AstroVR: Improving usability of an educational VR experience

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Abstract

The objective of the project was to improve an existing prototype called AstroVR. AstroVR is an educational VR experience with the intent of teaching astronomy to middle grade students. The goal of the masters thesis was specifically to make the product more usable and increase its effectiveness as a teaching tool.

The product was improved over multiple iterations. Each iteration contained a design meeting, development, and small scale testing. The final product was then evaluated using a more structured test at the school Lerbäcksskolan in Lund during which a survey was performed (SUS) and video was recorded.

The resulting product got a SUS rating of good to very good and review of the video showed no major issues that prevented users from using the product successfully.

When looking at the test results as well as when making comparisons to users' interaction with the previous version of AstroVR, I deem that the project has sufficiently improved in target areas that the goal can be considered reached.

Keywords: Virtual Reality, Usability, Education

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Contents

Chapter 1
Introduction

1.1 Background

Today's school is drastically different compared to the school of 20 years ago. Ever improving technology has made devices such as ipads a core part of today's teaching environment. We often see that these new devices are introduced without a clear plan for their use and many teachers have a hard time using them effectively for education.

With the developments in technology over the last years, it's only a matter of time until it becomes part of many schools' technological suite. For virtual reality (hereby VR) to be effectively integrated into the curriculum, software needs to be designed from the ground up for this purpose.

This master thesis with a focus on interaction design takes on the task of improving an already existing prototype, AstroVR, which was created at LTH and is a VR experience with the purpose of teaching astronomy to middle school students.

The goal of the masters thesis is specifically to make the product more usable and increase its effectiveness as a teaching tool.

1.2 Difficulties when teaching astronomy

Teaching astronomy is more difficult than it seems at first glance. Türk (2016) argues that students struggle to understand the three dimensional systems involved in astronomy and that a possible reason for this is that they are often taught using two-dimensional models. [9]

A study from skolverket also reinforces that the use of 2D images increase the difficulty of learning the moon phases. [12]

Ampartzaki Kalogiannakis (2016) argues that difficulties in understanding the position and relative movements of celestial bodies primarily stem from the fact that the student's understanding of this is based on their own experiences when viewing celestial bodies such as the sun and moon. This earth-based perspective is the source for this problem since young students often lack the spartial abilities to translate this information to a space-based perspective. Ampartzaki Kalogiannakis (2016) gives the following suggestions for improving astonomy education for young students: [1]

1. Building an Understanding of the Earth-Based Perspective
2. Building an Awareness of Shape
3. Building an Awareness of Size, Scale, and Perspective
4. Building an Awareness of the Position, Direction, and Movement
5. Developing Skills in Spatial Representation: Maps, Mapping, and Modeling
6. Understanding Two Important Phenomena: Gravity and Light an Understanding of the Space-Based Perspective
7. Shifting Between the Earth-Based and SpaceBased Perspectives

One of the strengths of VR as a teaching tool lies in its ability to display information in three dimensions which makes it very fitting for use in astronomy education. Switching from a 2D representation of a model to directly showing said 3D model removes and need for the student to use their spatial abilities to translate between different 2D perspectives thus removing a big hurdle when teaching younger children. The 3D model also has the upside of easily showing a space-based perspective which is hard to communicate properly using a 2D medium.

1.3 Previous Work

The earlier prototype was designed and developed during the LTH course "Interaction: 1, Neuro Modeling, Cognitive Robotics and Agents" and the report from this course can be found in Appendix C. The goal of the product was to teach astronomy to middle school students using VR. During the course formal testing was done to evaluate usability of the product. It's been extensively used in the VR lab at Lund University for demo purposes. [1]

1.3.1 Design Principles

The overarching philosophy was simplicity, both in design and complexity of gameplay. This was focused on with the realization that VR equipment would be shared amongst many students and therefore students would be limited in time when using the software. The students would also be assumed to have no prior experience with the VR equipment as well as VR itself.

Because of this we decided early that we would have no menus and that the gameplay environment would be room-scale and offer no locomotion alternatives for the user. Because

[1]Demo video of existing software: https://www.youtube.com/watch?v=08Y8-Jw_Wjs

we perceived the hardware of the controllers (HTC Vive) to be flawed the design was centered around using only one button.

The above restrictions gave us a very limited amount of space to work with and our solution was to design multiple different rooms with specific purpose such as showing relative planet sizes, illustrating gravity etc. Anytime a user would need to manipulate objects in more complex ways this would be achieved using in game objects that mimicked real world objects. This allowed us to use the user's real world experience to navigate their environment.

This drove the creation of a room centered design where the experience was separated into distinct rooms where each room had a specific focus. The implemented rooms were the following:

- Planet Inspector: In this room the user could play around with the planets as if they were balls of different sizes.
- Moon Thrower: The user would throw the moon into orbit around the earth.
- Slingshot: Using a slingshot the user would shoot the planets into their correct place.
- Solar System Overview: The user was placed inside a model of the solar system. The user could control aspects of the model such as time and position by using a control panel.

1.3.2 Educational Approach

The core design philosophy for the program was that the user would be free to explore and experiment in the environment. To facilitate a smooth exploration experience I wanted to minimize the risk that the user would fail at a specific task. Therefore I chose to avoid traditional game-design elements, since a core part of games is the possibility of failure. Instead of specifically designed challenges, the program would use the user's own curiosity to drive their engagement. The software is designed to be used as a complement to traditional education allowing the software to focus on very specific subjects that we deemed that VR would be better suited to teach.

The different rooms had the following teaching subjects:

- Planet Inspector: Relative sizes of the different planets
- Slingshot: Planet order in the solar system
- Moon Thrower: Gravity
- Solar System Overview: Relative orbital distances and velocities for the planet

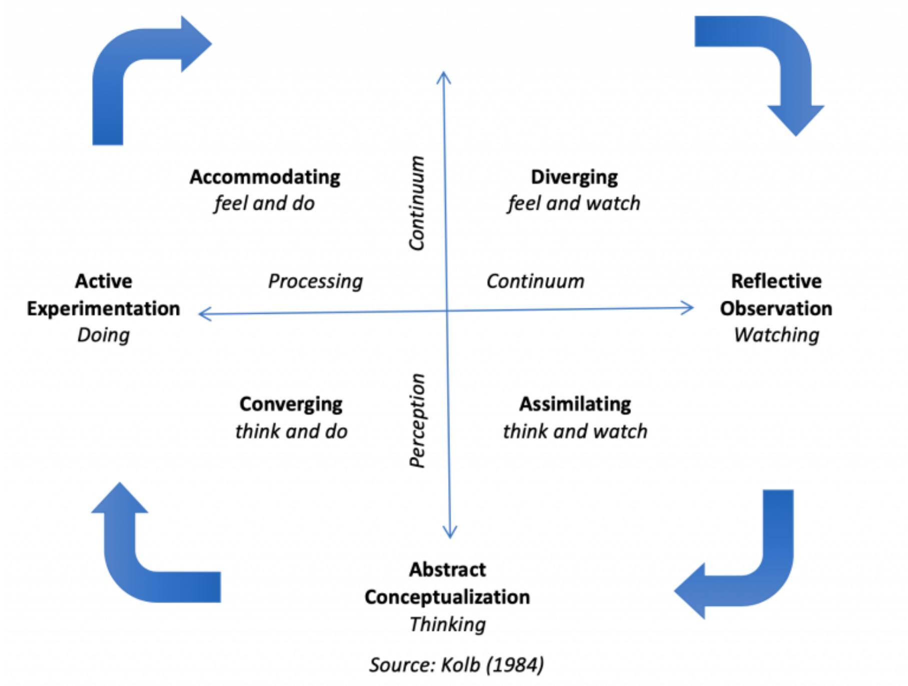

Figure 1.1: Kolb's learning cycle.

The teaching approach focused heavily on the "do" part of Kolb's Learning Cycle (See Figure 1.1). This allowed it to fit cleanly into traditional teaching methods that generally focus on the other parts of the cycle. [7]

1.3.3 Prototype Overview

Room Selection Room

The first room that the user entered was an empty room with a selection of doors that led to the different rooms.

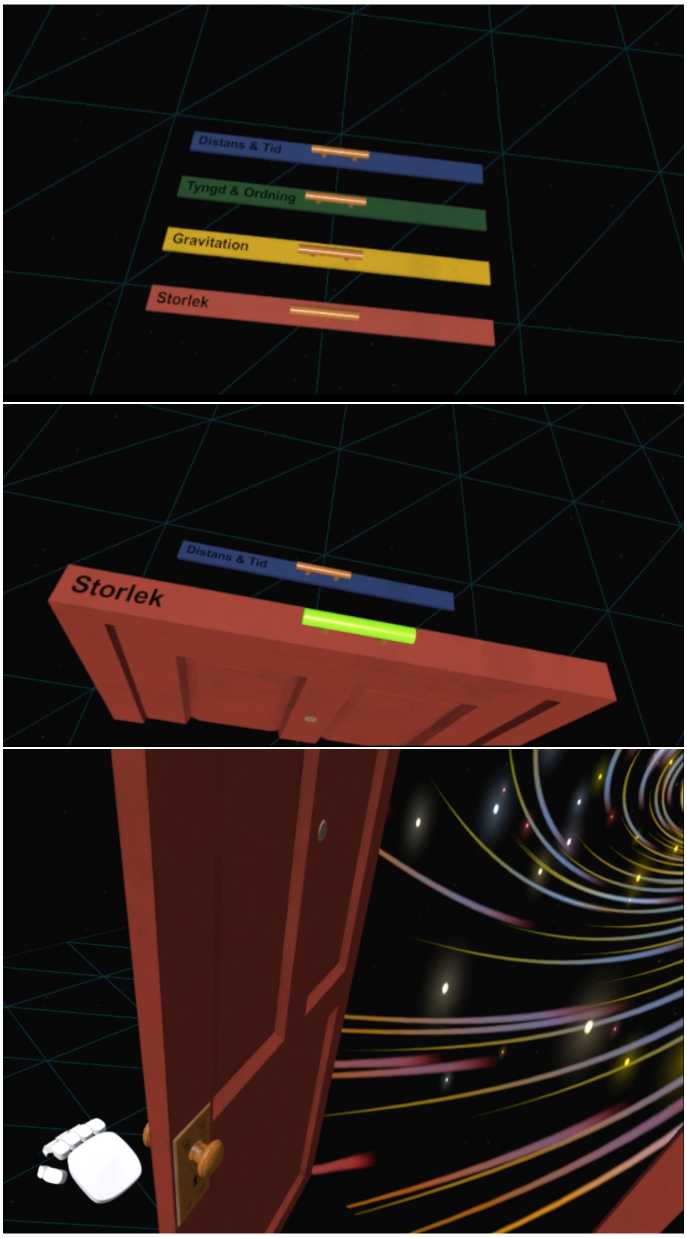

Figure 1.2: Door selection on the floor in the first room.

The user would drag on the handle and the door would be revealed. The door contained a portal that took you to the room corresponding to that door.

Planet Inspector Room

Here there were planets strewn around the room. The planets were interactable and could be picked up and thrown like a ball. The room also contained a planet station that the user could use to inspect the planets closer and get to know their names.

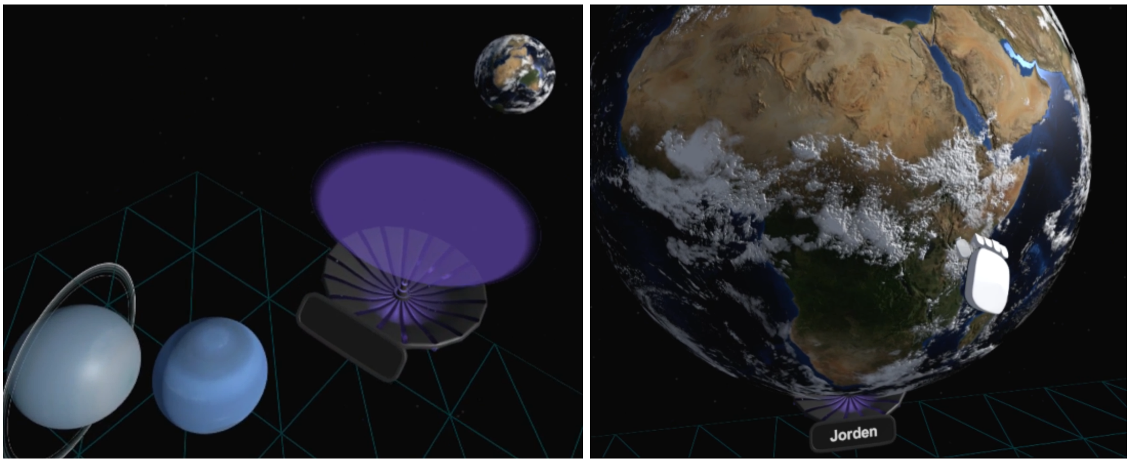

Figure 1.3: Planet station in the Planet Inspector Room.

Moon Thrower Room

In this room the user would first use a so-called Moon-spawner to create a Moon. They could then pick up and throw it around the Earth and observe how the Moon is affected by Earth's gravity.

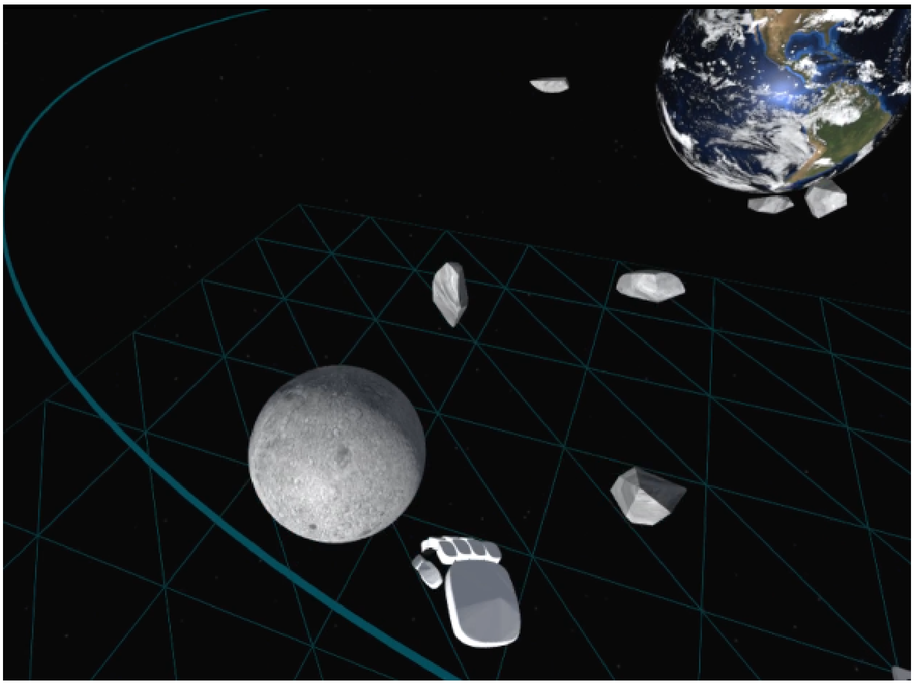

Figure 1.4: User throwing moon in the Moon Thrower room.

Slingshot Room

In this room the user would use a slingshot to shoot the planets into the correct position relative to the sun.

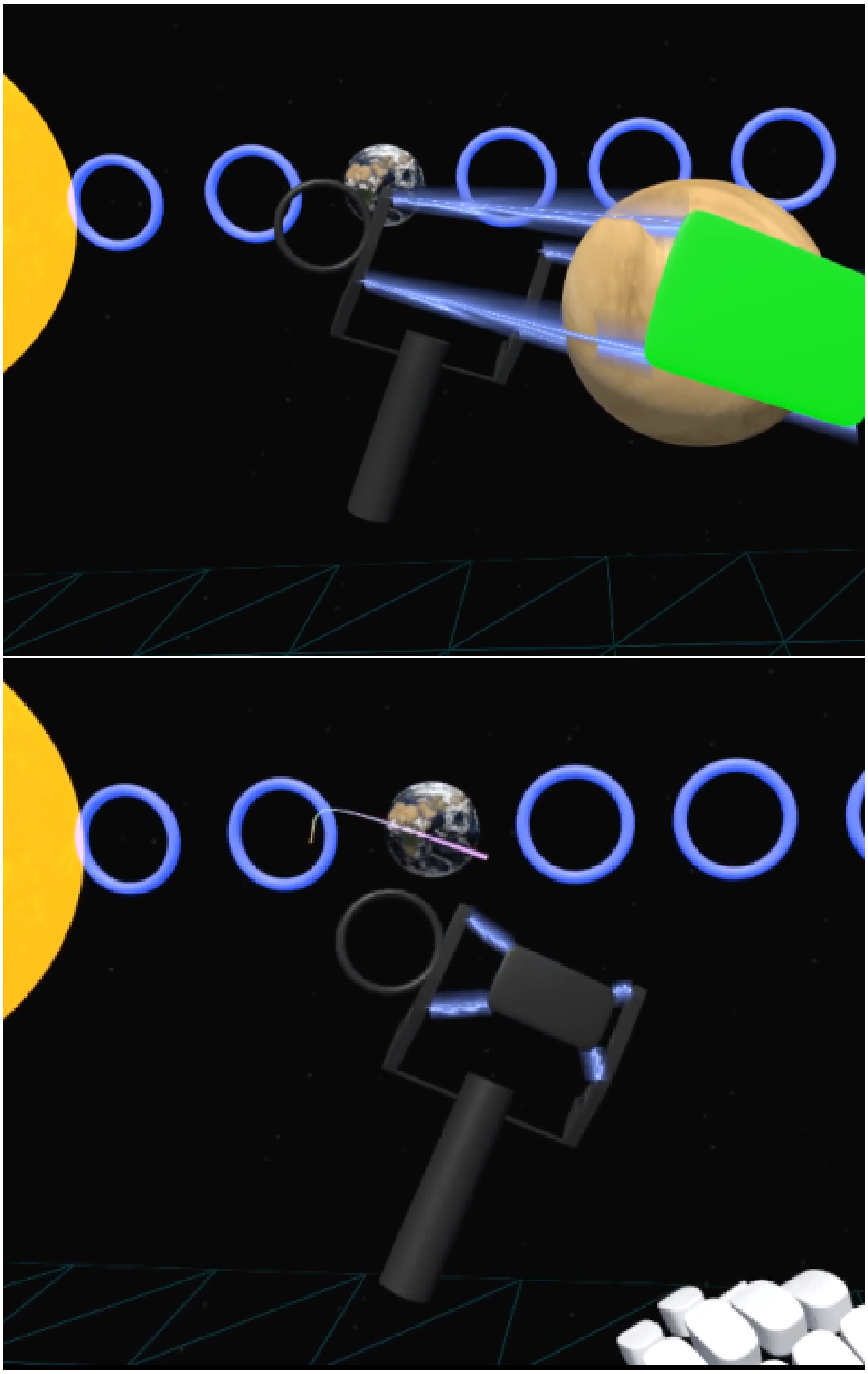

Figure 1.5: Slingshot in use.

Planet Overview Room

Here the user had a control panel that they could use to control a simulation of the entire solar system.

