Tsuboniwa: A Garden Dream

An Audio-Visual Virtual Reality Experience

A Major Qualifying Report
submitted to the faculty of the
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science

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Date: 01/27/2022

Abstract

Virtual reality (VR) is a new and emerging technology with a multitude of uses ranging from the gaming industry to medical usage. In this project, we create an immersive audio-visual experience that is planned to be showcased in an art exhibition with the support and guidance of Kyoto VR and Atticus Sims. We used sound sets from partnering musical composers with spatial audio implementations. We created a mixture of software used throughout the project, consisting of original scripts, assets from Mr. Sims, and packages utilized and altered to fit our needs. The development and implementation of scripts used programming in C#. We aimed to create a strong alpha build of the first stages of the experience to support Mr. Sims' artistic vision and to provide support and resources that would allow for easy alterations and accessible and understandable software.

Acknowledgements

We would like to take the time to acknowledge the many students, faculty, and sponsors that assisted us throughout the term.

Firstly, we would like to thank our sponsor, Atticus Sims of Kyoto VR. Mr. Sims is the creative mind behind *A Garden Dream* and its components, and his support and feedback throughout this project allowed us to create an end product that we are proud to present to him at the end of this term. We would also like to extend our gratitude to Samuel Andre and Christopher Fryman for their contributions to the musical elements of this project.

Next, we would like to extend our deepest gratitude to John Frazia and Laurie Mazza for their contributions to this project. John's experience with and passion for audio design in games helped us to tackle the musical components of this project and taught us a lot about a subject we originally had little knowledge of. His work in implementing binaural beats and in creating and refining the audio system for the moths contributed largely to the audio design of *A Garden Dream*. Laurie's guidance and knowledge of virtual reality was crucial in helping us get comfortable using Unity and assisted this project through to completion. Her experience in technical art helped bring the visual components of *A Garden Dream* to realization and her assistance in troubleshooting Unity saved us many hours of debugging.

We would like to recognize the assistance of Ellen Lincourt and the Academic Technology center for their help in acquiring an Oculus Rift S, and Jeremiah Valero Araujo and the rest of the Global Lab staff for providing us with lab space and a PC to use.

Many thanks to Ruth McKeogh from the WPI IRB for all of her knowledge and assistance during the planning phase of our playtesting. We also extend warm gratitude to all of our lovely student playtesters.

Finally, the completion of this project would not have been possible without our advisors Professors Jennifer deWinter and Charles Roberts. Their guidance and advice were crucial to our success this term and we cannot thank them enough.

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1.0 - Introduction

Tsuboniwa: A Garden Dream takes its name from the small gardens that occupy the spaces between buildings in many Japanese towns and cities. These courtyard gardens often contain only a few carefully arranged elements and bring nature to an otherwise man-made environment (Keane, 2016). Our sponsor, Atticus Sims, describes his tsuboniwa (see Figure 1.1) as "the soul of my house, and in a way, [...] my soul as well". Both the physical and spiritual representations of the garden inspire his vision for this virtual reality experience, which informed our development throughout the term.

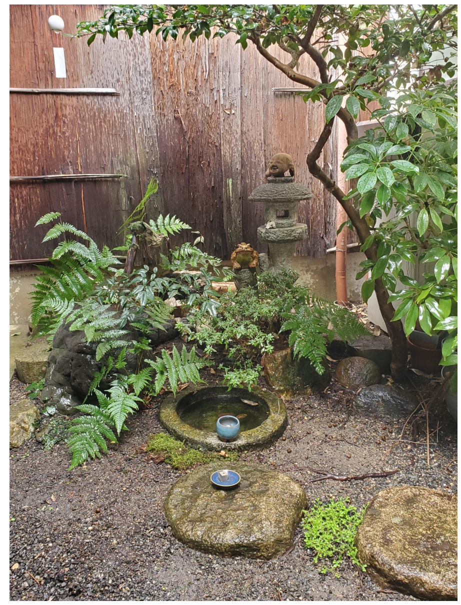

Figure 1.1: Garden of Atticus Sims

With the help of our sponsor *Kyoto VR* and the creative vision of Atticus Sims, our development this past term consisted of creating a working prototype for the first stages of a virtual reality experience incorporating interactive elements and spatial audio components. During development, we took into consideration that Mr. Sims will display the final experience in an art exhibition intended for museum goers and those with artistic interest. Sims provided artistic guidance and supporting material that explained the elements of the experience and how each phase should appear. Our design goals consisted of creating three interactive scenes, called Abyss, Earth, and Ground, to serve as prototypes for the final art installation.

In the first scene, the user is in a pitch black abyss, which is one large room, with the user being able to walk around using the joystick on the controllers. While the final specification includes plans for the user to physically walk around the space, we decided to adjust this capability in our prototype due to the limited space in our playtesting area. There is an audio file of binaural beats associated with each quarter of the room, allowing the user to hear up to two audio files at a time depending on their position in the space. Following this, the user experiences the next scene, where they are introduced to a light that attracts a flock of moths. The moths eventually interact and are controlled by the user's right hand movement. Due to time limitations, we were only able to briefly introduce the third phase of mycelium, which quickly transitions to the floor of the user's experience. The final prototype underwent user testing, where we were able to gather data and make minor adjustments based on collected feedback. The following contents of the paper provide further explanations of the technical components utilized in development, design components, playtesting results, communication in documentation, and a postmortem.

