple answers) *

- ☐ I have not used 3d modeling tools
- ☐ Blender
- ☐ Maya
- ☐ Cinema4D
- ☐ SketchUp
- ☐ ZBrush
- ☐ 3DsMax
- ☐ GravitySketch
- ☐ Sonstiges:

Please leave your (active) e-mail address, so that we can contact you! *

Meine Antwort

Thank you for participating in the questionnaire!
You will receive a follow-up mail, informing you about the date and time of the testing.

Prototype Questionaire:

After testing the experience

THANK YOU FOR PARTICIPATING <3

this is a 2-3 min questionnaire about your experience with the tool. Please answer honestly and don't feel rushed. This will be part of the qualitative analysis and your answers matter :)

name *

Meine Antwort

email (from the first formular)

Meine Antwort

How much prior experience do you have with Augmented Reality? *

	1	2	3	4	5	
low	○	○	○	○	○	high

How much prior experience do you have with Virtual modeling? (tiltbrush, google blocks, gravity sketch, ...) *

	1	2	3	4	5	
low	○	○	○	○	○	high

How much prior experience do you have with physical building blocks? (LEGO, Kapla, magnetic sticks, ...) *

	1	2	3	4	5	
low	○	○	○	○	○	high

Are you experienced in using the following types of tools? *

- [ ] Game Engines (unity, unreal, GoDot, ...)
- [ ] 3D Modelling tool (blender, zbrush, maya, ...)
- [ ] None of them

how effective where you able to build your personal virtual learning Material? *

	1	2	3	4	5	
low	○	○	○	○	○	high

what did you find most helpful? *

Meine Antwort

what was missing and whould help you to build your learning material? *

Meine Antwort

how effectively could you transfer the physical learning material into the digital space? *

	1	2	3	4	5	
low	○	○	○	○	○	high

do you prefer to use the tested tool to create your learning material? Or what would you prefer? *

Meine Antwort

for what purpose or field of education would you use the tool? *

Meine Antwort

Senden