Figure 1.6: Control panel in overview room.

The control panel gave the ability to focus on a specific planet and controlling how fast the time was simulated. The size of the solar system could also be controlled using a toggle.

Chapter 2
Technical Background

2.0.1 What is VR?

Virtual reality (or VR) is a technology that simulates an environment and attempts to induce a feeling that the user(s) is spatially connected to this world by imitating and replacing real world sensory stimuli for the user(s). [11]

2.0.2 3D User Interfaces

Interaction within a VR environment is complex and according to Herndon, users struggle to understand 3D environments and find it difficult to perform interaction in an "empty space". [5]

A 3D user interface is a user interface that allows the user to interacts directly with a 3D world and allows the user's tasks to be performed directly in the 3D spatial context of the application. [8]

According to LaViola et al (2017), a user can perform the following basic actions in VR:

- Movement. To partake in a virtual environment a user needs to be able to move within the environment.
- Selection. Depending on the purpose of the virtual environment, a user will need to interact with virtual objects in different ways. To achieve this they first need to be able to select which objects are of interest.
- Manipulation. When one or more objects are selected the user can translate, rotate or scale them.
- System Control. In many VR applications the user needs to be able to control system settings etc. using different types of commands.

2.0.3 Presence

When taking part of an immersive experience, presence is the degree that a user is feeling that they are physically and spatially located within the simulated world. [11]

2.0.4 Tracking

Tracking is a term describing different technologies used to constantly register and update the position and orientation of an object or a body part. This data is then used to update the position and orientation of the user's avatar within the 3D world to achieve the illusion that the user is part of the simulated world. Tracking technologies can be divided into two major groups, inside-out and outside-in. For an inside-out tracking system, all tracking hardware will be placed on the VR headset whereas an outside-in tracking system will require external hardware for tracking purposes. An example of an outside-in tracking system is the one used in the HTC Vive, where small devices called lighthouses need to be placed at an elevated position in two of the corners of the tracking area. [11]

2.0.5 Standalone vs Tethered VR Headsets

A tethered VR headset is a headset that acts as a display for another device such as a PC or a game console. Contrary to this, a standalone headset is able to run the VR software using on-board hardware.

2.0.6 Room-scale VR

In an experience designed for room-scale VR, the user's position within their real world room is tracked and reflected by their in-game position. This gives the user the ability to explore the environment in a natural way and if properly implemented it can greatly increase presence. Alternatives to room-scale VR that are frequently used in today's commercial VR products are standing and seated experiences. In these the user is confined to sitting/standing when interacting with the VR world. [11]

2.0.7 Locomotion

One of the biggest restrictions of VR applications using current commercial technology is that user is limited by the real world area that they can move around in. This limited movement is reflected in the area that the user can traverse in the game. To create bigger experiences users will need other ways to move their in game avatar than movement in the real world. Techniques that solve this are referred to as locomotion techniques and these techniques can be divided into types such as controller-based and teleportation-based locomotion.

When using controller based locomotion the user will use a controller to move their real world avatar. This is commonly done by using an analog stick on the controller to move the avatar directly in a linear fashion. For teleportation based movement, the user has the ability to teleport around the room. A common way to achieve this is for the user to select the teleportation destination by aiming the controller. [8]

2.0.8 VR sickness

Similar to car sickness, some users can feel nauseous when within a VR experience. The extent of the sickness felt depends on many factors such as personal sensitivity, performance of VR hardware/software and locomotion useage. Depending on type and design, locomotion can have a massive negative impact on the amount of nauseousness users report. Other than ensuring that the application runs smoothly on the target hardware, locomotion is the biggest factor influencing VR sickness that the software developer can control. [11]

Chapter 3
Method

During design and development i used a design process called User-Centered Design. The process hightlights three main principles: [3]

- **Early focus on user tasks:** The user should be central to the design process. Understanding of the user's behaviour should be a key part of the decision making process.
- **Empirical measurement and testing of product usage:** Testing and measurement should play an essential role when evaluating the final product. During testing, measurements should focus on on the ease of learning and useage of the product.
- **Iterative design:** Development and improvements to the design should be done over multiple iterations in order to increase the product's efficiency and to meet ever-changing client needs.

3.1 Workflow

The project was divided into two primary phases.

- Using experience from it's previous use the application's usability was improved.
- The product's usability was evaluated.

Development of the product would take place over multiple iterations were each iteration would contain the following:

- Design meeting between me and my supervisor where improvements of the current version of the product are determined.
- Development of the planned changes.
- Evaluation of the product, generally through small scale in-house testing.

3.2 Test Design

The test took place at Lerbäcksskolan and the test participants where volunteers from the 8th grade classes at the school. I was participating over zoom and took notes. After the test was performed, the users would fill out a short survey. The survey used was System Usability Scale (SUS). [2]

Video was also recorded in order to allow for deeper analysis at a later date. For privacy reasons the recorded video was comprised of the in-game view of the user together with the audio from the classroom which I deemed was sufficient for my analysis. For the video review I divided the rooms into tasks in order to give structure to the analysis. These were the tasks for each room:

Onboarding Room Tasks

- Throw ball
- Shoot soap bubbles
- Use door to progress to next room

Planet Inspector Room Tasks

- Pick up planets
- Pick up large planets with two hands
- Find button
- Use button to open cage
- Notice black hole
- Throw planet into black hole
- Use door to proceed to next room

Moon Shooter Room Tasks

- Pick up moon gun
- Notice Lever
- Understand gun charge mechanic
- Use door to proceed to next room

Solar System Overview Room Tasks

- Grab the planets
- Understand orrery metafor
- Understand time controller

Chapter 4
Development Iterations

In order to target a hardware platform more suited for use in a school environment, the target hardware was changed to Oculus Quest. This had the upside of being a cheaper headset that used inside out tracking and did not need an external computer. This removed the need for an expensive computer as well as the need to mount external devices around the room. The old hardware would practically require the school to have a dedicated VR room whereas the new hardware could use any room as long as it has enough clear space. Even if this required quite a bit of development time I deemed it worth it because of how much it improved the product for in school use.

In the old software there was a room that didn't fit in with the others, namely the slingshot room. All the other rooms allowed the user to explore the environment at their own pace and they were free to experiment with objects in the room without any specific way being more right than the other. When they were satisfied with the current room they would go to another room. For the other rooms, knowledge attained before entering the experience didn't influence the user's ability to complete the tasks within the room, contrary to this the slingshot room would act more like a quiz of the solar system order. This didn't sit right with me as this discrepancy also seemed to influence players to "succeed" in the following rooms where no such condition existed. Therefore I decided to remove this room despite it being the room that most players enjoyed interacting with the most.

Another change was that I enforced a strict order for which the rooms would be accessed to give a more consistent user experience and allowed subsequent rooms to build on the knowledge attained in previous ones.

4.1 Planet Inspector Room

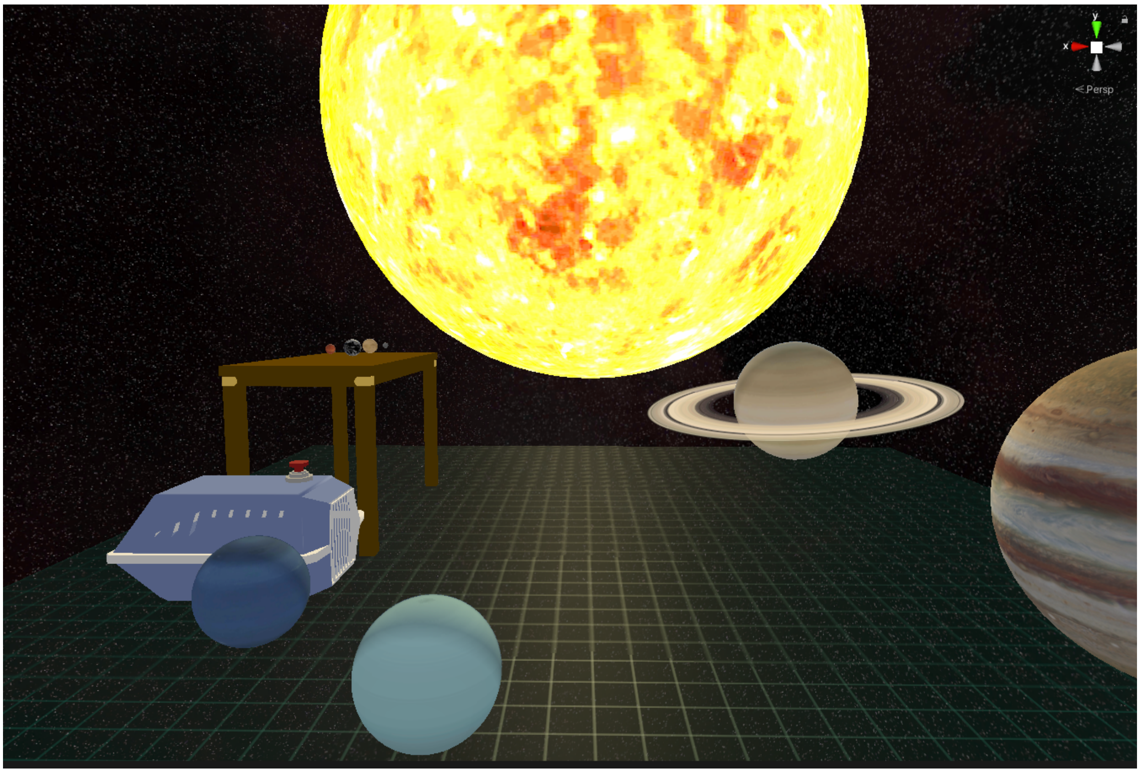

Figure 4.1: Final version of the planet inspector room.

The primary purpose of this room is to give the student a feeling of the different relative sizes of the planets. The room also allows the user to familiarize themselves with the planets and provides the player with information about each planet such as name, look and relative weight.

The previous iteration was a room where the user could interact with the planets like they were balls of different sizes. There was also a planet station where the planets could be placed in order for the user to get the name of the planets.

The existing prototype was good at conveying the size difference of the planets but lacked tasks for the user to do. Some users would tire of the room quickly and would want to move on. The primary purpose was to give the room something more for the user to do.

4.1.1 First Iteration: Back to Basics

For the first iteration I removed everything superfluous and kept only the environment and the planets. Most notably I removed the "planet station" that was a way for the user to inspect the planets closer. The station also played a small audio byte with interesting information about the planet. [1]

[1] HurricaneVR: https://www.cloudwalkingames.com/

The new platform did not support the VR interaction framework used in the previous version so I needed to obtain a replacement. The new framework I used was more sophisticated and added the following features:

- Hand collision with world objects
- Automatic finger posing when grabbing
- Physical grabbing of objects
- Two handed grabbing

The purpose of the change was to increase presence by having more natural interaction with the environment compared to before. Using the old framework, the user's hands would pass through in-game objects and held objects would share the same characteristics and physical limitations would not be communicated to the player. For the new framework, the user's hands could interact physically with objects and impart force upon them allowing the user to push objects in a more natural manner. Due to the physical nature of the grabbing system a sense of weight could be communicated to the user and heavier planets like Jupiter would need two hands to lift.

While this version improved the interaction with the planets and gave an increased sense of weight of the planets it retained most of the problems from the previous version namely that it lacked user retention for some users and there was no way to get name of the planets.

4.1.2 Second Iteration: The Black Hole Game

For this iteration I decided to add a mini-game to the scene. The mini-game takes the form of a black hole and when a planet was thrown into the black hole it would get sucked in and display the name of the planet (Figure 4.3).

An attempt to use the physics engine to simulate the black hole was unsatisfactory because there was no mass for the black hole which could reliably catch the planet without risking that the planet was flung away at frightening velocities on throws that just barely missed. To combat this I made a catching mechanic that guaranteed success if the planet hit a spherical volume around the black hole. Upon entering the volume I calculated the angular velocity of the planet around the black hole as well as the velocity of the planet towards the black hole. I then programmatically rotated the planet around the black hole while increasing the velocity along the radius. I managed to get a seamless transition while still guaranteeing successful capture of any planets that hit the target volume.

Figure 4.2: Planet display after Earth was thrown into the black hole.

Limited in-house testing found that some users had problems finding the black hole and once found not all identified its purpose. Some users did not understand that the planet was caught by the black hole and would look to the next planet before the information popped up. Some users focused too much on the black hole and did not focus enough on the planets.

4.1.3 Third Iteration: The Cat Carrier and a Flashy Entrance

My idea to help highlight the existence and functionality of the black hole was to have it hidden at the start and to somehow give it a flashy entrance that conveyed it absorbing objects. Luckily the current christmas calendar on SVT gave me an idea. [2] In the TV show a black hole escaped due to a malfunctioning containment device. I realized I could use this concept to have the black hole in the scene and somehow have the user trigger the release of the black hole.

[2]https://sv.wikipedia.org/wiki/Mirakel($TV - serie$)

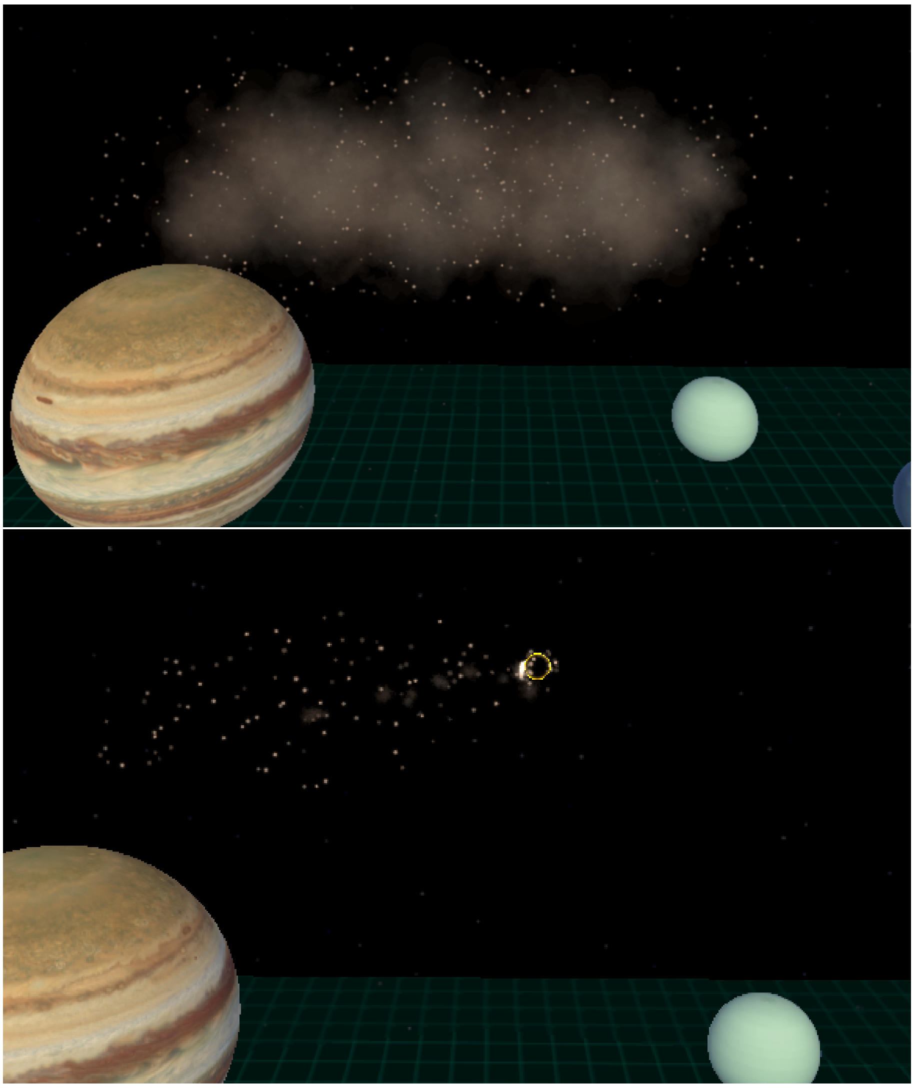

Figure 4.3: Particle cloud used to illustrate black hole attraction.

Since a black hole containment device is a bit too alien and its functionality doesn't have real world analogues I decided to use a less high tech analogue. I chose to use a cat carrier because it has a clear purpose and hopefully makes the black hole less scary by keeping it in the same way you would keep a pet.

To open the cage and trigger the animation sequence I added a large red button on top of the cage. When the button is pressed, the gate of the cat carrier opens after which the black hole escapes and sucks up a nearby particle cloud which increases its size. To encourage exploration of the whole environment instead of just the black hole game the cat carrier was slightly hidden behind the table.

In order to give feedback to the player that the planet was successfully caught by the black hole I added a sucking noise that played as the planet was being dragged in. The sound was taken from the recording of a draining bathtub.

Testing showed that some users were unsure what to do due to the increased complexity of the tasks in the room.

4.1.4 Final Iteration: Botty Leads the Way

To guide the users I made a helper robot called Botty that gave hints for the users throughout the experience. When entering this room Botty would give a short introduction of the overall purpose of the room and inform of the presence of the caged black hole. After this he would disappear and only appear if the user failed to progress in time. First possible lead he gave was if the user failed to release the black hole in time. He would then spawn next to the button and start to examine it curiously until the user pressed the button. For the second lead he would spawn and push Jupiter into the black hole.