The usage of virtual reality (VR) in this project allows us to observe how new technology is constantly changing and being reimagined, and there is no surprise new art forms can come in the medium of VR. Historic uses of VR include the Information Communication Technology industry, consisting of software and operating systems, web-based information, telephones, and instructional software. (Idaho ATP, n.d.) However, in recent years, it has grown to be more popular in the education and entertainment industries. (Daniela, L., & Aierken, Y., 2020) VR uses technology and devices to create an immersive digitization of images. In some cases, users are provided with a headset that alters their perception of what is being physically presented to them. (González-Zamar, M. D., & Abad-Segura, E., 2020) It has individuals surrounded by a three-dimensional computer-generated representation. They are able to move around in the virtual world and interact with it from different angles. VR provides a real-time viewer-centered head-tracking perspective with a large angle of view, interactive control, and binocular display.

(Cruz-Neira, Sandin, & DeFanti, 1993) It fully immerses the users' vision into a virtual world and provides a sense of personalized audio to maintain the simulation of a separate world. When experiencing this environment, users are fully immersed in the artificially created space and are normally unaware about what is around themselves in real time. (González-Zamar, M. D., & Abad-Segura, E., 2020)

With various kinds of experiences that users can interact with, the scientific community is working to increase public engagement with virtual reality. Recently, scientists created a VR experience at an astrophysics festival. (Kersting, M., Steier, R., & Venville, G., 2021) This was aimed to improve public outreach of scientific communities that undertake evidence based investigations. They were able to propose four aspects of participant activity, immersion, facilitation, collaboration, and visualization. (Kersting, M., Steier, R., & Venville, G., 2021) The study found that VR enabled the visitors to interact and understand science in easily understandable and more diverse ways. These experiences allowed the visitors to understand its complexity, while still being usable and dynamic. Understanding these dynamics and learning how VR technology impacts public outreach, we have decided to develop a virtual reality experience of our own for an art installation.

In this project, we use VR to create the foundational elements of the first three stages of the experience. One of the largest technical components of these elements consists of a flocking algorithm. The flocking algorithm is a simulation of how animals self organize into large groups effortlessly. It is an elaboration of a particle system, with the simulated animals being the particles. The combined motion of the simulated flock is created by a distributed behavioral model like a natural flock. (Reynolds, 1987) The flocking simulation is created by the coordinated motion of groups or flocks of entities called boids. The flocking represents group behavior, and in this project we worked specifically to adjust and create a behavior that fit our sponsor's vision and met his needs. These behaviors include how often a boid will spawn, the pattern in its movement throughout the space it is traveling in, how the flock groups together, and where the flock travels to. In order to implement these behaviors, we used open source software from various GitHub repositories, and followed YouTube tutorials. In order to get an implementation that matched Mr. Sims' artistic vision, a variety of different tutorials were observed and utilized to create a modifiable version.

In programming, open source software and the ability to use and manipulate code to fit the needs of the project prevents programmers from rewriting code that is already written to ensure they dedicate their time to writing code that isn't written. (Dey, T., Karnauch, A., & Mockus, A, May 2021) With Unity being a platform with a large community of developers, there are packages with endless functionalities at one's fingertips. In order to maximize our limited time of only having seven weeks to complete the project, we decided that incorporating a purchased Unity package containing multiple boid behaviors enabled us to ensure an implementation approved by our sponsor. While our original implementation was not used, our understanding and implementation of the package was streamlined due to our understanding of flocking algorithms from our previous development work.

Throughout the development of this project, we had to undergo many phases within a span of seven weeks. This included going through different iterations of programming to ensure all additional elements were compatible with each other, playtesting, and debugging. Developing this prototype allowed us to be introduced to Unity and navigate learning fundamental aspects of VR development such as creating GameObjects, understanding different pipelines, creating and manipulating components, among other aspects that are discussed throughout this paper. As we pass off this project to Mr. Sims to continue further development, we look forward to seeing the final rendition of the project once it becomes open to the public at a local art museum in Kyoto, Japan.

2.0 - Design and Development

The final goal of this project is for the experience to be displayed at an art museum in Kyoto, Japan. With implementations of musical elements, the user should be exposed to a zen experience that is relaxing and calming. The musical element in the project is to compliment the user's interactions as they move around in the space. Additionally, the user is only able to walk around the space which is limited to a room, and can only interact with elements by guiding them, not by interfering or colliding with anything. The design of the project is largely influenced by the request of Mr. Sims, who provided us with materials that supported his vision and expectations of the project. We were able to work with two musical composers, Samuel Andre and Christopher Fryman. Additionally, Mr. Sims provided assets for us to use to create objects within the space.

2.1- Virtual Reality Implementation

2.1.1 - Development Platform

To develop this project, we used Unity version 2020.3.22f1 and an Oculus Rift S, which required a large learning curve for both team members as it was the first time either of us developed a VR experience. Unity is a multi-scripting language, utilizing C#. Throughout the development process, there was a large combination between finding documentation of how to use different features, understanding what different GameObjects were, how different components interacted with each other on a GameObject, and how different scripts work together. In Unity, we also have the project in High Definition Rendering Pipeline (HDRP), which allows for the project to appear in high graphics with sharp and clear imaging for the user. The Oculus Rift S allowed us to develop specifically for the device, but due to the nature of the Rift it requires users to be tethered to the computer and limits their mobility.