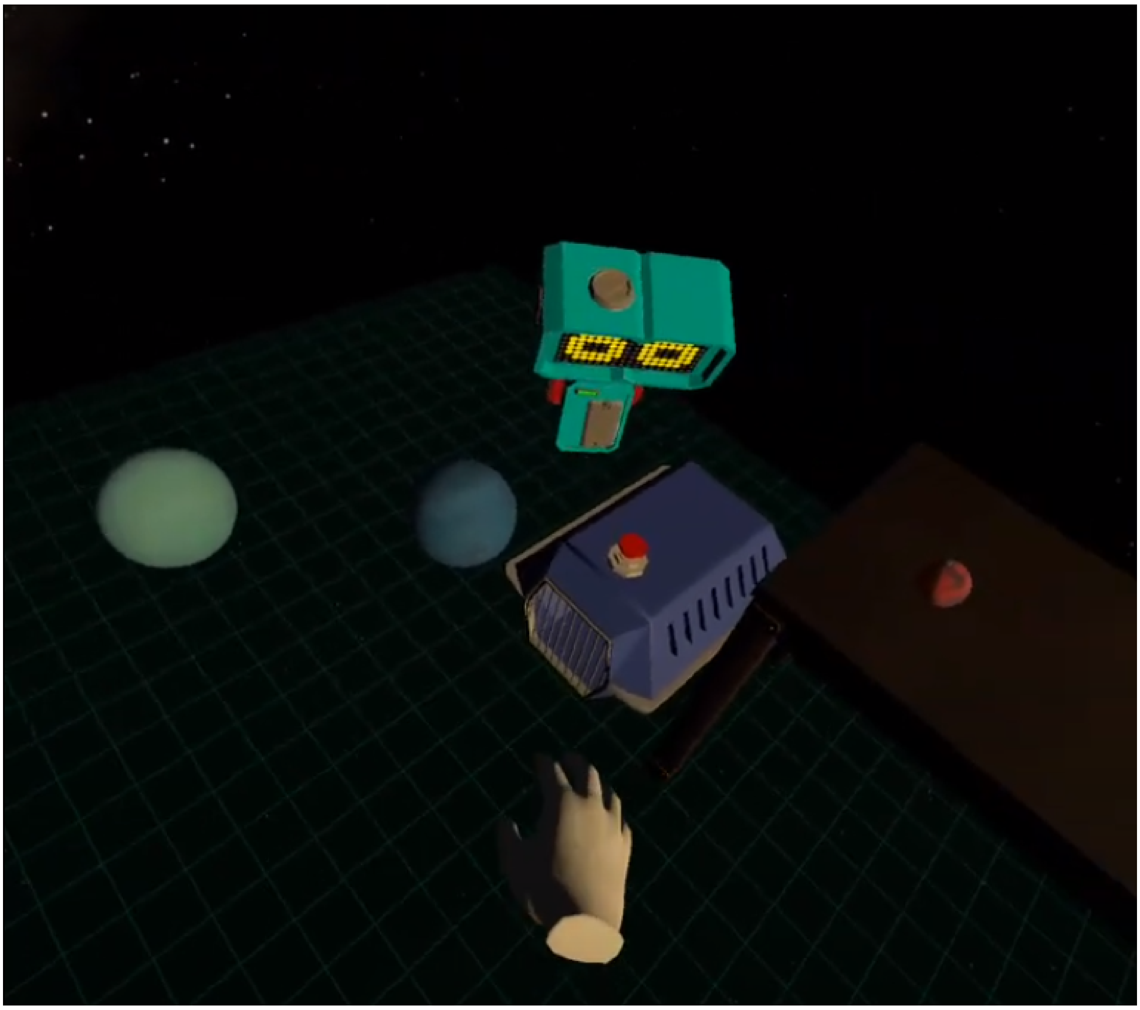

Figure 4.4: Botty leading the user to the button

4.2 Moon Shooter Room

The purpose with the reworked version was to make the earth smaller and centrally placed in the room allowing the user to observe the interaction between celestial bodies in 360 degrees. This meant that throwing the moon wasn't feasible any longer since fine motor control is generally lacking in VR. Instead a tool would need to be developed to facilitate the needed precision.

4.2.1 Fist Iteration: Proof of Concept

For the new tool I wanted a way for the user to be able to launch moons in a precise and consistent manner while still maintaining control of velocity. I chose a pistol concept and created a simple white box prototype that contained the desired functionality. The gun fired a single moon when the trigger was pressed and the projectile velocity could be adjusted by pressing the A and B buttons on the controller. The gun also had a display showing the current velocity. As a spur of the moment decision I threw together a second pistol in between tests for no other motivation than that I thought it would be fun to play around with. The new gun continuously fired meteorites when the trigger was held (See Figure 4.6).

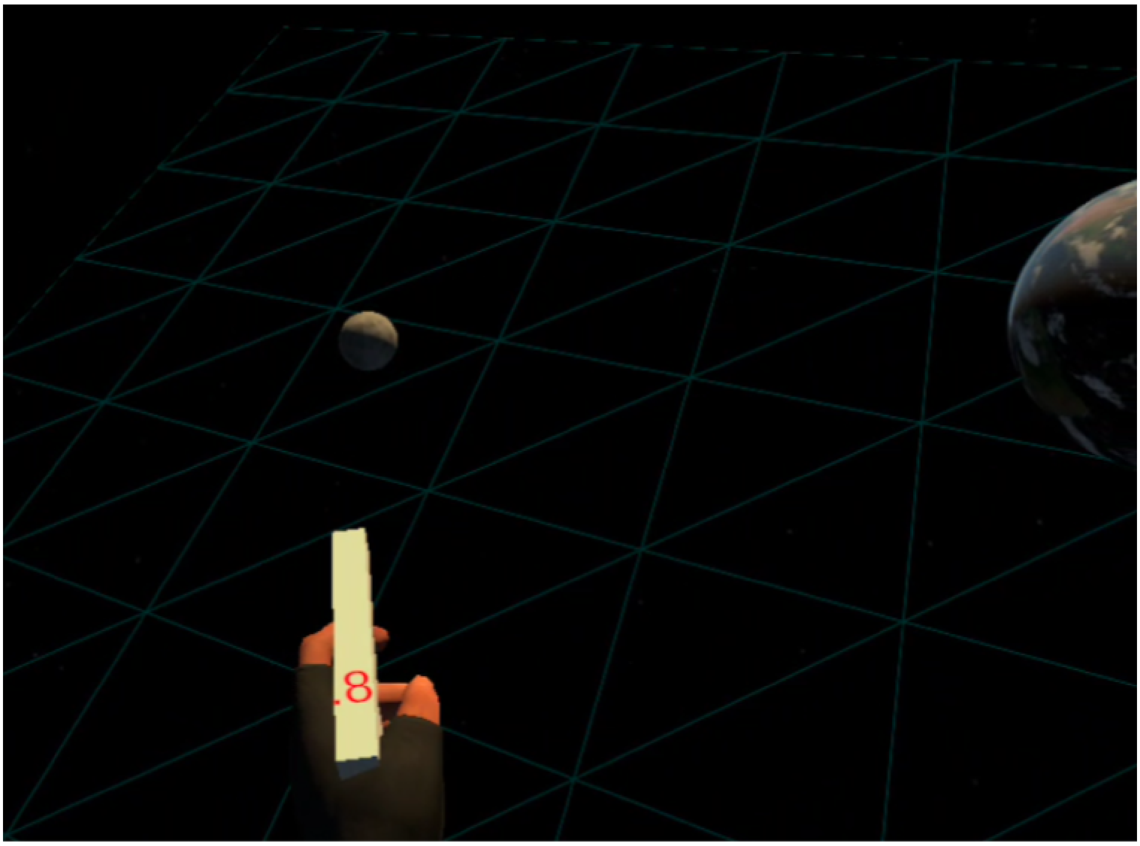

Figure 4.5: White box prototype of moon gun

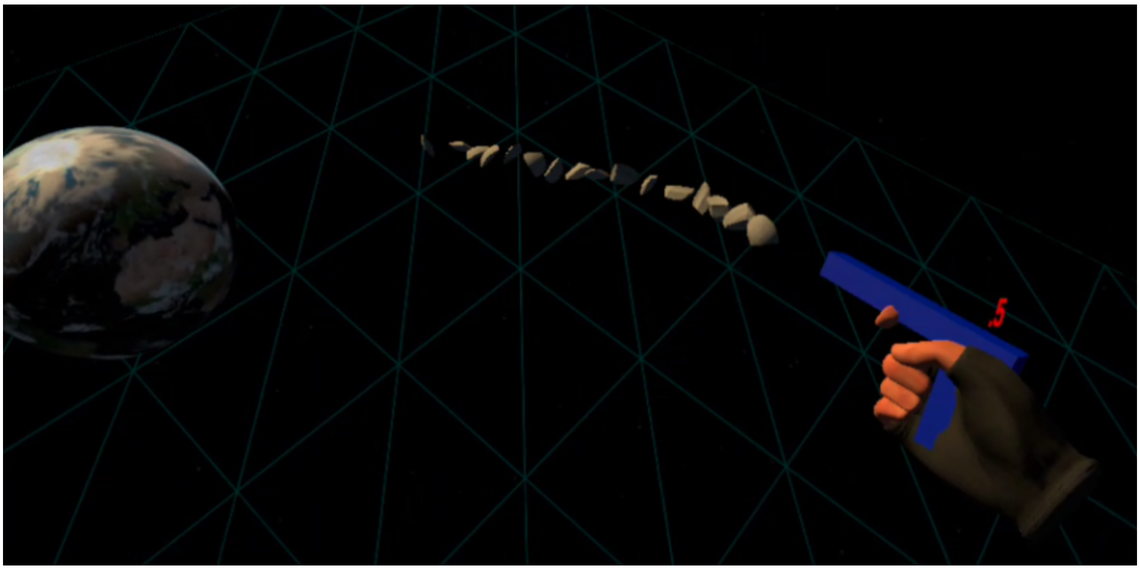

Figure 4.6: White box prototype of meteor gun

Small scale in house testing gave overall positive feedback for the concept. The users would stay engulfed in the experience for around ten minutes and would experiment with the different features that existed. The meteor gun got surprisingly good feedback despite it being a last minute addition.

During testing the following problem areas where identified

- Using two pistols made the users prone to playing around excessively.
- While playful behaviour should be encouraged the user needs to also observe and reflect in order to learn.
- often saw users pause when some interesting reaction happened between launched projectiles.
- Changing projectile velocity was unclear and the buttons were hard to find for some users.
- Users struggled somewhat with keeping using the grip button to keep the gun held.

4.2.2 Second iteration: Refining the Gun Concept

Since the first concept showed promise I decided to continue development along this path. I found that both types of gun showed promise and seemed to work well together. The meteor gun acted to quickly show how the gravity worked through brute force but velocity had to be relatively high and the projectile needed a short lifespan otherwise the meteorites quickly cluttered the scene. On the other hand, the slower rate of fire of the moon gun allowed for permanent projectiles with more complex gravitational interaction.

In order to slow the users down to achieve an act-observe-reflect pattern the two guns were combined into a single gun with the ability to toggle between the two fire modes.

Gun Functionality

To facilitate switching between fire modes I created a large lever on the side of the gun. The user could grab the lever with their free hand to slide it along a track and it would snap to the closest position when released. When released the fire mode would also change. Forward was the default position which corresponded with the moon gun from the previous iteration since I viewed it as the primary fire mode of the gun.

The early design decision to keep controller interaction as simple as possible meant that using a/b buttons on the controller was infeasible. This meant the ability to change projectile velocity would need to be reworked.

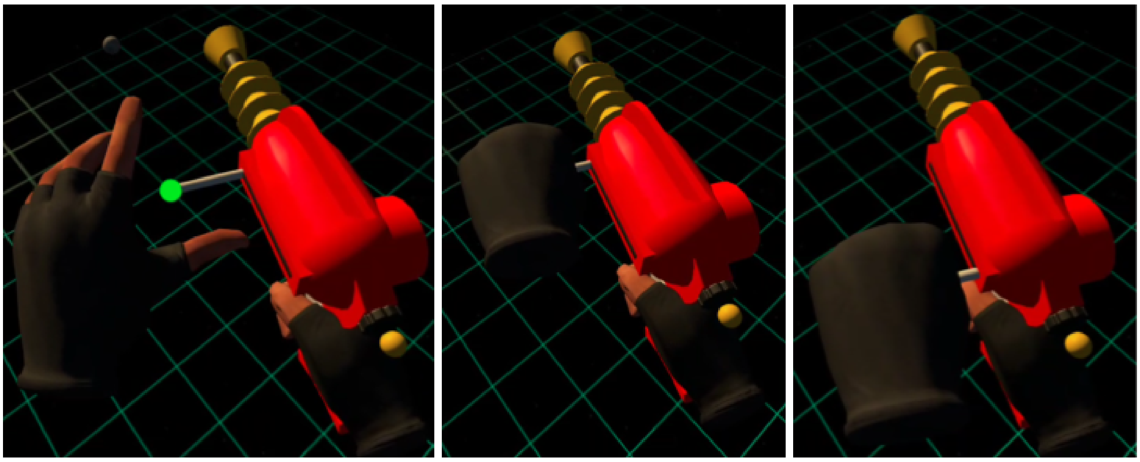

Figure 4.7: Gun handle functionality

For the moon shooter mode I implemented a feature to allow the user to charge up shots by holding down the trigger. The longer the trigger was held down the faster the projectile would be when fired. This meant that the user could vary the projectile velocity without additional buttons. For the meteor mode I set a fixed velocity that was high enough that it avoided clutter.

Visual Design

For the model it was important to have something that didn't look like a modern firearm because of the young target audience. I found a "retro laser pistol" that fit my needs well. The handle (See Figure 4.7) was designed as a horizontal bar The end was affixed with a green knob with a glow to draw attention from the user. Issues Testing of the prototype was small scale but this time contained some users in the target demographic.

- Users in the target demographic dropped the gun very frequently, often within seconds.
- The concept of holding the trigger to charge up the velocity of the moon shooter fire mode was hard to understand and users in the demographic failed to grasp the concept even when receiving instructions.
- Users did not find the toggle handle on the gun without guidance.
- Users kept hold of the handle expecting fire mode to change.

- Users wanted a lower velocity for the meteor shooter mode.

4.2.3 Third iteration: Audio Work and Polish

During testing of the second prototype it became clear that the increased complexity of the new pistol prototype meant it needed to communicate its functionality to the user. A majority of the time spent during this iteration was to add audio.

My overall purpose for the audio was to provide feedback to the user while still giving a silly or cartoonish feeling to further remove the model from realistic firearms.

The following audio clips were added to the game:

- Feedback when charging up moon shooter mode
- Feedback when moon shooter mode is charged insufficiently
- Shooting charged
- Shooting auto
- Audio when the handle is used to change fire mode.
- Background music

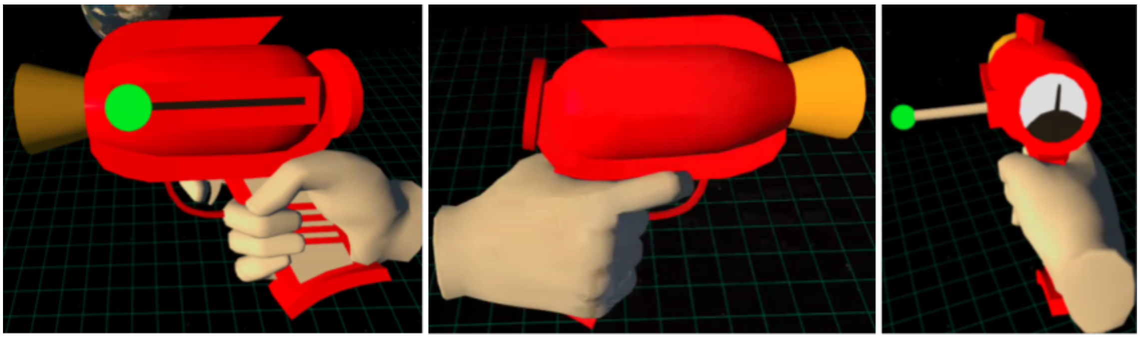

Figure 4.8: Reworked model for moon gun

Model Improvements

The gun model was remade from the ground up. The model was drastically simplified for performance reasons which is crucial for VR development, especially for the Oculus Quest which runs on mobile hardware. Furthermore this model looked even less like a real world gun. A display was added to the rear of the gun which I designed like a pressure gauge which would indicate the charge amount when in moon shooter mode. The metaphor I tried to achieve here is that the display indicates the "pressure" that shoots the moon. The user's virtual hands were also changed to give a less realistic feel to fit better with the overall cartoonish theme of the application.

Functional Improvements

To combat the severe issue of users being unable to keep hold of the gun I decided to remove the use of the grab button. All the interaction now only used the trigger. To enable the user to shoot the gun once grabbed the gun will remain attached to the hand once grabbed.

The gun is no longer placed on the floor like in previous iterations but is now placed below the moon and slightly toward the user. The gun will follow the user as they move around the room. The position was chosen in order to ensure that the user both found the moon and the gun at the same time.

For the meteor shooter mode, collision between meteors was removed as well as collision between the meteors and the gun. This meant some realism was lost but it drastically reduced the clutter of the screen. The reduced risk clutter allowed to significantly reduce the fixed velocity of the projectiles as well as increase their lifetime. This allowed the meteors to be much more clearly influenced by gravity and improved users ability to visualize orbits.

The meteor shooter mode also made the default fire mode for the gun. This was to further highlight the strength of the fire mode to quickly illustrate gravity's interaction through brute force. This gives users a good baseline understanding for when they change to the moon shooter fire mode.

Issues

Limited testing showed that users struggled somewhat with the charging mode used when shooting moons. They often missed the dial on the back of the gun and its purpose.

4.2.4 Final Iteration: Dial Rework and Gun Shake

To highlight that the dial on the back shows the pressure build up as the user charges the gun I remodeled it to resemble a pressure gauge. I also added a tube connecting the gauge to the main body since that's where the pressure would increase as the gun is charged.

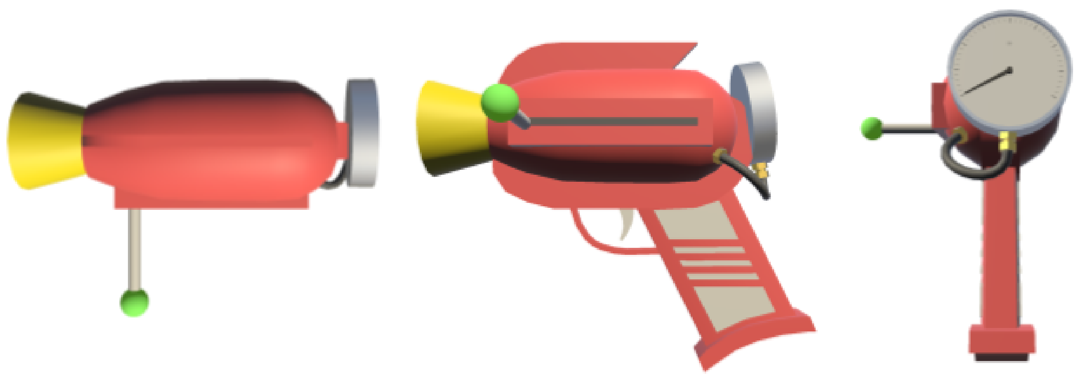

Figure 4.9: The final version of the moon gun

To further highlight the pressure increase, the gun would start to shake when charged. The shaking would increase in frequency and amplitude as the charge power increased.

A left handed mode was added that mirrored the model when the gun was grabbed in the left hand. This was because the left handed users would struggle to use the lever.

4.3 Solar System Overview Room

This room focused on giving an overview of the planets of the solar system with the primary purpose of teaching their relative orbital distances and durations.

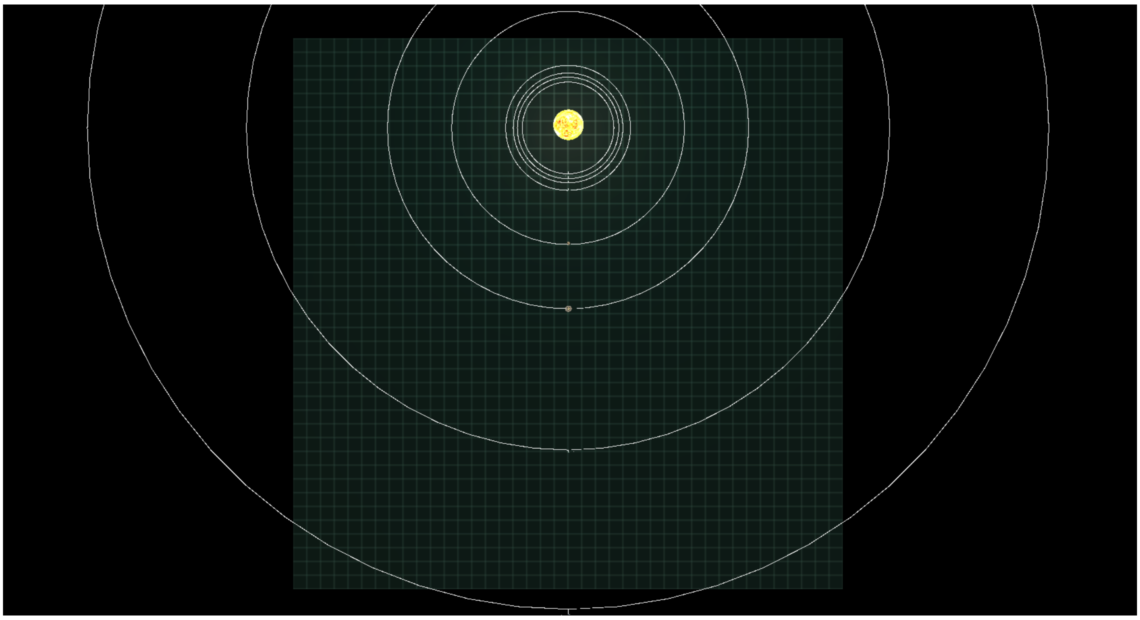

Figure 4.10: Top-down view of the overview room

In the previous version the user was surrounded by a miniature version of the solar system. The user had access to a control panel that allowed the user to move between planets and control the time of the simulation.

In the previous version of AstroVR this was the room that had the most problems. A majority of users would need a complete explanation of the control panel functionality in order to successfully use it. Most users lacked excitement for the room and quit quickly without the urge to explore it further.

However, those users that would experiment would often make a comment about some insight they had gained from its use.

The idea for the new version was to drastically rework the means of controlling this room while still keeping the core intact. The new control system needed improved usability and user engagement.

4.3.1 First Iteration: The Orrery

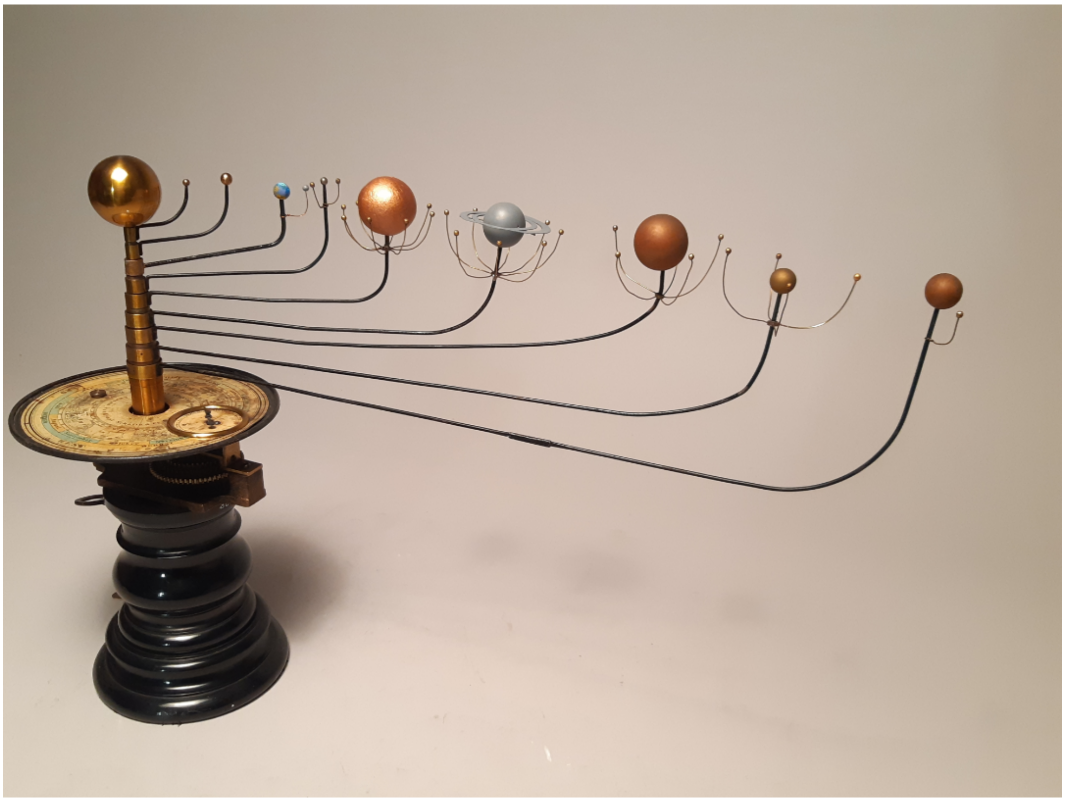

Figure 4.11: A mechanical orrery which was used as an inspiration for the Overview room.

The idea now is to make a room scale model that acts like an orrery (See Figure 4.11) where the user is able to move the different planets by grabbing them. Once a planet is in motion the rest of the planets would move as well while keeping the relative speeds the same as the relative orbital velocities of those planets.

This concept showed to be somewhat lacking as users often failed to successfully interact with the planets and therefore failed to get a feeling for the relative orbital velocities of the planets.

4.3.2 Final Iteration: The Time Controller

To give a more controlled way to display the model in a way that highlights the planets' relative orbital velocity I decided to add a tool that the user could use to control the speed of the simulation.

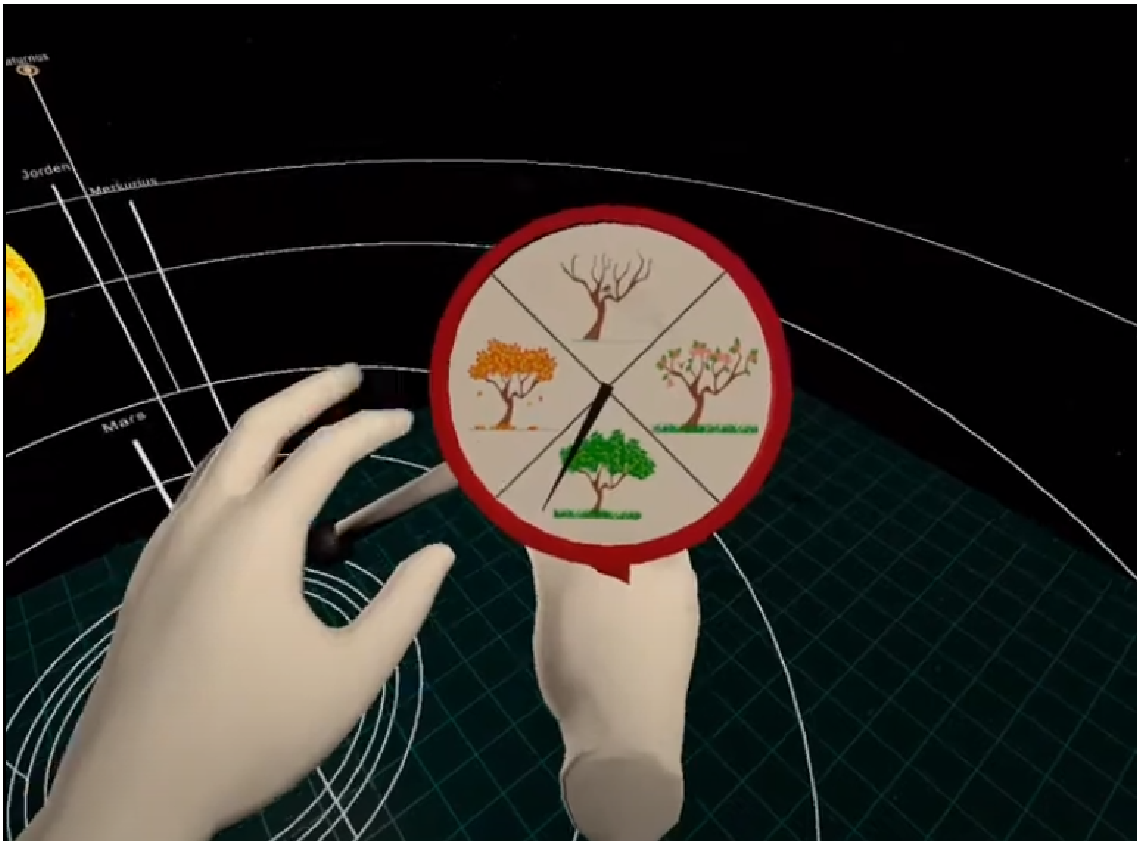

Figure 4.12: Time controller in use.

For this I needed some tool that was able to control time. Here I could reduce the modeling work by reusing parts from the moon gun. By combining the display, handle and side lever or the gun I was able to achieve the tool shown in Figure 4.12. The display shows pictures of the four seasons and the dial's rotation is synched to the earth's position. This gives additional connections between the rotational speed of the planets and the passage of time. By having a lever I was able to control the minimum and maximum speed or which the user would see the simulation. The minimum speed was set to a speed where Mercury (the fastest planet) was easy to follow. However at these speeds Neptune would be practically standing still since it has a much larger orbit radius as well as an orbit velocity almost exactly a tenth of Mercury. I therefore set the maximum to a speed where Neptune could easily be seen moving along slowly. I felt that this span would be the most efficient at communicating their relative velocities.

4.4 Onboarding Room

This room is a new room with the purpose of quickly introducing the user to the basic controls and concepts of the software. Additionally the room serves to introduce the game's guide, Botty, to the user.

4.4.1 First and Final Iteration

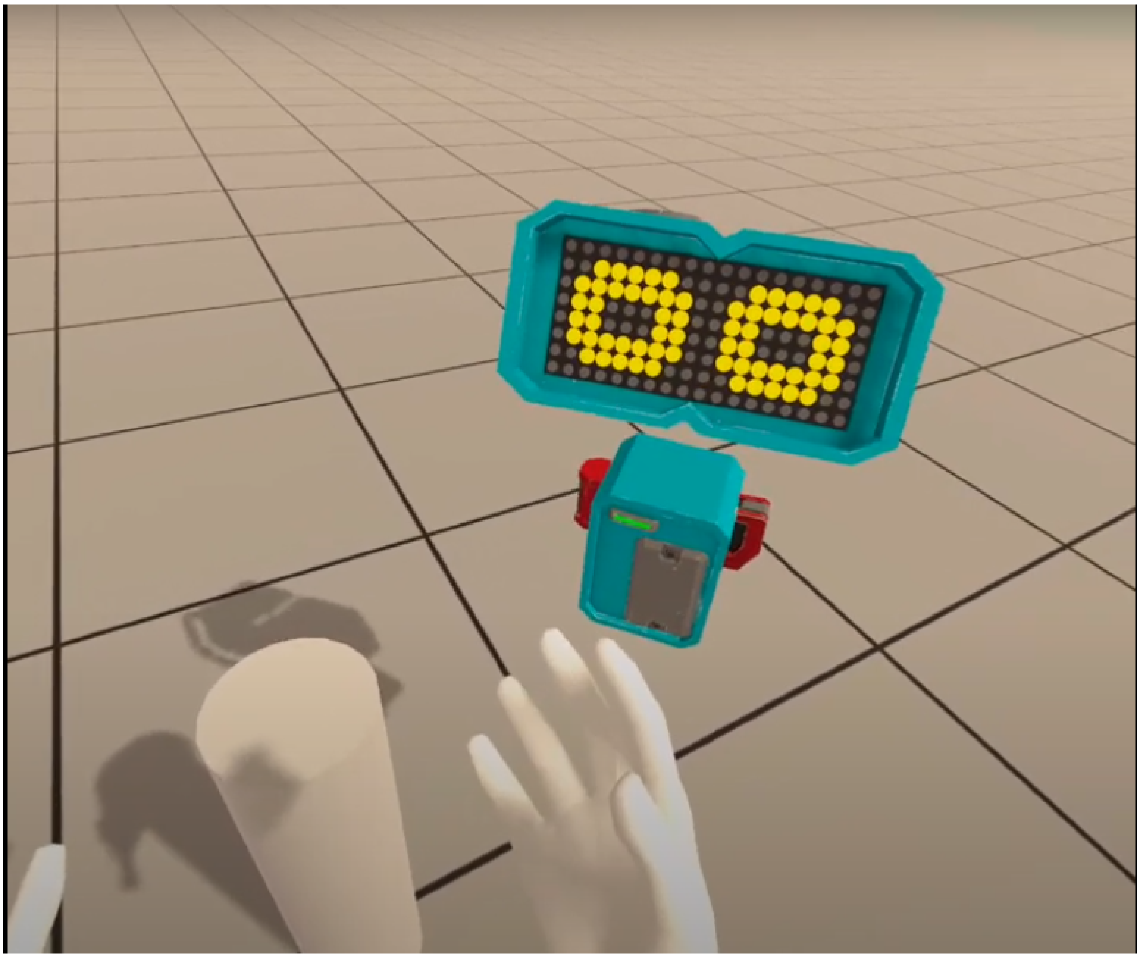

Figure 4.13: Botty at the start of the Onboarding room

Because the room was added late in the development of the project, only one iteration was performed. The user is given the following tasks:

- Pressing the grab button.
- Grabbing and throwing a ball.
- Picking up and using a soap bubble gun.
- Find and use the door to the next room.

4.5 Botty: the In-Game Guide

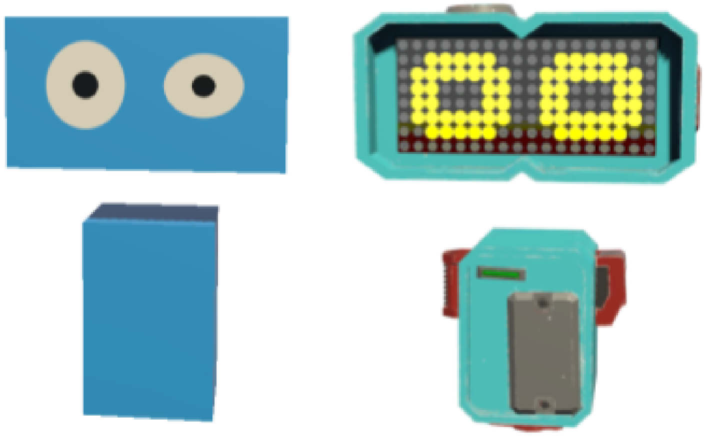

Figure 4.14: Botty's evolution from early prototype to final design

The purpose of Botty is to act as a guide for the user to ensure that the user can successfully complete the different tasks of the experience. Botty shall also be able to clearly communicate information about each room. By placing Botty within the same world as the user, Botty is able to directly guide the user within the world by using gaze and gestures. [6]

Botty shall also strive to be cute and to act as a travelling companion for the user. Veletsianos (2007) highlights the importance of having pedagogical agents make sense in the context of the in game environment so since AstroVR uses a futuristic setting I thought that using a robot would fit well. [10]

The robot design also has the upside of minimizing the impact from real world stereotypes that are linked a more human looking avatar. [4]

4.5.1 Overall Concept

To keep the overall design cohesive it's focused on reinforcing the story behind Botty. The story takes inspiration from the video game Portal[3] and the movie WALL-E[4]. The design tells of a robot that keeps happily doing its task long after its expected lifetime ends. The reasoning behind this is to invoke a compassionate response from the user as well as giving an in-game excuse for his somewhat limited functionality.

While Botty itself can only communicate using beeps and gestures it has access to pre-recorded audio clips provided by its creator.

[3] https://en.wikipedia.org/wiki/Portal_(video$_game$)
[4] https://en.wikipedia.org/wiki/WALL-E

4.5.2 Visual Design

Figure 4.15: Inspiration sources for Botty's design.

The first inspiration from the design process for Botty was the robot from the SVT christmas carol Jakten på Tidskristallen (See Figure 4.15). The LED matrix display for eyes, color and two part design was from here, however for ease of use I wanted it to be flying instead of using wheels. The LED display has the upside of easily conveying emotions while keeping complex animations to a minimum.

When looking for ways to convey emotion using LED eyes I found a YouTube video[] that drove the eye design and overall head shape.

To keep in line with overall design principles, Botty has chipped paint and scratches all over. Covering his body is an assortment of random parts that he seemingly attached himself as he made emergency repairs. On the front he has a light that lights up when he is playing a narration clip. The light's intensity is based on the amplitude of the audio clip played in order to communicate that Botty is the source of the sound.

4.5.3 Animations

Despite the rigid nature of Botty's different body parts I wanted to give him a more lifelike appearance and therefore avoided the rigid and stiff movements commonly associated with robots. A common technique used to create more fluid animation is called squish and stretch where the object's dimensions are modified to simulate movement. This didn't really fit here since I still wanted to keep the solid nature different parts of Botty intact. This is part of the reason why I kept the body and head of Botty separate as it allowed me to move them independently of each other. The feeling I wanted to replicate was that the two parts moved as if connected by a stiff, non-bouncy spring. The animation was then made by having the head act as the driving object with the body following according to the above requirement.

Botty has the following animations:

- Idle, slowly bobbing up and down.

- Curiously inspecting, Booty leans forward and moves his head as if to look from different directions.
- Happy reaction, a small bounce combined with a happy noise.
- Teleporting in/out, movement is frozen as a plane of light moves across Bottys body, revealing him.

4.5.4 Audio Design

When it came to selecting a way for Botty to communicate with the player I struggled to find a suitable voice for it. Looking at different cute robots in pop culture I found that cute robots generally don't speak complex sentences but communicate using other means such as beeps (R2D2), gibberish language or repetition of a single word (WALL-E). Since one of Botty's primary purposes is to clearly communicate information, neither of these were good alternatives as a primary way of communicating.

Video games and movies often solve this by having a narrator that tells the story by speaking directly to the player. However, the intimate nature of VR results in a disembodied narrator being creepy and I would need to find a diegetic[5] way to deliver the narrator's lines.

Therefore I came up with the model of having Botty communicate using beeps but having pre-recorded messages from a narrator that he can play to introduce each room. By doing this I could use clearly narrated instructions while not making Botty feel stuffy and boring. This also had the upside of simplifying Botty's interactions since the user didn't expect him to speak when reacting to dynamic situations. To further reinforce that the narrator's voice was separate from Botty the audio was modified to sound like it was played through an old speaker. To achieve this I applied a filter that simulated the compression that happens in old telephone networks. I also added crackling sounds from an old LP record player to the audio clip.

4.6 Optimization for Oculus Quest

Optimization for the Oculus Quest is a challenge since it uses older mobile hardware while still retaining VR requirements such as high FPS and high resolution. Since the AstroVR 1.0 was made for a high end gaming PC it suffered from subpar performance on the Oculus Quest. In order to properly run it on the new hardware many performance optimizations would need to be made.

4.6.1 Rendering Background

When creating something in 3D the scene is made up of triangles. These triangles are given a material, a collection of parameters and textures that define how the surface looks. The triangles that share a material are grouped together and sent to the GPU for rendering. These

[5]Diegetic audio refers to audio that is part of the world. The opposite to this is non-diegetic audio such as background music.

are called batches and each batch has a performance overhead that is quite large on mobile GPUs.

4.6.2 Texture Atlasing and Mesh Baking

To start out I applied techniques that can be applied without modifying the core program. These are all about reducing batching since it's unnecessary overhead that doesn't give any increase in graphical fidelity.