2.1.2 - Unity Integration and Movement in Virtual Space

In order to create a project for virtual reality, we needed a camera capable of handling the headset's movement and access to the position of the Oculus controllers. Oculus provides a package specifically for VR development in Unity that contains a camera rig and controller prefabs automatically enabled to sync up with Oculus devices. We replaced Unity's default camera with the Oculus rig and attached a left and right hand controller prefab to make *A Garden Dream* functional with the Rift S.

Next, we needed to determine how we would implement movement in our virtual space. There are three major methods of locomotion in VR: physical movement, teleportation, and joystick movement, and each have their benefits and setbacks (Ribeiro, 2021).

Physical movement is Sims' end goal for future iterations of *A Garden Dream*, where he would provide users with a 3x3 meter space to walk around in, mapped to a virtual space of the same size. However, our on-campus lab did not have the space to accommodate this, only providing about half of the desired space for physical movement. Because of this, we determined that physical movement was not suitable for our prototype.

Teleportation is a common locomotion method in VR since it is less likely to cause motion sickness than other forms of stationary movement (Ribeiro, 2021). The user selects a location in the virtual space with their controller and instantly teleports there (see Figure 2.1).

There are no in-between frames to show continuous movement, so the user may become lost or confused about their location. Since we wanted to simulate the end goal of physical movement the closest we could, we determined that the discontinuous nature of teleportation was not aesthetically ideal to what both we and our sponsor sought.

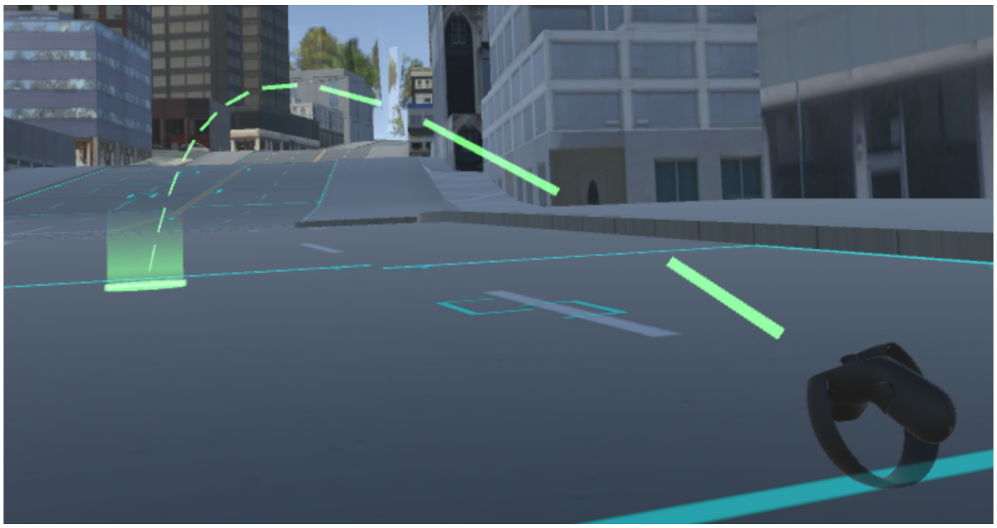

Figure 2.1: Teleportation Functionality in VR
(https://www.fanpop.com/clubs/alpha-and-omega/images/41234295/title/valves-unity-vr-teleport-system-photo)

Joystick movement is the stationary locomotion method that mimics physical motion the most. However, it comes with its own drawbacks in the form of motion sickness. When the users view themselves moving in virtual space but their physical body is stationary, this causes a phenomenon called 'Vestibular Mismatch', where the user may become dizzy or nauseous (Ribeiro, 2021). Through testing the project ourselves, we found this most evident when the user moves in a different direction than their head is facing. Implementing 'Head-Relative' locomotion logic, where the developer maps joystick input to whatever direction the user faces, is a method we found that could decrease motion sickness in our users (Artificial VR Locomotion - Controls and User Input, n.d.).

Through this discussion, we determined that a combination of joystick movement and physical movement was the route to take for movement in our virtual space. The user can walk around and rotate within a 1x1 meter space in our lab, but if they need to move a larger distance, they can utilize the joysticks to do so.

Once we established a base for working in virtual reality, we moved on to discussing how we should integrate Sims' specific goals for visual and technical development.

2.2 - Abyss: Binaural Beats and Mandala

Abyss is the introduction to the experience and utilizes binaural beats to create atmosphere. A binaural beat is an auditory illusion created by listening to two tones of different frequency in each ear. Listeners hear the tones together as one sound that fluctuates between the two frequencies like a wave (Reedijk et al., 2013). Studies indicate that binaural beats may have an effect on cognition due to their pulsating rhythm, and as such are the foundation for some concentration and study music (Frank, 2016). In Abyss, the user encounters different binaural beats throughout the space as they move around. Four speakers in the north, south, east, and west walls of the virtual room output a different binaural beat clip in a specific range, with some speaker ranges overlapping as shown in Figure 2.2. Each clip, arbitrarily placed, uses logarithmic rolloff, meaning that the volume of the beat is dependent on how close or far the user is from the speaker. The design of these placements provides a sense of depth in the space, causing the sounds and vibrations of the audio to differ based on the user's position.

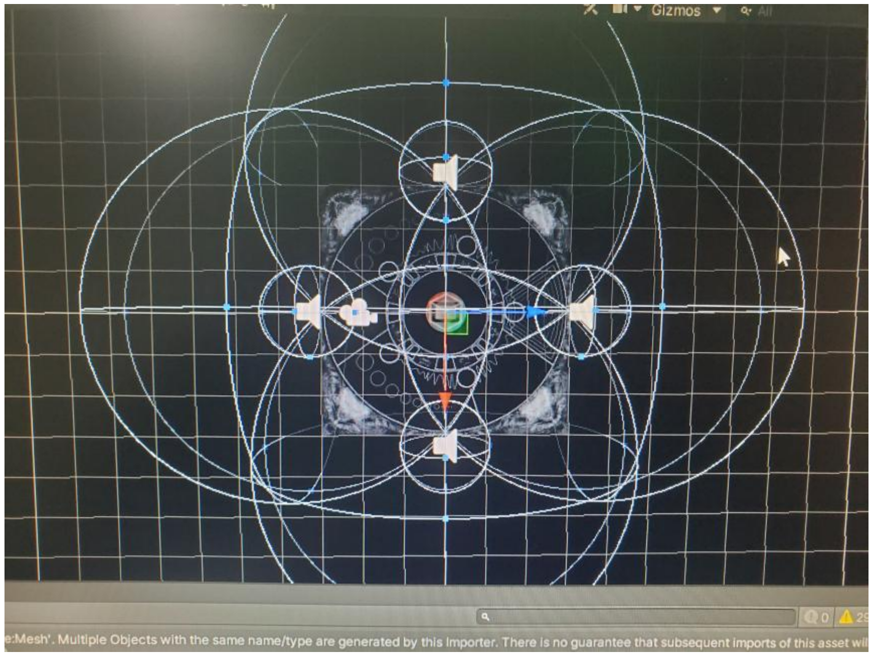

Figure 2.2: Range of the Binaural Beat Speakers in the Unity Editor

Abyss takes place in an enclosed room with six black planes that prevent the user from exiting the space. On the floor is an image of a mandala created by Mr. Sims (see Figure 2.3), which we imported into Unity as a texture. The mandala consists of geometric shapes presented in patterns across the floor and slowly fades in as the user begins the experience. Abyss utilizes a monochrome color palette to encourage relaxation and minimize distraction from the mandala, with pitch-black walls surrounding the user. After a minute of exploring Abyss, the mandala fades to black and the binaural beats disappear, signifying the transition to the next phase.

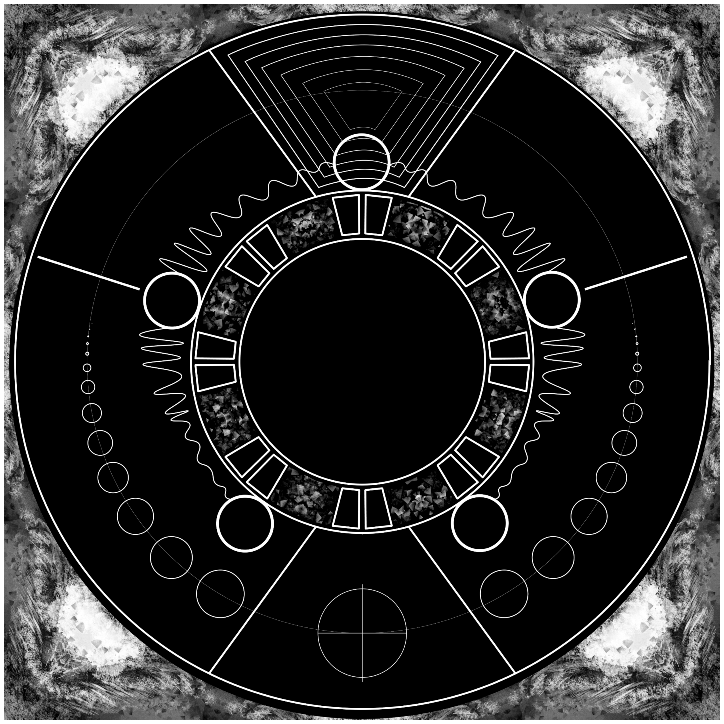

Figure 2.3: Original Mandala Image by Atticus Sims

2.3 - Ground: Flocking Moths

The next phase, Ground, opens with a beam of light that slowly expands to light up the room. A group of moths begin to appear from the periphery of the space and flutter around the light in a circular motion, each emitting the sound of a bowed bell. After 30 seconds, the moths turn their attention toward the user's right hand, allowing the user to control the group's movement. After 90 seconds, the moths will no longer follow the user's hand and will spiral into a hive-like shape around the light beam. Finally, the moths' movement and audio ceases and they fall to the ground and disappear.

2.3.1 - Flocking Behavior Algorithm

In order to create the moths' behavior, we utilized flocking algorithms: simulations that mimic flocks or herds of animals (see Figure 2.4). Craig Reynolds popularized the idea of bird-like flocking behavior in 1986 with his ‘boids’ (bird-oid object) implementation (Reynolds, 2001). Three key behaviors control Reynolds’ boids: cohesion, alignment, and separation. Cohesion prompts each boid to move toward the average position of its neighboring boids, alignment ensures that the boids move in an average heading direction, and separation causes the boids to avoid colliding with one another (Bourg & Seemann, 2004). These three behaviors serve as the basis for many modern implementations of flocking, including the composite behaviors that we created for *A Garden Dream*.