Texture atlasing is the act of combining multiple materials into one. Ideally all objects using the same type of material should share the same material meaning they can be grouped into one big batch.

Mesh baking is similar to texture atlasing but for 3D models. It's the act of converting all non moving parts of your 3D model into one. This relies on texture atlasing if the model contains multiple materials. This is usually mostly for static geometry since dynamic objects are automatically batched together if they share the same material. However, I used it whenever possible since Unity's dynamic batching is limited to a relatively small amount of triangles.

To achieve this I used an asset from Unity Asset Store called MeshBaker[6] which allowed for the process to be automated. This still required plenty of hands on since all objects needed to be separated into different parts before baking.

4.6.3 Botty's Eyes

To achieve the LED grid for the eyes I first made a custom shader that used a low resolution image where each pixel showed the intensity of LED light at that position to construct the LED display. I then extended the functionality of the eye shader to use a grid of eye images for different emotions and blinking states. By controlling different parameters of the shader I could select which of the images that was displayed at any given time allowing me to show multiple different emotions which each had a separate blinking animation (see Figure 4.16)

Figure 4.16: Eye texture used to display Botty's eyes.

[6] https://assetstore.unity.com/packages/tools/modeling/mesh-baker-5017

However, when optimizing I realized that this custom shader used a bit too much resources for what it gave. To solve this I wanted to make an atlas like the low resolution light data atlas but with the final rendered product instead. Since MeshBaker didn't support custom shaders like mine I made a custom way to save the eyes as images. I set up an isometric camera that looked at Botty's eyes then programmatically saved the image from that camera to a file which I then repeated manually for each of the eyes in the matrix. I then merged those images using the image editing software GIMP. This atlas could then be displayed on a regular material without the need for additional shaders.

4.6.4 Reducing Per-Pixel Rendering

When developing for mobile VR it's critical to remove almost all sources of per-pixel rendering. This is because the high resolution screen means lots of pixels to render. This is why I removed all post-processing effects since they by definition render per pixel. This unfortunately had a large impact on graphical fidelity but it just wasn't feasible to keep.

Other common sources of per-pixel rendering are lights and shadows. Since VR development is done using a forward renderer each different light source will render the scene all over again. Because of this I only used a single light source and turned off shadows. This generally only reduced the graphical quality of the product but in one case it posed a usability problem, namely the light on Botty's chest indicating that the narrator was speaking. The removal of the lights used to illuminate the surrounding area made the light much less apparent. To fake these lights I made a small model that overlaid the area around the light. I drew a semi-transparent texture showing the light would spread from the light and applied it to the model. By controlling the transparency of this image I could then vary the intensity of the faked light.

4.6.5 Reduction of Triangle Count

While the models made by myself were deliberately made to use as few triangles as possible, there were some models I had gotten online which clearly were not. Some of these used unnecessarily high triangle counts for their purpose so I remade those myself in Blender with drastically lower polygon counts. Examples of these were the moon gun, table and door.

4.7 Doors

To transition between scenes the older version used doors that acted like portals. The doors started partially hidden below a transparent floor and only the top few centimeters are visible. On the top of the door there was a handle making them look like a drawer when below the floor. This allowed the door to have a minimal footprint in the scene while still being available at all times without the need for the user to access additional buttons on the controller.

The doors posed a massive challenge when porting the product to the Oculus Quest. Since making portals that show another scene is somewhat demanding of the GPU this is quite difficult to achieve on an older mobile hardware in the first place. Add to that the very high resolution of the headset's display and the need for a high frame rate and such effects are even more difficult. To even further complicate the matter, the previous implementation of the portal used engine technology (render textures) that did not render properly when rendering for the two eyes of the Oculus Quest.

Another complication of the matter was that the door needed to be hidden when below the floor which I achieved through an invisible plane that hid specific things behind it. This interacted with some of the possible technologies making them unfeasible. However, as I was working on a solution I realized that I could make a simple door model split into the side and the top and then scale these objects in order to achieve the same effect without any use of a shader. I was then able to use stencils and manipulation of the rendering order to achieve a portal effect with minimal performance impact.

4.7.1 Inside the Portal

For the inside of the portal I wanted to give a hint of the next room. However, actually showing the next room was unfeasible since it would require the second scene to already be loaded. At the time of writing this, Unity does not allow for truly asynchronous loading of scenes and loading a new scene will freeze gameplay momentarily which is unacceptable in VR. The only real possibility would then be to keep all scenes loaded at all times which is unfeasible due to performance reasons.

The solution for this was to make a fake, low fidelity version of the next room and add a rippling effect to the portal surface. The low-fidelity version of the next room consisted of simplified versions of the objects that were either low polygon versions or rendered into 2D images when possible. The low fidelity version also only contained objects visible through the portal.

4.8 Test Data

The SUS that was performed gave an average of 87 with a standard deviation of 5.8. A graph of the different scores can be seen in Figure 4.17. The survey also contained two free form questions. The first question was "Do you think AstroVR would have been fitting to use as a part of astronomy education in school?" and answers can be seen in Table B.2. The second question was "Here you can write with your own words what you think about AstroVR" and answers can be seen in Table B.3.

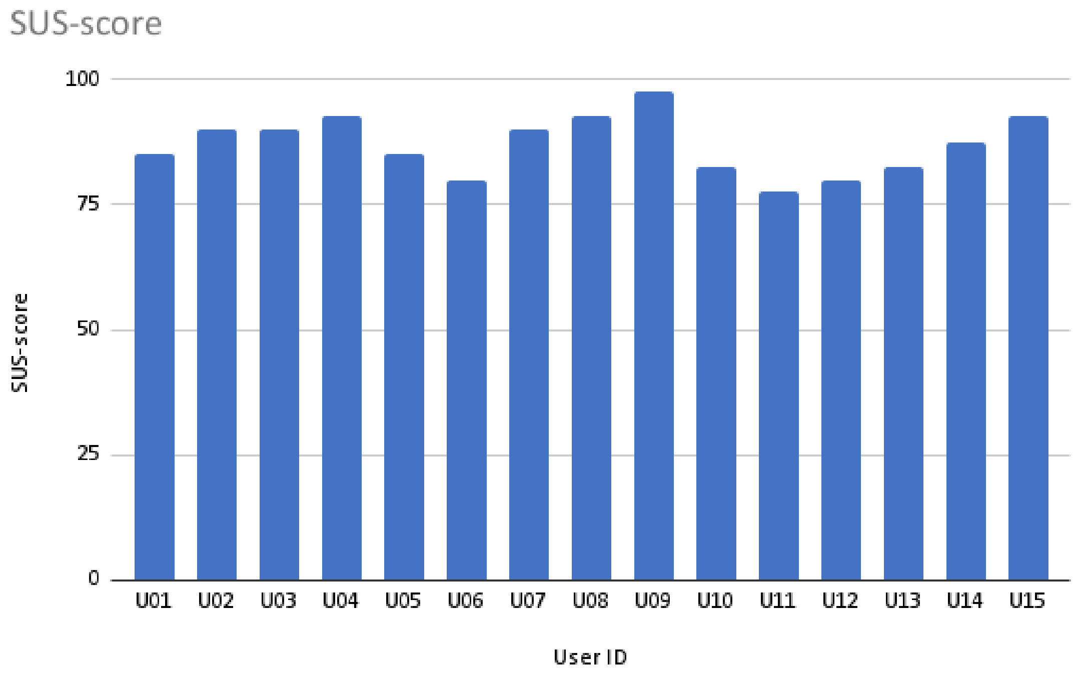

Figure 4.17: Table showing SUS-score of each participant

Answers to "Do you think AstroVR would have been fitting to use as a part of astronomy education in school?"

User ID	Answer
U01	It is a fun way to learn. It should adapt to what we are interested in, meaning technology, games etc. It's also encouraging me to learn
U02	Can see better visually than with words. Works for the majority of subjects. Education more fun for uninterested students. Easier to see the real scale which can be hard to understand using numbers.
U03	It would have been a more fun and easy way to learn.
U04	I think that gravitation and how long it takes for all planets to orbit a whole lap would be good to know. I learned new things from AstroVR that I wouldn't have known otherwise.
U05	It depends on who it's meant for. What was brought up was pretty simple and is more fitting for a astronomy education in a lower grade. If it's to be used at school you need a lot of space for each student which can be problematic. However, I recommend it. Was fun!
U06	I think it would help with understanding differences in size and how fast they move
U07	I think that visualization, interacting and to try yourself is the simplest and most effective way to learn.
U08	Clear instructions and you learn about gravitation and such in a fun way.
U09	It's easier to learn in a test/try-context.
U10	Yes, it was a fun way to learn. It was a break from the usual education. You remember the rooms you were in and for example what you could say about the planets. You can present the fact in different rooms, a good way to learn!
U11	Would have been a good way to, for example, learn about gravitation.
U12	It would have been a fun way to learn.
U13	It's cool to see the planets in a different way.
U14	You got an understanding about how space works for example how quick a year on Earth is compared to Neptune.

Table 4.1: Translated free form answers to the question "Do you think AstroVR would have been fitting to use as a part of astronomy education in school?"

Answers to "Here you can write with your own words what you think about AstroVR"

User ID	Answer
U01	It was really fun. To be able to learn things at the same time as you're playing. It was cool as well. It looked sooooo real. But some criticism: There were times where I didn't know what I was supposed to do. It reminded me about an escape room. You had to guess and find clues. For example to release the black hole. At the start it was a bit unclear if I should open a door and if so that I should bring it up out of the ground. But as I said, it's really cool and something I can recommend.
U02	Interesting how fast VR has developed. Just a few years ago the best thing you could get was a headset that you put your mobile phone in. A step closer to making a virtual world. In the future you might be able to make virtual senses.
U03	I think it was a fun way to learn.
U04	I think it was a good and potentially a very good and education game. The game was interesting but I would also like to see stuff about other planets such as dwarf planets and exoplanets and the sun. Something with out galaxy would also have been exiting. Like seeing how much gravity our galaxy has.
U05	I like the idea a lot and it was very fun. I think it might be hard to get for the school but can probably be a thing you buy for your home. Thank you so much that I got to experience this.
U06	I thought it was fun and you got to learn more about astronomy.
U07	I think it it a good to interact and feel, in order to learn. Got some pain in my eyes in the end but that's probably (due to) inexperience. Specially for people that have a hard time to focus, on for example, text. To have applications such as this is something that I think can increase understanding for the book. For example how slow Neptune is rotating in relation to The Earth.
U08	I think it's a good game with clear instruction, good graphics and good purpose.
U09	Good design. Easy to use. Cool. Fun.
U10	Very pretty rooms with fun tasks such as throwing planets into black holes! Fun that it was a bit playful with good facts.
U11	Fun and amusing :)
U12	It seems fun and exiting.
U13	Very cool experience and (I) think you should do this more than once.
U14	I think it was super cool.
U15	I think it would have been super fun to have it in the curriculum. It worked well and the assistant explained well which made it easy to use so that many can use it. You learned quickly and it was a fun but educational game!

Table 4.2: Translated answers to the question "Here you can write with your own words what you think about AstroVR".

Chapter 5
Discussion

5.1 Methodological Reflections

When outlining the methodology in the goal document I outlined the following three phases for the project:

- Test of existing product.
- Development
- Test of improved product.

However, over the course of the project, a few methodological changes had to be made. Due to COVID-19, performing structured testing was unfeasible at the start of the project due to strict restrictions. This was unfortunate, since the plan was to use the test data from the first testing round to guide future design. The basis for the improvements would instead depend on the judgement from those that had used the product for demo purposes in the VR lab which fortunately were myself and my supervisor.

5.2 Review of Test Results

The SUS score average indicates that the software has good to very good usability. Looking at the table in Figure 4.17 we can see a small amount of deviation between each individual score which highlights that the average is a good approximation.

Looking at the free form answers in Table B.2 and Table B.3 we see further positive answers as well as criticism highlighting previously known issues.

5.2.1 Task review using video

Planet Inspector Room

- **Pick up planets:** All participants succeeded with this task, although some users failed at properly using both hands to lift heavier planets and would attempt to drag them instead.

- **Use button:** Some participants didn't find the button and asked for assistance from the demonstrator but only needed a vague hint to look around the room in order to find it. Once they found the button they were generally quick to press it. However, there were a user that voiced their confusion about being able to open the door using the button and would try to directly open it by grabbing the door.

- **Interact with black hole game:** After seeing the entrance animation of the black hole most users were able to understand that they needed to throw planets into it. Some users even commented that things were getting sucked into the black hole which is a good sign that its intent was communicated properly. Botty's hint was generally missed and those users and generally only caused confusion.

- **Use door to proceed to next room:** Here it was common for the users to miss that the door had appeared and they would need to be guided by the demonstrator.

Moon Shooter Room

- **Pick up moon gun:** At this task every user was successful. Many even grabbed the moon gun within a few seconds of entering the room, even before the introduction audio finished playing.

- **Interact with lever:** All of the users eventually used the lever correctly to switch between charging modes but it was common that it took a while because they were excited by the asteroid shooting mode of the gun.

- **Understand gun charge mechanic:** The charge mechanic of the moon gun was generally poorly understood. The participants would often quickly press the button upon changing firing modes and be met with the error noise and give up and change back.

Solar System Overview Room

- **Interact with planets:** This task was partially completed by all and they interacted with the planets in one way or another. However, many simply released the planet without moving it and then kept looking around the room.

- **Understand orrery metafor:** Due to the high failure rate of the previous task this task was generally unsuccessful and few test participants displayed full understanding of the metaphor. However, I speculate that more would be successful if the introduction of the time controller was delayed since many were interrupted as they started to experiment with the planets.

- **Understand time controller:** This task was successful for all participants. All successfully used the lever on the side to control the orbital rotation of the planets. Many also commented on the display of the time controller and how the different seasons reflected the earths position.

Onboarding Room

- **Throw ball:** All users were successful in throwing the ball.

- **Shoot soap bubbles:** All were successful, however, there were some that seemed hesitant to release the button and press again to fire. This stems from the choice to use only use a single button for all interaction. A compounding issue is that there is currently no implicit explanation highlighting the difference between equipment that sticks to the hand and regular throwables that are only held as long as the button is held.

- **Use door to progress to next room:** This was the most problematic task in the test. This was expected because of its somewhat complex metaphor.

  The participants found the door successfully but a large majority were unsure about how to interact with it and asked for help from the demonstrator. Despite this, all except two succeeded with the task without an answer from the demonstrator. I would speculate that their insecurity in large part stemmed from the fact that all previous tasks were stationary and this was the first task where arm movement was insufficient for completing the task.

  While all eventually went through the portal, many were hesitant because they found it a bit scary.

Botty

Users, especially children in the target audience, were overwhelmingly positive to Botty's design. He often successfully invoked compassionate reactions.

The primary issue I found was that users often missed the separation of Botty's voice and the narrator. This can mostly be attributed to a poorly worded voice line when introducing Botty. The phrase used was "Detta är Botty, säg hej Botty" (roughly translated: This is Botty, say hi Botty) whereby Botty beeps hello to the user. This was misinterpreted by many users as directed to them instead of Botty and they therefore greeted Botty. For further reading, the voice manuscript can be found in appendix x.

5.3 Conclusion

The goal for the project was to increase the usability of the product and to increase its effectiveness as a teaching tool. The core of my approach was to make a more focused product with no superfluous parts were everything had a purpose. Everything that wasn't conducive to the learning experience was cut or heavily reworked regardless of how popular it was. The few additions that were made were all made in order to further align the room with the others in order to make for a cohesive experience. This reduced the extent of the experience and allowed me extra time to focus on polishing what remained. By using this approach I would argue that the project was a success since the resulting product was deemed to have good to very good usability through testing and the introduction of the in game guide, Botty, allows the product to be used with minimal guidance.

5.4 Future Work

There's still some way to go until the product is ready to be published for the market. The application currently needs a more clear ending for example that the user is placed in a lobby room where they are able to choose amongst the different rooms.

Right now the game also starts instantly which is sufficient for testing purposes but for a final product the game should start at a menu. In addition to the normal mode that's focused on new players, returning players should be able to instantly get to the lobby room if they want to replay a specific part of the experience.

The menu should also contain different locomotion alternatives such as teleporting or using the joystick to move. While this isn't how the game is designed to be played, it could help for users with mobility problems. I also recommend adding an option for remote grabbing to better facilitate those that struggle with bending down and grabbing things on the floor.

Planet Inspector Room

- Overall sound balance work
- Reduce size of the room slightly
- Ensure that Botty is seen before he pushes Jupiter into the black hole. Increase auditory feedback to alert the user to Bottys presence then wait for the users to look at him before triggering the pusing animation.
- Ensure that Jupiter is in the right position before pushing it. Currently this condition is not checked and if Jupiter is moved then the purpose of the hint fails. While this is a corner case I've only seen a handful of times it could be worth taking into consideration.

Moon Shooter Room

The concept of the charge mode needs a proper introduction. I would suggest introducing it into the onboarding room.

Solar System Overview Room

Explain that it's the last room, many users look for a door. Consider focusing more on the time controller and introducing it immediately.

Onboarding Room

A major improvement would be if it somehow forced the user to move about in the room. As it is, the user would often need to be prompted to move about once they entered the next room. A suggestion would be to move the pedestal after they throw the ball. If the pedestal also varied in height so the user was forced to bend down slightly it should reduce the issues many users have with the door since it primes them that they might need to bend down to perform some tasks. Since the user needs to be centered in the room as they walk through the door I would suggest forcing them to turn around before they move. By doing this twice we can have the user move about in the room and still return to the center at the end. I also recommend adding an additional gun that shows how the charging mode of the moon gun works. Additionally add some hint that the door is always the way to advance to the next room. As it is, users often don't look for the door when they want to leave the next room.

Botty

Botty has performed very well in testing overall and at the moment it is mostly in need of small audio tweaks.

In order to communicate that the narrator is separate from Botty first the problematic voice line would need to be changed to something clearer. Botty's animations could be improved to make it clearer that he is being spoken to.

To further highlight that it's a prerecorded voice line and not Botty that's speaking I have the following suggestions at changed to the audio recording: Start the audio clip with a few seconds of no narration, only the vinyl crackling. Maybe add some audio feedback at the start. Add a throat clear before speaking.

These would all serve to highlight that the audio clip is recorded through a microphone and not something that Botty would generate when speaking.