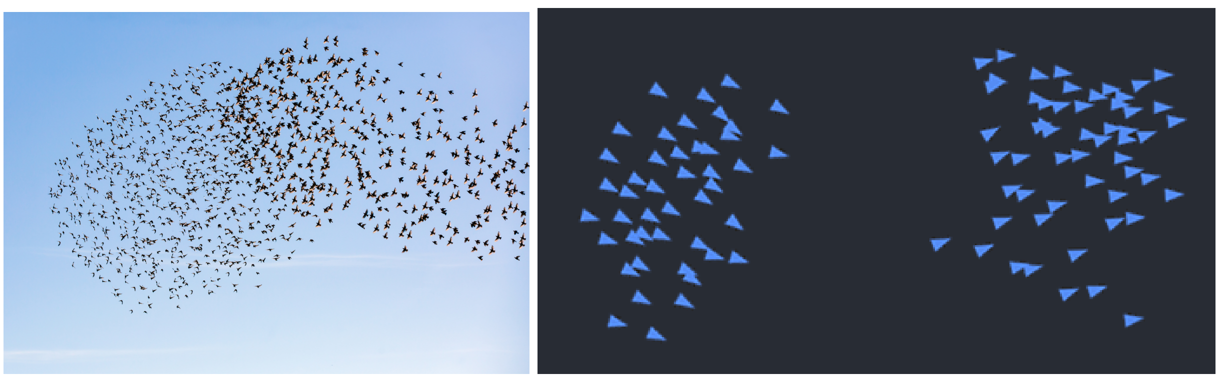

Figure 2.4: Flocking Birds (Left), Boids Implementation (Right)

(https://www.mercurynews.com/2017/02/09/birds-flying-in-formation-are-more-impressive-than-you-think/, https://eater.net/boids)

To create our flocking behavior, we utilized the Unity package FlockBox, created by Cloud Fine. This package contains initial implementations of twelve flocking behaviors that we edited and combined to create the final behaviors that you see in the project. Additionally, we extended the FlockBox scripts to handle the audio implementation that we needed for the project, which we further explain later in the chapter. We created two types of flock agents with different behaviors for our moth flock: a leader moth, and a follower moth.

Figure 2.5: Moth Agents Flocking toward Light Source

A single leader moth is the first agent spawned in the flock. This moth is not visible to the user and has four behaviors that it cycles between: LightBehavior, HandBehavior, SwirlBehavior, and DoNothingBehavior. The primary purpose of the leader moth is to move to a specified attractor point and stay there so that the follower moths can all follow its path. As such, LightBehavior draws the leader moth to the scene's light source (see Figure 2.5) and HandBehavior to the user's hand. SwirlBehavior sends the leader in a random circling movement at a higher speed to mimic being swept up by a gust of wind. Finally, DoNothingBehavior does exactly what its name suggests: it stops the leader in its tracks, suspending its position in midair.

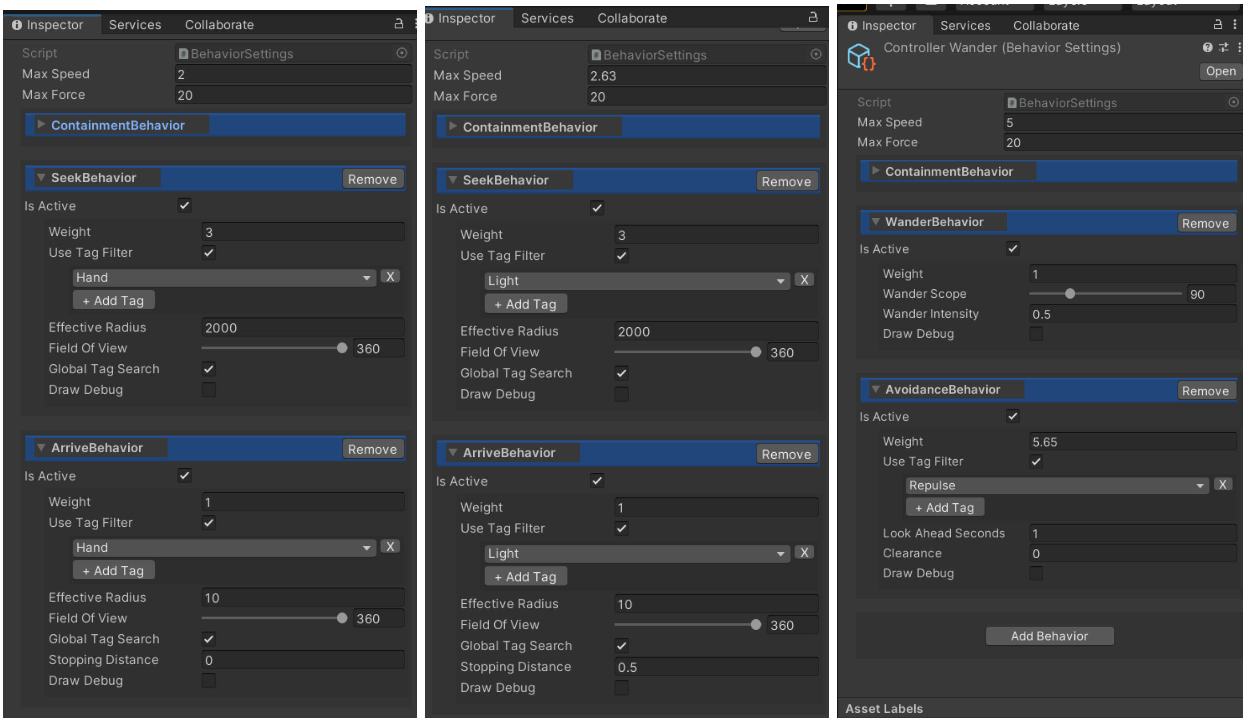

Figure 2.6: Hand Behavior, Light Behavior, and Swirl Behavior in the Unity Inspector

Next, the flock spawns multiple follower moths with two behaviors: FollowBehavior and DoNothingBehavior. These moths are attracted to the leader moth and will follow it wherever it goes, and then fly around its resting position. FollowBehavior utilizes FlockBox's built-in leadership behavior while also mixing in separation and cohesion behaviors to ensure that the agents do not crowd one another. The followers also use the same DoNothing Behavior as the leader and will halt their movement at the same time. We can adjust the parameters of each of these behaviors in the Unity inspector window, as shown in Figures 2.6 and 2.7.

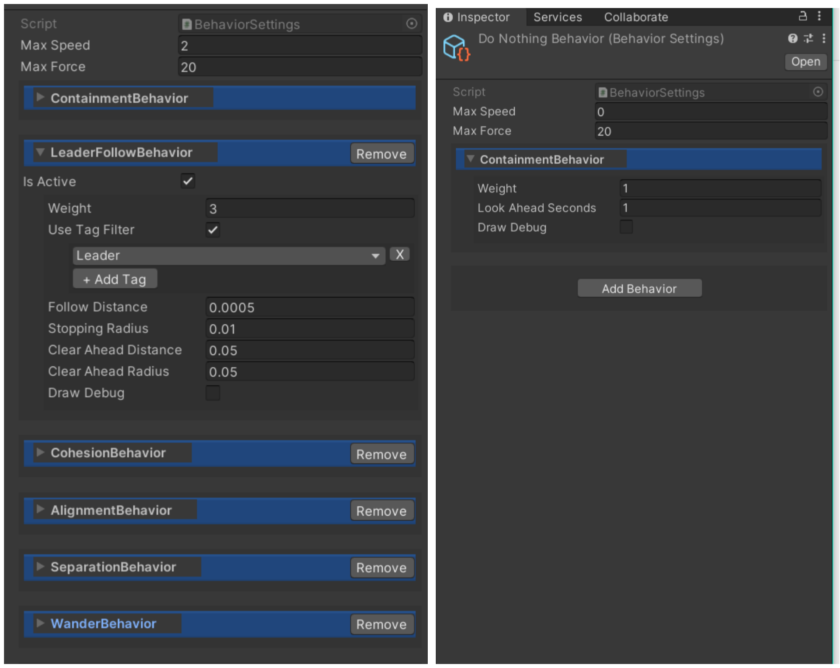

Figure 2.7: Follow Behavior and Do Nothing Behavior in the Unity Inspector

2.3.2 - Moth Audio Design

Ground makes use of procedurally-generated music in order to provide the user with a unique auditory experience each time they enter the space. Terry Riley's *In C* inspired the feel of the music for this section. A 1964 composition considered one of the first works of minimalist music, *In C* contains only 54 short, repeating motifs, some not even a second long. Each musician in the performance decides how many times to repeat each motif and when to transition to a new motif, all relying on one another to work together and create a cohesive song (Carl, 2010). As such, *In C* may sound completely different at each performance.

Figure 2.8: *In C* Sheet Music
(https://nmbx.newmusicusa.org/terry-rileys-in-c/)

Robert Carl describes *In C* as akin to a piece of software, as it contains “a series of rules and predefined relationships that execute a task,” and “the user can then customize input and tweak aspects of the rules and relations to produce a product that is regarded as personal” (Carl, 2010). Because of this nature, *In C* and similar compositions are ripe for procedural-generation via an algorithm, with a computer making decisions during runtime about the motifs instead of individual musicians. User-defined parameters such as motif repetition chance, the number of instruments used, and the number of digital ‘musicians’ playing those instruments all have an impact on the final sound of the experience, but computer-generated randomness creates an additional factor that is not present in a human performance of *In C*.

To mimic the composition of *In C*, each moth arbitrarily selects one of eleven audio files from Samuel Andre's 'C Moth' sound set. Together, the moths create a procedurally-generated song together as they move throughout the space. All of the audio is spatialized, meaning that the volume of each sound varies depending on their location in the space relative to the user. For example, if the moths are mostly to the left of the user, then the audio will be significantly louder through the left headphone than the right. This creates a more immersive and realistic experience in the virtual space, as the spatialization mimics how we perceive sounds in real life.

2.3.3 - Moth Audio Implementation

As explained in Section 2.3.1, we used the external package FlockBox as the basis for our moth agent implementation. While many of the resources FlockBox provides were functional right from the start, we needed to make some changes to its code in order to reach the functionality we desired. In order to turn the flock into a group of musicians that procedurally generate a song, we extended the FlockBox code to handle loading in audio clips from our resources folder and assigning them to 'sequences' that each moth agent will play.