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Appendices

AppendixA
Test document

Planetrummet

Mål

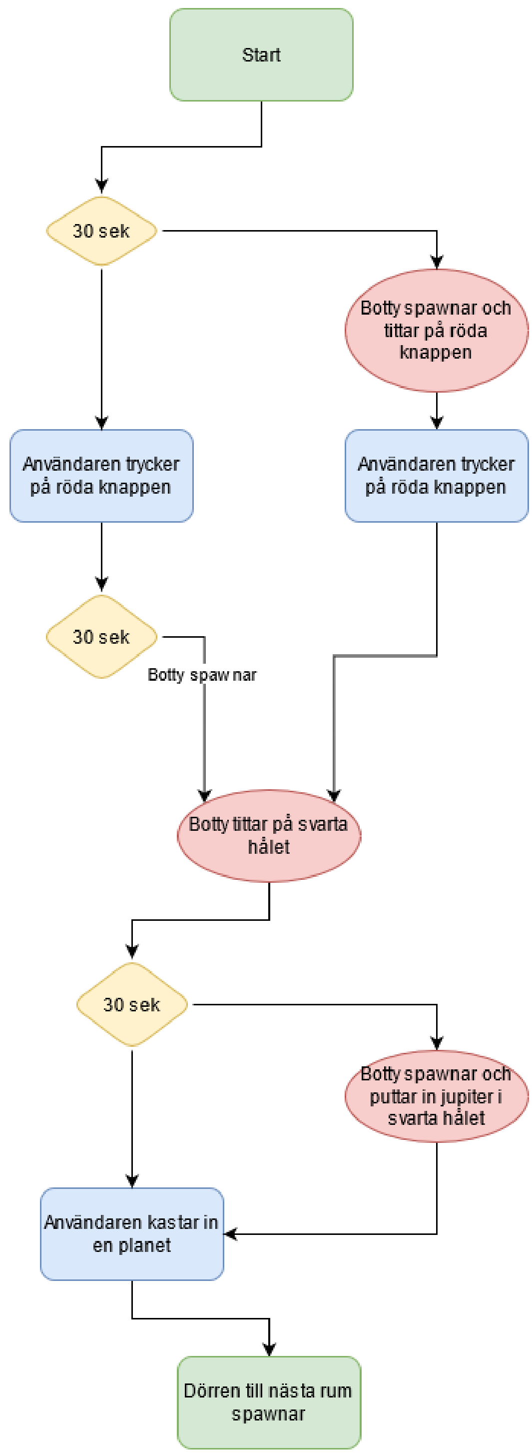
Ge en känsla för den relativa storleken mellan de olika planeterna.

Objekt

Solsystemets planeter, kattbur med röd knapp på.

Funktionalitet:

Användaren kan greppa planeterna, de tyngre planeterna behöver båda händerna.
En röd knapp startar ett minispel där användaren kan kasta in planeterna i ett svart hål för att få info om planeten.



Gravitationsrummet

Mål

Ge en känsla för gravitation

Objekt

Jorden, månpistol

Funktionalitet

Användaren använder en månpistol för att skjuta asteroider och månar och se hur de påverkas av jordens gravitation. Spaken på pistolens sida ändrar skjutläge. I asteroidläget skjuts asteroider kontinuerligt när knappen är nedtryckt. I månläget laddas skottet upp genom att hålla inne knappen.

Översiktsrummet

Mål

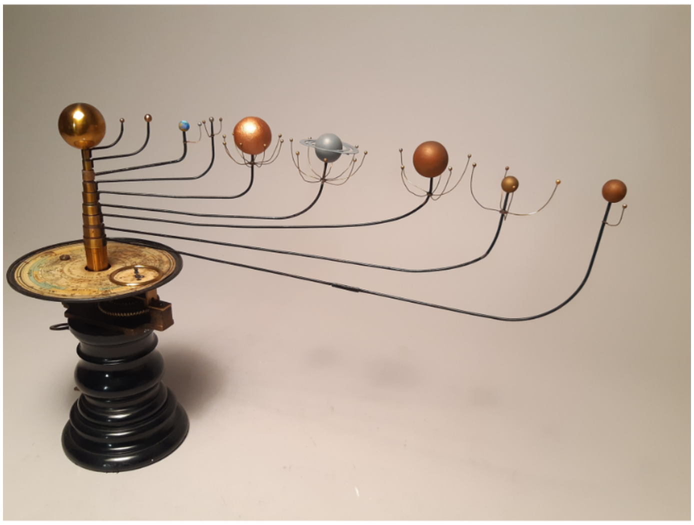
Visa relativ omloppsbana samt omloppstid för de olika planeterna.

Objekt

Översikt av solsystemet med linjer för omloppsbanor. En tidsstyrare som styr hastigheten på omloppstiden.

Funktionalitet

Planeterna är länkade likt ett planetarium (bild nedan). Användaren kan greppa eller slå planeterna för att flytta dem. Det finns även en tidsstyrare där användaren kan använda spaken på sidan för att ställa in hur snabbt tiden ska gå. Tidsstyraren har en display som indikerar jordens årstider.



OnBoarding (Max 2 min)

Användaren hittar inte pekfingerknappen
"Du har en knapp under pekfingret"

Användaren lyckas inte greppa
"Du greppar med den knappen du tryckte precis"

Användaren lyckas inte plocka upp pistolen
"Testa att plocka som du gjorde med bollen"

Användaren lyckas inte blåsa såpbubblor
"Släpp pekfingerknappen och tryck igen"

Användaren förstår inte dörren
"Ser inte det ut som ett handtag där nere på marken, vad händer om man greppar det?"

Planetrummet (Max 5 min)

Användaren hittar inte knappen
"Vad är det där som Botty tittar på?"
"Ser inte det där ut som en röd knapp?"

Användaren försöker inte kasta in planeten i svarta hålet
"Undra vad man kan göra med det svarta hålet?"
"Testa att kasta in en planet i det svarta hålet"

Användaren vill lämna rummet men hittar inte dörren
"Hur kom du in i detta rummet?"
"I förra rummet fanns dörren nere under marken"

Gravitationsrummet (Max 6 min)

Användaren plockar inte upp pistolen
"Ser du pistolen, gå fram och plocka upp den"
Användaren hittar inte spaken (1 min)
"Ser det inte ut som en spak där på sidan."
"Greppa spaken med andra handen"

Översiktsrummet (Max 5 min)

Användaren förstår inte tidsstyraren:
"Greppa spaken med andra handen"

AppendixB
Raw test data

SUS Questionnaire Data

User ID	Question Number																	SUS-score
	1	2	3	4	5	6	7	4	9	10	11	12	13	14	15	16	17	
U01	5	1	3	1	4	2	5	1	3	1	5	5	3	4	2	4	2	85
U02	4	1	5	1	5	1	4	1	5	3	4	5	3	4	3	4	3	90
U03	4	2	4	1	5	1	5	1	4	1	5	5	5	4	3	3	3	90
U04	3	1	5	1	4	1	5	1	5	1	3	4	5	4	2	4	2	92.5
U05	4	2	5	1	4	3	5	2	5	1	4	2	1	4	1	3	2	85
U06	3	2	4	1	4	2	5	1	4	2	4	4	3	3	1	3	3	80
U07	4	2	5	1	5	1	5	1	4	2	5	5	4	3	2	3	2	90
U08	4	1	5	1	4	2	5	1	5	1	4	5	3	3	3	3	2	92.5
U09	5	1	5	1	4	1	5	1	5	1	5	4	3	3	2	3	2	97.5
U10	3	2	5	2	4	2	5	1	4	1	4	4	4	4	2	2	2	82.5
U11	3	1	5	4	5	3	5	1	4	2	5	5	2	3	2	2	1	77.5
U12	3	2	4	2	5	3	5	1	5	2	5	5	2	3	2	3	3	80
U13	3	1	5	1	3	3	5	1	5	2	5	5	3	3	2	3	2	82.5
U14	5	1	4	1	5	2	4	2	5	2	5	4	3	4	2	2	2	87.5
U15	4	1	5	1	5	2	5	1	5	2	4	5	4	4	2	3	3	92.5

Table B.1: SUS questionnaire data including calculated SUS- score for each participant.

Answers to "Tror du att AstroVR skulle passa som en del av astronomiundervisningen i skolan?"

User ID	Answer
U01	Det är ett roligt sätt att lära sig på. Det skulle anpassa sig efter vad vi är intresserad av, dvs teknik, spel osv. Det intresserar mig också att lära mig.
U02	Ser bättre visuellt istället för (med) ord. Funkar till de flesta ämnena. Undervisning roligare för ointresserade elever. Enklare att se riktiga skalan som kan vara svår att förstå med siffror. Det skulle varit roligare och lättare att lära sig.
U03	Jag tycker att det med gravitation och hur långt det tar för alla planeter att snurra ett helt (varv) kan vara bra att veta. Jag fick lära mig nya grejer från AstroVR som jag annars inte hade vetat.
U04	Det beror på vem den är menad för. Det som togs upp var ganska enkelt och blir mer en lägre årskurs fakta av astronomiundervisningen. Ifall den ska användas på skolan måste man ha mycket plats för varje elev vilken kan bli problematiskt. Rekommenderar dock den. Var roligt!
U05	Jag tror att det skulle hjälpa en att förstå storleksskillnader och hur snabbt de rör sig.
U06	Jag tror att visualisering, att interagera och testa själv är det enklaste och mest effektiva sättet att lära.
U07	Tydliga instruktioner och man lär sig om gravitation och liknande på ett roligt sätt.
U08	Det är lättare att lära sig i ett testa/pröva-sammanhang.
U09	Ja, det var ett kul sätt att lära sig. Det blev ett avbrott i den vanliga undervisningen. Man kommer ihåg rummen man var i och t ex vad man kunde säga om planeterna. Man kan hänga upp faktan i olika rum, ett bra sätt att lära sig på!
U10	Hade varit bra för (att) t ex förstå gravitationen.
U11	Det skulle vara kul att lära sig
U12	Det är coolt att se planeterna på ett annat sätt.
U14	Man fick en uppfattning på hur rymden funkar t ex hur snabbt ett år på Jorden (är) i jämförelse med Neptunus.

Table B.2: Answers to "Tror du att AstroVR skulle passa som en del av astronomiundervisningen i skolan?"

Answers to "Här kan du med dina egna ord skriva vad du tycker om AstroVR"

User ID	Answer
U01	Det var riktigt roligt. Att få lära sig saker samtidigt som man spelar. Det var coolt också. Det såg sååå verkligt ut. Men lite kritik: Ibland visste jag inte vad jag skulle göra. Det påminde om escape room. Man behöver giss och hitta ledtrådar. T ex att släppa ut det svarta hålet. Sen i början var det lite oklart om jag skulle öppna en dörr och i så fall att jag skulle ta fram den ur marken. Men som sagt, det är riktigt coolt och något jag kan rekommendera.
U02	Intressant hur snabbt VR ha utvecklats. (För) bara några år sedan var det bästa man kunde få (ett) headset man sätter mobil i. Steget närmare att göra virtuell värld. I framtiden man kanske kan göra virtuella sinnen.
U03	Jag tycker att det var ett roligt sätt att lära sig.
U04	Jag tycker att det är ett bra och potensiellt ett väldigt bra och lärorikt spel. Spelet var intressant men jag skulle också gärna vilja se grejer om andra planeter som dvärgplaneter och exoplaneter och om solen. Nånting med våran galax hade också varit spännande. Typ att se hur mycket gravitation vår galax har.
U05	Jag gillar iden väldigt mycket och det var väldigt roligt. Tror det kan vara svårt att skaffa till skilan men kan nog blir en sak som man köper hem. Tack så mycket för att jag fick uppleva detta.
U06	Jag tyckte att det var kul och att man fick veta mer om astronomi.
U07	Jag tror det är ett bra sätt att interagera och känna, för att lära. Fick lite ont i ögonen mot slutet men det är nog oerfarenhet. Speciellt för folk som har svårt att fokusera på t ex texter. Att ha applikationer som denna tror jag kan öka föreståelse för boken. T ex hur långsamt Neptunus roterar i förhållande till Jorden.
U08	Jag tycker att det är ett bra spel med tydliga instruktioner, bra grafik och bra syfte.
U09	Bra design. Lättanvänt. Coolt. Kul.
U10	Väldigt fina rum med roliga uppgifter som att kasta in planeter i svarta hål! Kul att det var lite lekfullt med bra fakta.
U11	Roligt och kul :)
U12	Det verkar kul och spännande.
U13	Mycket cool upplevelse och (jag) tycker man skall göra detta fler gånger.
U14	Jag tyckte att det var jättehäftigt.
U15	Jag tycker det hade varit jättekul att ha det (i) undervisningen. Det funkade bra och assistenten förklarade bra vilket gjorde det enkelt att använda så (att) många kan använda det. Man lärde sig snabbt och det var ett roligt men undervisande spel!

Table B.3: Answer to "Här kan du med dina egna ord skriva vad du tycker om AstroVR".

AppendixC
Report from earlier prototype

SpacEd - Interactive Astronomy Education in a Virtual Environment

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CONTENTS

Abstract—**When studying outer space in elementary or high school there are many concepts even adults have a hard time understanding. The force of gravity, the vast distances and the enormous differences in size are a few examples of this. With the new virtual reality technology being introduced, the possibilities of how to visualize outer space have changed. This report describes the development process of *SpacEd*, an educational game in virtual reality aimed towards children in the ages between 10-12. The goal of *SpacEd* is to help children grasp various complex aspects of outer space and give them a deeper understanding of astronomy.**
Due to the advancement of virtual reality technology during the past years, a new genre of entertainment has emerged. With VR, the user can be immersed in a virtual environment in a way that has not been possible before. Like previous technologies, virtual reality can be used for other purposes than entertainment such as communication, device management and education. Since the target user of *SpacEd* is children, the main goal was to provide a mixture of entertainment and education to keep them interested while they learn. The project is based on Kolb's theory of experiential learning, which is the process of learning by doing or more specific, learning through reflection on doing. This gives the student a deeper understanding on the specific subject compared to just reading a textbook. However, the purpose of *SpacEd* is not to replace traditional astronomy education but rather complement it. *SpacEd* utilizes the high-end VR system HTC Vive, making the user experience as interactive and immersive as possible.
This report begins with a background on the system we chose to use, a more detailed explanation on Kolb's theory and similar, already existing software. This is followed by information on the game's structure, design and the team's method for development. The report ends with results of the design and testing process, and a thorough discussion of different aspects of the project.

I. Introduction

The aim of SpacEd is to give the students of ages 10 to 12 a more hands on experience of outer space. The program has several game modes, that specializes in different aspects of space. There are scenes for gravity, distance, density, size and orbits. When developing SpacEd, one of the main goals was to develop an educational game with strong focus on interaction. It was important that the interaction with planets and other objects in SpacEd came intuitively. In addition, it was important to illustrate the solar system in which both gravity and sizes were as realistic as possible.

II. Background

A. Choice of System

When developing the SpacEd software, the Virutal Reality system *HTC Vive* was used, see Fig. 2. The alternative was to use the main competitor on the market - Occulus Rift. In this project HTC Vive has a few advantages compared to Occulus rift. The primary one is that HTC Vive has been developed to let the user move around while playing. The Vive's tracking system uses 70 sensors to map out the room, up to 5x5 meters. Occulus Rift uses a camera with infrared light to track the user, and is more suited for sitting down or standing still while playing. This made HTC Vive superior to Occulus Rift for this project, since we wanted the user to be able to move around and interact with objects. Also, at the time of this project, Occulus Rift had not released any controllers, forcing the user to use an Xbox controller to interact with the virtual world [1].

B. Experiential learning

Experiential learning is the process of "learning by doing", or more specifically "learning through reflection on doing". David A. Kolb is probably the most prominent spokesperson of this type of education. He developed and described four steps of learning, called Kolb's Learning Cycle [2], as depicted in Fig. 1.

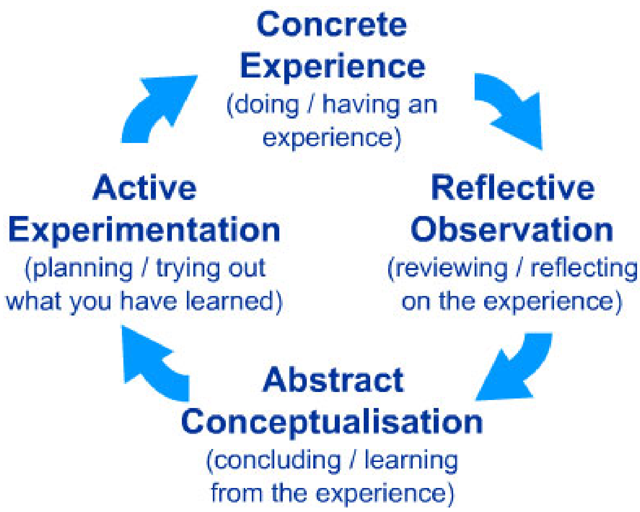

Fig. 1. Kolb's Learning Cycle

In most school systems today, focus is centered on Reflective Observation and Abstract Conceptualisation, while Concrete Experience and Active Experimentation is neglected. This is understandable since experiences and experiments requires a lot more resources than traditional classroom education. Geographical distances can also be an obstacle; it is rarely possible for a school class to visit for example China while learning about its history. This, however, is what makes Virtual Reality a perfect supplement to the classroom. Virtual Reality can give students experiences and move them to places that would never be possible in the real world, giving them the opportunity to use their knowledge in "real" situations. It can also be used to give students a concrete experience on which they can reflect and conceptualize.
SpacEd should be used in combination with regular astronomy education, to cover the steps "Concrete Experience" and/or "Active Experimentation" in Kolb's Learning Cycle. Classes should probably be divided into smaller groups of 3-4 students before using the software. When everyone has played through the game, they can discuss their experiences together with a teacher.

C. Existing Software

Educational tools about the solar system has already been developed. Take *Titans of Space 2.0*[3] as an example. The big difference between this and SpacEd is the target of our audience, as well as the interactive approach. The software available today is basically non-interactive, illustrating the different celestial bodies and stating facts about them. When the target audience is in the ages between 10-12 it is important not to overwhelm them with information and facts about planets, since this would probably make them lose interest. The focus of SpacEd is to make the students understand different aspects of the solar system through playful interaction.

Fig. 2. HTC Vive Head-mounted Display

III. Game Structure

The game is structured with one starting room from where doors lead to other rooms, see Fig. 3. This starting room works as the main menu of the game. To change between scenes the user will open the doors doors and walk through them. Each of the different game rooms contain a door leading back to the main scene.

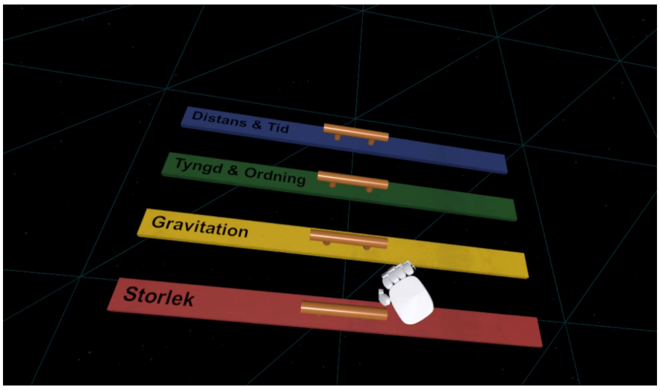

Fig. 3. Starting Room

In addition to the main scene, the game consists of four rooms: The *Ball Room*, the *Moon Thrower Room*, the *Slingshot Room*, as well as the *Solar System Room*. Important to remember is that these are not the names of the rooms that are used in-game but the names used during development. The actual names represent what the user will learn in each room and acts to prime the user for what to look for. The names in the game are:

- Ball Room is named: Storlek
- Moon Thrower Room is named: Gravitation
- Slingshot Room in named: Tyngd & Ordning
- Solar System Room is named: Distans & Tid

A. Ball Room

The primary purpose of the Ball Room (Fig. 4 and Fig. 5) is to illustrate the relative size of the planets in our solar system. In addition to this the user can investigate the planets more closely and listen to various fun facts about the planets.