In our initial implementation, each moth agent would select a random sound from the FlockBox's list of sound files and play it. Afterward, the moth agent would select another random sound, and so on. Therefore, every agent would have access to every sound file FlockBox imported. This created a song that was cacophonous and unpleasant, so Sims requested that we instead split the moth agents into smaller groups and assign each group a sequence where each moth in that group plays the same set of sounds in the same order. As shown in Code 2.1, we handle group designations when spawning agents.

```
IEnumerator createFlock(){
foreach (AgentPopulation pop in startingPopulations){
  if (pop.prefab == null) continue;{
     currentPrefab = pop.prefab;
     flockSize = pop.population;
     for (int i = 0; i < pop.population; i++){
     SteeringAgent agent = GameObject.Instantiate(pop.prefab);
     //assign that flock agent a group designation
     if (groupCounter < manager.mothGroupSize){
     //add that flock agent to the current group
     agent.groupDesignation = numGroups;
     groupCounter++;}else{
     //create a new group and add the flock agent to that group
     numGroups++;
     agent.groupDesignation = numGroups;
     groupCounter = 1; //reset groupCounter
     generateSequence(); //create a sequence for that group}
  agents.Add(agent);
  agent.Spawn(this, RandomPosition());

  //wait a bit before spawning the next agent

  yield return new WaitForSeconds(spawnTime);}}}}
```
Code 2.1: Flock Generation and Group Designation Code

Our audio implementation code takes in values for the number of audio clips in a sequence and the number of moths in each sequence group. We created the generateSequence() function (see Code 2.2) to randomly generate lists of audio clips. FlockBox keeps track of each sequence it generates in a list so that moth agents may refer back to their sequence at any time. A moth agent's group designation number is the same as the index of its sequence in FlockBox's 'sequences' list.

```
void generateSequence(){
      //generate a list of audio clips and add it to the list of sequences
      List<AudioClip> sequence = new List<AudioClip>();
      for (int i = 0; i < manager.sequenceLength; i++){
            //pick a random audio clip from the sounds list and add it to the
            sequence
            int sequenceIndex = UnityEngine.Random.Range(0, sounds.Count);
            sequence.Add(Resources.Load<AudioClip>("Sounds/" + manager.soundSet +
            "/" + sounds[sequenceIndex]));
      }
      sequences.Add(sequence);
}
```
Code 2.2: Flocking Random Sequencer

In addition to sound motifs, the moth agents also have a chance of staying silent for a period of time. Sims requested that this length be a variable so that he and his sound team may test different values to see which works the best for the composition. In order to implement this, we created a 1 second long audio clip with no sound and added it into the FlockBox's audio clip list. To achieve variable length, instead of changing the length of the sound clip, we created a loop in the moth agent's script which repeats the single second clip for the length of the desired silent period (see Code 2.3).

```
if (FlockBox.sounds[soundIndex] == "silence"){
   int silentCount = 0;
   if(silentCount < FlockBox.manager.silentPeriodLength){
      if(!audioSource.isPlaying){
         audioSource.Play();
         silentCount++; }}}
```
Code 2.3: Silent Period Looper

This code makes use of Unity's built in sound systems, which can detect when an audio clip has finished playing. When a second of silence ends, the next one plays, until the loop reaches the desired length of the silent period.

Something we discovered while working with the flocking parameters and audio sets was that the inspector window for the Flock object was cluttered. In order to provide a cleaner interface going forward, we moved all audio parameters to a new object: the SoundManager.

2.3.4 - Sound Management

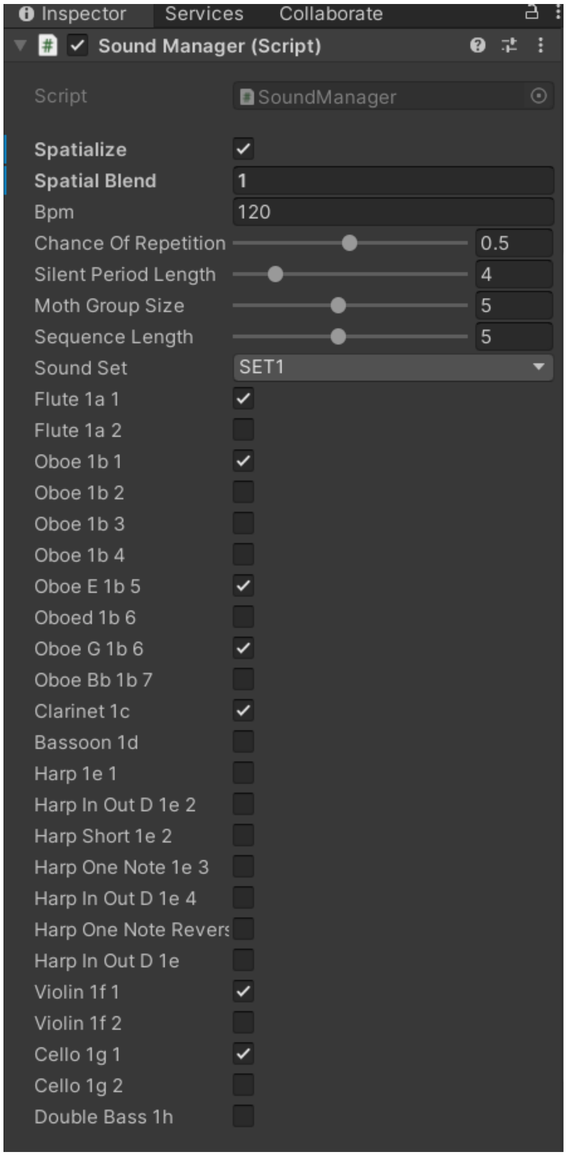

Figure 2.9: SoundManager in Unity Inspector

The SoundManager object handles the selection of audio clips and other flocking audio parameters. The FlockBox script takes a SoundManager object as a parameter to access its information. In theory, this means that future developers on this project may develop multiple SoundManagers that they can switch between without needing to change the FlockBox parameters each time if need be.