Fig. 4. Ball Room

In this scene it is possible to pick up, throw, compare and examine the planets of our solar system. It is also possible to retrieve information about the different planets with help of a force field planet holder. When a planet is placed within the force field, a voice will be heard, telling the user fun facts about the planet.

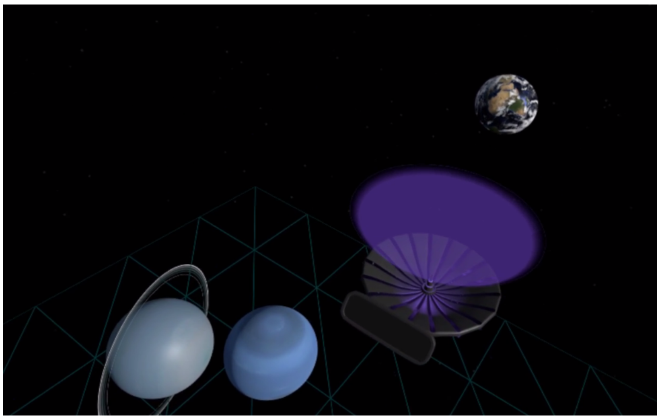

Fig. 5. Planet info holder

B. Moon Thrower Room

The Moon Thrower Room (Fig. 6) is used to get a more hands on experience of how the gravity affects bodies in outer space. This scene consists of the Earth with the Moon in orbit. The player can grab the moon and try to throw it into orbit again. To succeed in this, the angle and force of the throw has to be right. By testing different angles and force, the user can send the moon into different orbits. It is also possible for the user to create new moons allowing the user to study their interaction with each other. This also avoids the situation where the user throws the moon outside of the gameplay area. To help the user achieve a proper orbit, a circle is drawn around the earth corresponding with the moons orbit. This room simulates n-body gravitation between the bodies according to newtons gravitational laws which is the most accurate simulation we can do in real-time and is more than sufficient for our purposes. If the moons in this room collide the moons will explode into several smaller pieces, which also will be affected by gravity. While initially a decorative feature we noticed that the smaller pieces help saturate the area and assist with illustrating the gravitational field.

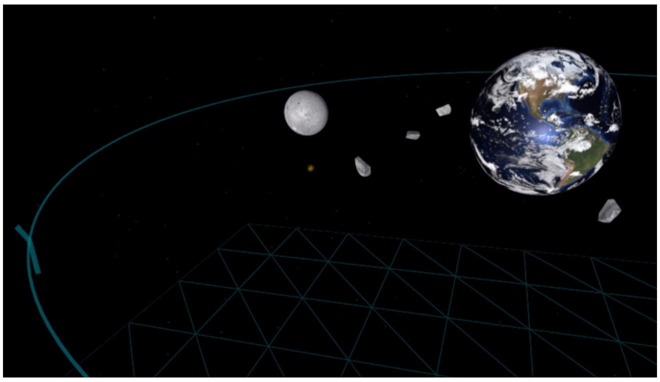

Fig. 6. Moon Thrower Room

C. Slingshot Room

The Slingshot Room (Fig. 7) is used to show the order of the planets in the solar system, as well as the relative weights of the planets. The scene consist of a slingshot, a platform suspended in outer space, as well as a model to spawn the planets that act as the slingshot projectiles. Far away to the left is the sun and to the right of it are targets where the planets are supposed to be. The user's goal is to use the slingshot to shoot every planet into its correct position. If the position is correct the planet will stick to target and the next planet is spawned. When every planet is positioned correctly relative to each other, fireworks will indicate that the room's task is completed.

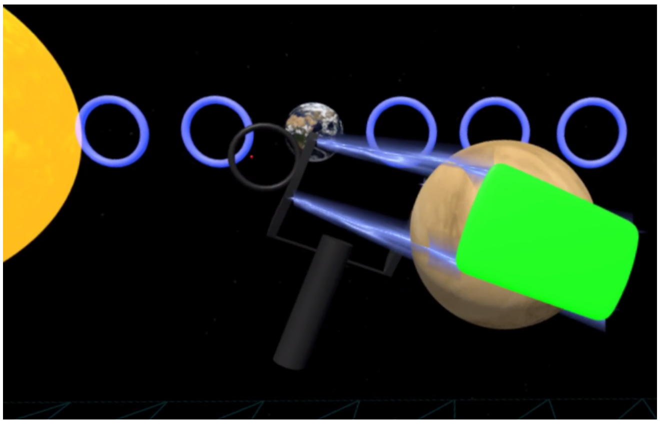

Fig. 7. Slingshot Room

D. Solar System Room

The Solar System Room (Fig. 8) lets the user experience distances, orbits and time differences. With the control panel it is possible to navigate by changing the users position to any of the planets in our solar system. In addition there is one slider to change the size of the solar system and one to set the speed of time. When changing the speed of time, the user will see the planets starting to move in their respective orbits. The user will notice that time will have to move quite fast for some planets to start moving. Neptune, for example, completes an orbit in about 165 years. Therefore, with a speed of one year per second, it would still take Neptune approximately two minutes to orbit the sun.

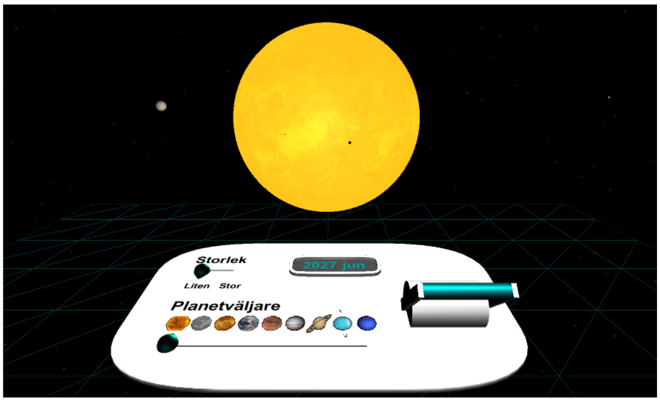

Fig. 8. Solar System Room

IV. Design

The overall design concept was to give the user as little help as possible to understand the tasks. This resulted in a very unadorned game, with few models and no menu system.

A. Interaction Design

The game is meant to be self-explanatory, avoiding menus and tooltips until absolutely needed. Natural mapping is used when possible, for example the use of doors to choose different game modes, as well as using hands instead of controllers.

Fig. 9. Vive Controller

To interact with the virtual world, HTC Vive Controllers are used, see Fig. 9. These can be rendered and shown in-game, looking exactly as they do in reality. In SpacEd cartoon hands are shown instead, see Fig. 10. This is because the mapping to the real world becomes more clear and users understand the interaction better. The change to hands instead of controls were made after the first round of tests, where great confusion arose when using the controls. The controllers have several different buttons, although only one is used in SpacEd. The Trigger Button on the backside of the controller is pressed with the index finger and used for all interaction. When this button is pressed the hand corresponding to that controller will close, as if grabbing.

Before the change to use hands the user could also trigger a tractor beam with a button on the front of the controller. This could be used to pull distant objects towards the user, and was used in the Moon Thrower room. When changing to hands this feature was removed and the user could no longer pull moons from far away, but instead one could spawn new moons to throw into orbit. This feature was removed based on the result from the performed tests. The removal of the tractor beam encouraged users to move around and interact in a more natural way, as opposed to standing still in the middle of the room, trying to interact with objects from a distance.

Fig. 10. Hands

There is no limit on the time a user can spend in each room. The Moon Thrower Room, Ball Room and the Solar System Room has no specific goal. Instead, the user can play around and explore until he or she is satisfied. The Slingshot Room on the other hand has a clear goal: to shoot all the planets into their correct position. When the user is satisfied with a room, a door can be pulled up from the floor. It can then be opened and entered to return to the Starting Room. From there, doors to other rooms can be pulled up and entered.

B. Assets

A positive aspect about working with outer space is the assets available. There is great interest in visualizing the different planets in our solar system and because of this it is easy to find high quality textures and bump maps. Most textures are made from photos taken by NASA and were found on VisibleEarth[4] and NASA[5]. The only planetary body we have had problems with is the Sun. This is due to the lack of high resolution textures and the need for animations to get a realistic representation. The final design of the sun is created with a plain sphere with only the color and a shine to illustrate its appearance, which is good enough for its intention.

Other than the different planets of the solar system, there is only a handful more assets available to interact with in the different scenes. These assets are doors, a slingshot, a model for spawning moons, one for retrieving planets and one for giving information as well as enlarging the current planet. There is also a field for holding planets, which makes them easier to control and compare in the Ball Room, as well as a control panel for controlling time, position and size of the Solar System. The doors could easily be found in Unity Asset store, but the other assets mentioned above are created in either *3DS Max*[1], or directly in *Unity 3D*[2]. Every asset (except the doors) created is designed to fit into the surroundings of outer space, but with a simple design for not drawing any attention away from the purpose of the room.

C. Feedback

In SpacEd the user will receive several different kinds of feedback; auditory, visual and haptic. The feedback will help the user to interact with the game and make the experience as user friendly as possible.

1) Visual: When grabbing and moving objects, the movement of the object must follow the movement of the controls in a way that feels realistic for the user. Different approaches where discussed but we settled for childing the object to the controller.

[1]http://www.autodesk.com/products/3ds-max/overview
[2]https://unity3d.com/

Fig. 11. Highlight

Interactable Objects will be slightly highlighted when touched, as seen in Fig. 11. This is used as a nudge, or indication that this specific object can be grabbed by pressing the trigger button. For example, this is used on the door knobs, the handles to pull the doors from the ground as well as the slingshot. When a user has grabbed one of these objects the hand will disappear and the object will change color to indicate it being grabbed. This is shown in Fig. 12

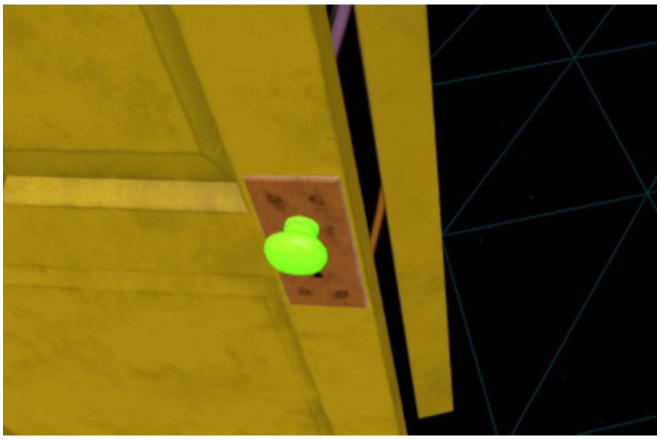

Fig. 12. Highlight 2

Text, instructions or directions are rarely used in the game, mostly because we wanted users to explore and interact in their own way. Although, the names of the planets will appear when they are spawned in one of the game's planet spawn models. We implemented this function because we wanted the user to be able to chose which planet to focus on. When we experimented with displaying the names of all planets it created a strong source of distraction and cluttered up the space with a lot of unwanted information. The user will also retrieve information in text in the Menu Room on the top of the doors. This text will give the users a nudge about what is to be achieved in every room. The Ball Room door says for example ”Size and information”, since learning about these subjects is the goal of the room.

2) Auditive: Auditive feedback is given in many different forms. When the door handles are pulled the user will hear a grinding sound. The doors will give a squeaking sound when opened, as well as a slamming sound if they are being slammed shut. This gives the user a more realistic experience of interacting with doors. In addition there is also a humming sound from the doors when they aren't shut, varying in strength depending on how much the door is opened.
In the Ball Room the user will be given information about the current planet with the help of an ”information disc” which enlarges the planet. When planets are placed here the user will hear a recording with lighthearted information about that particular planet. This is the only spoken information that is given to the user in the project and it's by design entirely optional.
In the slingshot room, auditive feedback will be given when pulling the slingshot backwards to indicate the strength of the pull. When a user hits the correct target, a sound will be played. When wrong target is hit another sound is played to indicate a miss. There is also a spawn sound when new planets or moons are created. At completion of the slingshot room a soundtrack of fireworks is played to enhance the visual experience.
In the solar system room auditive feedback is given when interacting with the different controllers. There is a sliding sound for the size and planet controllers and a ticking sound for the time-leveler.

3) Haptic: The haptic feedback is mostly used as a complement to the auditive feedback and is implemented as vibration in the hand controllers. This feedback is triggered every time a user is pulling objects in the game. For example when a user opens a door he or she will get a feeling of actually pulling an object. The vibration degree is depending on the acceleration of the hand and the mass of the pulled object.

V. Method

The process of development can be split into three different phases. Throughout the whole development an agile approach has been applied. This has given us the advantage of evaluating every decision before moving forward. The three different development phases are the Design, Development and Testing phase, which are executed on a weekly basis, except two greater test phases in the later half or the project.
To keep track of what was to be done each week and who was responsible for doing it, the SPM-tool *Trello*[6] was used. *Facebook Instant Messenger*[7] has been used for general communication, and *Slack*[8] regarding specific development aspects.

A. Design process

Every decision concerning the design of the game has been discussed in this phase. It has been done either with the whole project group, or in smaller sub-groups. Early in the project the team gathered to perform three more thorough sessions of both brainstorming and body-storming. A schedule of weekly session were later decided as a tool for evaluation and moving forward in the design process. When the project had reached a more mature phase two greater test phases was performed to make sure the project was on the right track.

1) Brainstorming: When performing brainstorming sessions, it was important not to discard ideas immediately. In the early sessions the structure of the game were the main objective and later on the interaction design as well as objects became the focus of interest. The main purpose of these sessions was to come up with several different ideas for the project as well as an overall theme of the game. These brainstorming sessions resulted in many different ideas of how to build this game and what to include.
Throughout the project the weekly brainstorming session of the group merged into becoming a more body-storming focused session where the project group itself evaluated and tested the work of other team members.

2) Body-storming: Because of the advantages of body-storming, this approach was used very often in the process of developing the game. In the first sessions the focus became the most basic interaction with the virtual environment. In the later sessions more advanced interaction were discussed and evaluated with the help of simple mid-fi prototypes implemented in *Unity*.

3) Design phase: After the brainstorming sessions it was time to narrow down the concept of the game and decide which ideas to include in the final product. The brainstorming sessions had produced both ideas of the different aspects to educate the users, as well as how to do it. It had also produced different ideas on narratives. In the design phase all these different ideas were narrowed down to only a handful of scenes and aspects to develop. The narrative was a great focus in the early phase of the development, but because of the great focus on developing a game where the interaction was as intuitive as possible, the narrative became less necessary for the user experience and was finally extracted from the project.

B. Development

When the design phase of the game ended, a development phase started where different prototypes were being developed from low fidelity (lo-fi) to high fidelity (hi-fi) in *Unity*. In the design phase the different scenes were ordered after importance, which made it easy to decide in which order the different scenes were to be developed. The development phase consist of mostly working with *Unity* for developing the different scenes as well as developing the belonging scripts in *Java Script*. It also consist of designing the different objects in the scenes, using *3DS Max* and *Blender*[9]. In the process of developing, the prototypes were constantly evaluated and improved.
One great advantage of working with *HTC Vive* is how creating prototypes in *Unity*, and immediately evaluate it in the virtual world, is done with ease.

C. Testing

The testing have been done on a weekly basis with the project group, as well as two greater test phases with external test subjects. When testing with the project group the focus was more on the design and interaction, instead of the user experience. This because it is hard to imagine the result of how an actual user would react. Both the test phases were performed on mostly students, since they were easier to retrieve.
The main focus of the testing was to see if the users understood the affordance and how they interacted with objects in the game, as well as what help the users would need to manage through the game. Another aspect was to evaluate what the user felt to be missing in the game. When gathering information from the user a *"think aloud"* method was applied. A test-plan was created, see the Appendix.
The final test phase was used to see if the implementations done after the previous greater test phase solved the problems seen. It was performed in a agile approach where the feedback from every tester was shortly discussed and immediate changes were performed between the tests.

VI. Result

In this section the different results of the project will be presented.

A. Design Result

The design result consist of the result of the different brainstorming and bodystorming sessions, described below.

1) Brainstorming: First it was discussed which features should be included in the game and how this could be done. Gravity, time, position, size, distance, density and orbits were the first ideas. This lead to the idea of throwing planets in outer space, as well as being able to place the planets in outer space and see what happens when gravity is turned on. Another idea was to have the celestial bodies in relative size to each other, as well as the idea to show the time/distance by "turning on the sun" and see how long it takes before the light reaches Earth. We also had the idea to show the relative distance and order from the sun by throwing the planets on different targets.
It soon became obvious that there was a need for several scenes to show all the different aspects and ideas, especially considering the limited room size in VR. With this realization

in mind, the team decided to have a starting scene that replaces a main menu. In virtual reality, menu systems are hard to use, since the user is moving around. For a menu to be easy to use, it must be in the same place at all times. If it were to follow the user, it would get in they way and need a button to hide it. To increase affordance, it was decided to use a mapping from real life: doors. If doors were to be used as the main entry and exit solution an actual menu would not be needed. Because of the mapping to doors, the scenes were to be called rooms.

The educational aspects were to be separated into several different rooms. The rooms were (all working names): *"Ball Room"* for showing relative size and detailed textures, *"Solar System"* where the user can see the solar system from the different planets positions and see the difference in orbits and time, a *"Slingshot"*, visualizing the order of the planets in our solar system, as well as their relative weights. The last room, with working gravity, was called *"Moon Thrower"*, where one could throw out moons and see how gravity pulled them towards the Earth as well as one another. The Moon Thrower would visualize both gravity, as well as how and why orbits works the way they do. The idea of "turning on the sun" should be implemented early in the game and the user would get information 8 minutes later that the light had now reached the Earth. This idea was set aside early and was ultimatley discarded.

Early in the development process every team member tried out different games available for *HTC Vive*. This created the idea of using tools in the game. Tools for changing gravity, creating new planets with size and weight, a magnifying glass to show information about the celestial bodies and a tractor beam. These different tools would be accessed through a toolbox, or a wall with tools. It was discussed if the toolbox would always be in the room or appear at the press of a button. Because of the desire to use as few buttons as possible while keeping the amount of clutter at a minimum, this became a great topic of discussion. This was also evaluated in the body-storming session and a prototype of the toolbox was created. If this toolbox were to be used, the doors would also be included in it to teach the users how to use it early. Later in the development process, it became evident that tools was an unnecessary function, since all interaction could be done with the basic hands. This also made the game more streamlined and less complicated.

The rooms were arranged in order of importance for development. This resulted in high priority for the *Starting Room*, *Moon Thrower* and the *Ball Room* and a lower priority on the *Slingshot* room and development was halted on the *Solar System* room. The tools were also planned to eventually be used mostly in the *Solar System*, which led to a full stop on developing tools.

In the *Starting Room*, the user had to be able to move forward to four different rooms. This meant having four different doors in the scene for the user to walk through. When trying out other games every team member agreed on that the ability to teleport in the scene should be avoided. For the Starting Room we quickly realized that placing three doors in one scene would lead to the room feeling crowded. Another issue is the positioning of the door in the scene. If the user walked through one door in the far end of the Starting Room the user would start the next scene in the far end instead of in the middle as desired. This issue were to be solved later on in the process after both body-storming and several weekly brainstorming sessions. This resulted in the doors being placed in the middle of the room, but hidden underneath the floor. The user could pull the desired door up from the floor, then open it and enter the desired room.

In the *Moon Thrower* room it was decided to keep the focus simple and only have the earth as well as several moons to interact with. Since the Earth and Moon are much more relatable for the students this would give them a better chance to understand how orbits and gravity actually works. To include a tractor beam in this room felt very natural since the moons could easily disappear out of reach from the user. This tractor beam was later removed from the scene (and later from the game altogether), mostly because of the change to hands instead of controls The switch took time mostly due to the difficulty of compensating for it's removal in this room. Instead a model for spawning new moons was introduced, which made it possible to spawn a new moon if the previous disappeared out of the users reach.

The *Ball Room* was also kept simple since this rooms main goal is to visualize the relative sizes as well as give the user a chance to study the planets closer. The users are also given a chance to retrieve information about the different planets.

When discussing the narrative for the game it became clear that this had to be dealt with later when the game is more developed. The ideas that came up were often related to aliens or Star Trek where the user would either be an alien rebuilding the solar system, or a humanoid investigating outer space. This was finally decided to be scratched at the moment, and the full focus was aimed at developing a intuitive game where the user understood how to interact with its surroundings.

a) Bodystorming: When evaluating the user experience of the Starting Room the team realized that it was not possible to have all the doors both visible and within reach of the user at the same time. The scene felt too crowded and placed the user towards the edges when entering a new scene. Different solutions to this problem emerged from the body-storming session. One idea was to position the doors inside the toolbox and transform them to real size when chosen. Another idea was to position the doors far away from the users and make it possible to use the tractor beam to pull the doors toward them. The final idea was for the user to pull the doors out of the ground with the help of a handle. This method was later implemented and chosen as the final design since the others all introduced new problems.

Due to the fact that the concept of a toolbox was discarded, the controls only needed one usable buttons each for all the intended interactions. As a result of this, the game became easier to play, which lead to the final decision that the game should focus on students of the age 10-12.

B. Testing Result

Throughout the project two rounds of tests were carried out. In all the tests a ”think-aloud” technique were applied, where the test objects were encouraged to mention everything they thought about, as well as what they assumed was the purpose. These tests were performed by adults with different degrees of technical background. The only information given in advanced was that this was a educational tool for children in the age of 10-12 focusing on giving the users an understanding of our solar system. Because of the aim to test how user friendly the game was it was made sure that all the test objects were not used to interacting in a virtual world. The result from these two are summarized here.

1) Test Phase One: In this first round of tests the main focus was to see if the test subjects were able to understand the purpose of every room, as well as the interaction in the game. Three thorough tests were made, where the test subjects got the instruction to interact in the game and mention everything they thought about. Every test subject played the game for approximately 30 minutes. After this both the test leader and the test subject discussed the outcome of the test to understand the reason behind the different difficulties experienced. The most important result of these three tests are summarized in this list:

- Every test subject had problem with pulling the doors from the ground. In this stage, the controllers were still used, and the test subjects did not move around in the game, but instead tried different combinations on the controls to pull the handle. It took several minutes, together with a nudge from the testers to bend down and grab the handles.
- The test objects often start with the Slingshot Room, which resulted in some confusion later on. This was because of the lack of a concrete goal in the other rooms, whereas the goal of positioning every planet at its rightful position resulted in a clear end of the room when this is fulfilled.
- The tractor beam could be used, but did not affect most objects. This caused great confusion for the test subjects.
- Because of the height difference between the test subjects it became a problem to handle the doors, since they have to be grabbed on the top to pull it back down.
- To walk through the doors made the test object uncomfortable, mostly because of the uncertainty of whats to come, as well as the transition behind the doors was a bit too frantic, without enough depth.
- The purpose of the different rooms was easy to understand, except the Slingshot Room. It took a while before the test objects understood the purpose of the target rings, and that these are positioned in the order of the planets. The realization that the planets had different weights was also hard to understand. Many test subjects believed that the trajectories had something to do with the distance to the targets.
- In the Moon Thrower Room, the moon was quite easy to throw out of reach. In this stage it was not possible to spawn new moons, which resulted in frustration from the test subject.
- To throw the Moon into orbit around the Earth proved to be quite hard, mostly because of the lack of help on how to perform a decent throw with the right angle and force.
- The Ball Room needs more information available, for example the names of the different planets and maybe more facts about them.
- The indication of where the user held the planet the previous time became confusing. The test subjects thought that it was an indication of where they should hold the planet.

After completing this round of tests several design decisions were made and implemented. It was these changes that were to be tested in the next test phase. The greatest changes was the change of controllers to hands, as well as changing the big slingshot to a hand-held slingshot. The names of the doors were changed to their respective educational goal. To increase the user experience the transition between the rooms was designed to give the impression of a greater depth behind the doors. Several models were also introduced, both to spawn planets and moons, but also to enlarge a planet and give information about it. The tractor beam was removed, as well as the memory indication in the slingshot room. Also, one more room was introduced, the Solar System Room, which was in great focus in the next test phase. Several other, smaller design changes was done as well, mostly to reduce the number of bugs in the system.

2) Test Phase Two: In this second round of tests the main aim was to see how the changes done had affected the user experience and the interaction in the game. This time eight tests were realized, also on adults. After retrieving the result of every test the developers tried to solve the problems found, which resulted in a more agile approach in this phase. The most important results from this test phase are summarized in this list:

- None of the test subjects now had a problem with reaching for the handles on the doors and pulling them up. The difference here being hands instead of controllers.
- Several test subjects had a hard time to find the red dot sight on the slingshot. When using it, most of the users had an easier time to hit the different targets.
- After the change of names on the doors, (for example ”Gravity” instead of ”Moon Thrower”) the user found it easier to understand the purpose of the room.
- The users still couldn’t understand why the heavier planets was harder to shoot. The reason for this is most likely because it needs to be visualized more distinctively. This would also be solved if the users have knowledge about the planets masses before playing the game, which would be the case with middle school students using SpacEd as

a part of astronomy education.

- With the rotating ring around the earth in the Moon thrower room, the test objects had a greater understanding on how to throw the moons to create an orbit around the Earth.
- The Solar System room was hard to understand in in several ways. The test subjects could also be placed inside the Sun, which resulted in confusion.
- In Moon Thrower the moons could easily get stuck on Earth and were hard to reach if they got thrown too far away.

Altogether this test round indicated that the changes made to the game gave a better user experience, and made the game easier to interact with, without any nudges given from us. After this test phase the greatest changes made are the transition between rooms, together with making the moons explode when colliding in the Moon Thrower room. Through these design changes the basic version of the game was done, and only minor changes and bugs remained to be fixed.

VII. Discussion

A. Design

With the educational goals in mind (gravity, time, distance, size, density and orbits) it became evident that the game needed different scenes to illustrate these aspects.

When designing the game it was soon decided that the interaction with game objects must be restricted to only the usage of the most affordable buttons. As seen in Fig. 9, the pressable button on the backside of the controls is the most affordable button using the index finger, but also the round area on the top side is easily reached using the thumb. After several brainstorming and body-storming sessions it was decided to use the backside button for interacting with the celestial bodies in the game (grabbing, throwing) and the front clickable area for the tractor beam. When changing from controllers to hands this feature was removed the only button that remained in use was the trigger button. Due to the simple control scheme the user no longer need any introduction or further explanation on how to interact in the game and can get started immediately to learn how to interact with its surroundings.

The change to hands was something that was discussed in the group at an early stage, but decided against because of how realistic the mapping to the original HTC Vive controls were. After the first rounds of tests it was clear that this did not work as intended. The users had a hard time understanding how to interact with its surrounding and wanted to use the controllers in a way similar to controllers in other, non VR games. This is understandable as controllers are generally devices that interact in an abstract way with the in-game world. This lead to users wanting to grab objects from far away and did not understand that the controls were ones hands in the game. When changing this mapping to actual hands every user immediately grabbed different objects with their own hands in the game.

Early in the brainstorming process it was discussed if the end user of the game should be students in the age 10-15. With the ages 13-15 included, the interaction would need to be more complex to be able to illustrate the more complex physics taught at those ages. With this in mind the game was supposed to include a menu or a toolbox. Since the menu/toolbox was hard to include in the controllers and also due to the lack of scene space it could not easily be included in the game. During development the choice was made to reduce the target audience to children in the age 10-12, which resulted in a simpler interaction scheme without the toolbox. This decision was one example of how this project was narrowed down from the original idea and where a narrower scope allowed for better, more focused interaction.

It was important that the movement between the rooms became as intuitive as possible. Because of the lack of a menu, this movement had to be implemented in the scene without becoming a distraction. Looking at already existing games for *HTC Vive*, we concluded that most games use an object that the user can use with the help of the controllers. This was one option, but when evaluating these games this was not as intuitive as one could hope. Due to the mapping to real life, using doors to move between rooms became the solution we deemed best. Now these doors exist in every room throughout the game, hidden below the floor. To use the door the user need to pull them up. It is a consistent solution that will be taught from the very first room and reused in every room. It also has the upside of being similar in look and feel to kitchen cupboards and that the user is taught to move around in the game.

B. Tests

In the first session of testing the most difficult task was to make the users understand how to use the controllers. It took several minutes before they understood that the controllers were supposed to be used as hands. Before this we had decided on using the controllers because of how realistic they were in the game, but because of this drawback it was decided to change to hands. This was tested in the next test phase, and the result was quite obvious. The users understood immediately how to grab different objects without any information from us, which greatly increased the user experience.

Another aspect which could result in confusion was to understand what to do in the different rooms. If a user started with the Slingshot room, which have a specific goal, they easily became confused when entering the other rooms where the purpose is to explore. During test phase the rooms were named after their working names (Slingshot Room, Ball Room etc.). Because of this almost every test subject wanted to try the Slingshot first, which gave them the wrong impression that every room had its own goal. When changing

the names it was not as obvious that a user wanted to try the ”order and weight” room and the problem disappeared slightly. By also placing the door for the slingshot room toward the middle and making it an uninteresting color we reduced this even further. This change of name also suggested that weight was something to take into account in the slingshot room.
The removal of the tractor beam had several reasons. Mostly it was hard to introduce later in the game without the use of explaining text, and finally we came up with different ways to make sure the game was possible to play without it (implementing a model for spawning new moons, as well as the destruction of the moons if they are colliding with the earth, which removed the need to remove the moons from it.) When the need of a tractor beam was removed there was no need to keep it. This also encouraged the user to move around the rooms instead of standing in the middle, trying to pull objects towards them.
Several test subjects did not understand what they were supposed to achieve in the Slingshot room and could not see that the targets represented planets. To improve this the Earth was placed in its correct position, to give the user an idea of what the circles represented. This reduced the confusion and hopefully solved the problem.

The tests overall gave some great ideas on how to improve the game. With these in mind the game was finalized and released as the final product of this project.

C. Educational Aspects

The object of this project has been to develop a complimentary tool for usage in school education to get a more hands-on experience on the aspects of outer space. Important to remember is the so called ”Doorway effect” [10]. This is the concept of forgetting things when entering a new environment. If one is to teach students facts about our solar system this will most likely not benefit from using a Virtual environment, because the environment itself will influence the student to remember the facts more accurate in the game and not outside. This is why the aim of our project is not to make students learn facts, but to use it as a complement to the classroom, giving the students a deeper understanding of how the different aspects of our solar system and universe works.

When looking at Kolbs experiential learning cycle one can argue that SpacEd will be used to give this hands-on experience to the students. This is our aim, but not properly tested. To use Virtual Realities for an educational purpose is a quite new subject for research, but unfortunately not evaluated in this project. The reason for this is the limited amount of time for the project, where the project group was united in the argument that a learning tool in VR must be properly developed before being used for this purpose. This is the reason why the game has been developed and evaluated to this extent, to make sure the usability and affordance is good enough for the game to be evaluated in its educational approach.

D. Brainstorming

We wanted to extract every possible idea from each other, which made the brainstorming-session fun and produced a lot of results. For each different concept, we discussed how it could be realized, what functions it could have, how it could be tweaked and so on. Every member of the team was engaged and didn’t hesitate to present their different ideas concerning the functions and layout of the game.

E. Bodystorming

The body-storming sessions were performed since the project group realized early on that it was hard to discuss both the Starting Room and the appearance of the tools without actually trying it out. We also needed to figure out the most favorable way for the player to interact with other game objects such as the slingshot. To properly illustrate and teach gravity it is important to implement the forces in a realistic way. Therefore, a script was made that uses Newton’s law of universal gravitation. The script applies force to the rigidbodies that Unity uses for it’s physics engine. This does not take expansion of space into account and is therefore not entirely realistic, however, it’s still exact enough for our purposes.

F. Group Dynamics

To improve the group dynamics, the team went out a couple of times for lunch and beer (”Öl-lunch”). The focus was on getting to know each other on a personal level. We openly discussed our previous experiences with group projects and the expectations of the project. To get a better picture of how we work in a group, we also talked about our different strengths and weaknesses as project members. In an effort to prevent any future quarrels we also talked about typical behavior of other team members that we don’t appreciate, such as being late to meetings. We decided that we would use a warning system, in which team members who behaves in a bad way or doesn’t contribute to the project would be warned as a first step. If the member misbehaves again, he or she will be reported to the mentor. This system proved to be effective as an deterrence, since no warning was delivered. To provide a clear picture of how much the different members worked on the project, a time reporting sheet was created and shared on Google Drive. Throughout the project, it became easier and more fun to work together since we got to know each other better.

G. Future work

The most obvious work to proceed with is starting testing on the actual users, both to increase the user experience, but also to evaluate if this game can be a complement to the classroom studies. Furthermore there are a number of things that would be a good idea to implement in the rooms.

- Room independent improvements - Short voice introduction in every room about the purpose of the room to make the game more self explanatory. At the moment the test leaders are able to help the test objects with spoken guidance during interaction in case the designed mappings and affordances aren't enough to guide the user. This is something that we want to minimize and instead build into the system.

- Ball Room - Give the user more information on what the purpose of the room is and how they use the different functions in the room, like the planet info holder. Record the "fun fact voice" in a professional studio. Implement a function that reveals what materials the different planets consists of, possibly splitting the planets with a cross section in the planet info holder.

- Moon Thrower - Guide users on how to throw the moons. Generally users have a hard time realizing in which angle they need to throw the moon to achieve a proper orbit. As this point they usually throw the moon directly at the earth leading to a crash or non orbit. The current guiding ring has some problems with affordance and could be re-designed. Add additional feedback like sound for explosions and vibration when destroying moons with the fist.

- Slingshot - Make it more clear where the planets hits the wall that exists behind the targets to help the user properly adjust his or her aim for the next shot. Implement a function to reset the room to its initial state. Highlight the slingshot with visual and auditive feedback to encourage the user to pick it up. Add various levels of difficulty. Show the planets masses on a display.

- Solar System Gravity - Today users can't look at the controls and planets at the same time. Possible solutions could be to add a handle to the panel to make it mobile. Another one to tweak the angle of the panel to let the user see what happens when they interact with the sliders and levers. In addition to this, implement some way to see the names of the planets as well as visually draw their orbits. Create more guidance about how to set the panel.

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Testplan Planetbuilder

Syfte

Planetbuilder är ett inlärningsverktyg för mellanstadieelever där målet är att få en mer konkret känsla för solsystemet. Syftet med denna studie är att få feedback på hur bra interaktionen i spelet är.

Frågeställningar

#0.1. Är information och feedback tillräcklig?
#0.2. Förstår man vad rummen är till för?

#1.1. Förstår man hur man tar sig till en annan scen från startrummet?
#1.2. Är det intuitivt att dra upp och öppna dörrar?
#1.3. Förstår man hur man tar sig tillbaka till startrummet?

#2.1. Förstår man hur man interagerar med planeterna?
#2.2. Förstår man hur man får tillbaka borttappade planeter?

#3.1. Är tractorbeamen intuitiv att använda?
#3.2. Hur känns det att kasta månar?
#3.3. Är informationen väsentlig/hjälpsam (angående hur man får fram planeter)?

#4.1. Förstår man hur man använder slangbellan?
#4.2. Är det lätt att förstå hur man lyckas/målet med rummet?

Fråga:	Kommentarer:
#0.1	
#0.2	
#1.1	
#1.2	
#1.3	
#2.1	
#2.2	
#3.1	
#3.2	
#3.3	
#4.1	
#4.2	

Testuppgifter

Uppgift:	Underuppgifter:	Korrekt slutförd när..	Maxtid
#1. Ta dig till bollrummet.	Dra upp dörren till bollrummet och öppna den. Gå igenom dörren.	FP står i bollrummet.	
#2 Lek runt i bollrummet.	Lyft, kasta, osv.	FP är nöjd.	
#3 Ta dig tillbaka till startrummet.	Dra upp dörren. Öppna den. Gå igenom den.	FP är i startrummet.	
#4 Ta dig till planetthrowerrummet.	Dra upp dörren till planetthrower och öppna den. Gå igenom dörren	FP står i planetthrowerrummet.	
#5 Försök kasta månen i omloppsbana kring jorden.	Greppa med triggern. Kasta månen med rätt kraft och vinkel.	FP är nöjd.	
#6 Kasta bort måne	Greppa en måne med triggern. Kasta och släpp triggern.	En måne är på väg bort från FP och vederbörande kan inte nå den.	
#7 dra till dig måne med tractorbeam	Sikta på en måne och tryck på “plattan”. Håll in tills månen fastnar eller är tillräckligt nära för att greppa med triggern.	Månen sitter fast i kontrollen.	
#8 skapa nya månar	Tryck på knappen för att skapa månar.	En ny måne har skapats.	
#9 Ta dig tillbaka till startrummet.	Dra upp dörren. Öppna den. Gå igenom den.	FP är i startrummet.	
#10 Ta dig till slangbellerummet.	Dra upp dörren till slangbellerummet och öppna den. Gå igenom dörren	FP är i slangbellerummet	

#11 Skjut iväg planeter och klara banan.	Plocka upp en planet. Placera den i slangbellan. Dra i slangbellan och sikta. Släpp slangbellan. Repetera tills färdig.	Alla planeter sitter på sina rätta platser.	
#12 Ta dig tillbaka till startrummet.	Dra upp dörren. Öppna den. Gå igenom den.	FP är i startrummet.	

Intervjufrågor

- Förstår man vad rummen är till för?
- Vilken typ av feedback skulle du vilja ha?
- Hur upplevdes systemet med dörrar?
- Hur kändes det att använda knapparna på kontrollen?
- Hur var det att använda slangbellan?
- Förstår man hur man återvänder till startrummet?
- Hur kändes det att kasta månar?
- Vad är den övergripande känslan för programmet?
- Känns tractorbeamen naturlig att använda?
- Övriga synpunkter?