We made each possible moth sound a variable that we can toggle on or off so that we can mix and match the different audio files to see which motifs sound better together. This is accessible in the Unity inspector window, as shown in Figure 2.9. Through discussions with our sponsor and his audio designer Samuel Andre, we determined that no more than eight motifs should play at once to avoid cacophony. In order to provide easy access to each toggle variable, we exposed the different sound motif parameters in the inspector so that we and any future developers do not need to edit the code to test different motifs.

Other parameters that the SoundManager handles for the flock include the Chance of Repetition variable (probability that a flock agent will repeat a motif instead of moving to the next), the length of the silent audio clip (in seconds), the Moth Group Size (how many moths in the flock will have the same sequence), and the number of audio clips that are in each sequence.

2.4 - Earth: Physarum Growth

The final section we worked on, Earth, contains a colorful simulation that extends out from the pool in the center of the space. This growth is made up of multiple small particles that move according to an algorithm based on the development of physarum, a species of slime mold (see Figure 2.10).

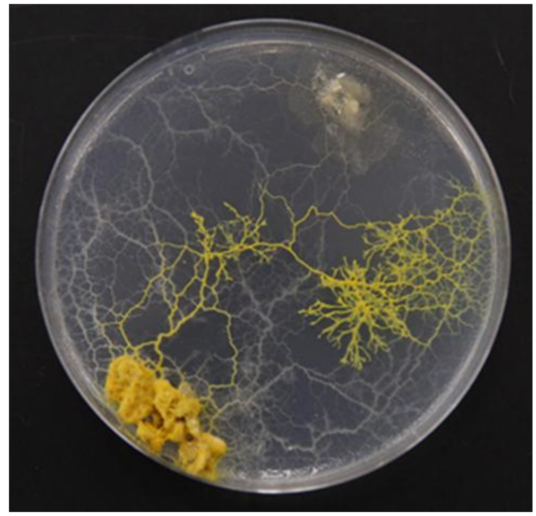

Figure 2.10: Physarum Slime Mold (https://www.hampshire.edu/faculty/physarum-polycephalum)

In order to create this functionality, we researched preexisting physarum algorithms that we could bring into Unity. We found two Unity packages that simulated the desired behavior, one in 2D and one in 3D. Since we wanted the growth to appear on the floor of the space, we first imported the 2D package into our project, but found that it was incompatible with the graphics rendering pipeline *A Garden Dream* utilized. With that established, we turned our attention toward the 3D package and began tweaking its settings to map it to the floor. The original version of the package generated the physarum growth as a sphere, so we simply set the vertical size of the sphere to 0 to make a flat circle. In order to bring some color into the otherwise monochrome space, we set the particles to generate in a range of hues, creating a vibrant image as shown below in Figure 2.11.

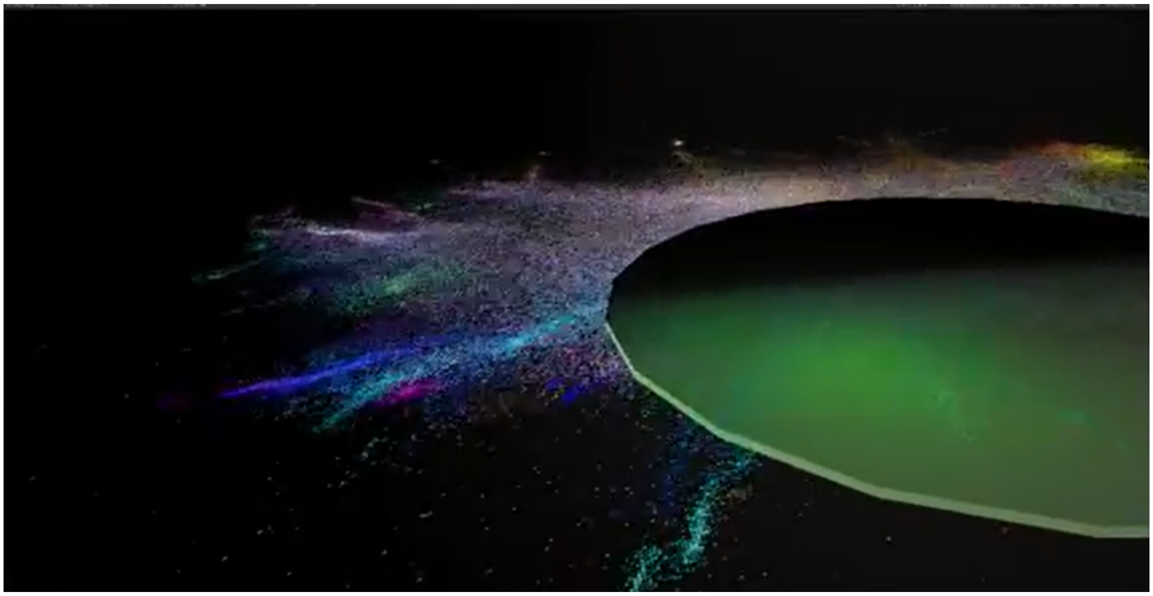

Figure 2.11: Beginning Stage of Physarum Growth

Our final implementation contains over 500,000 individual particles that start in the center of the space and grow to fill the floor. Each particle is visible in the Scene window in Unity (see Figure 2.12) so we can visualize their movement while debugging the project.

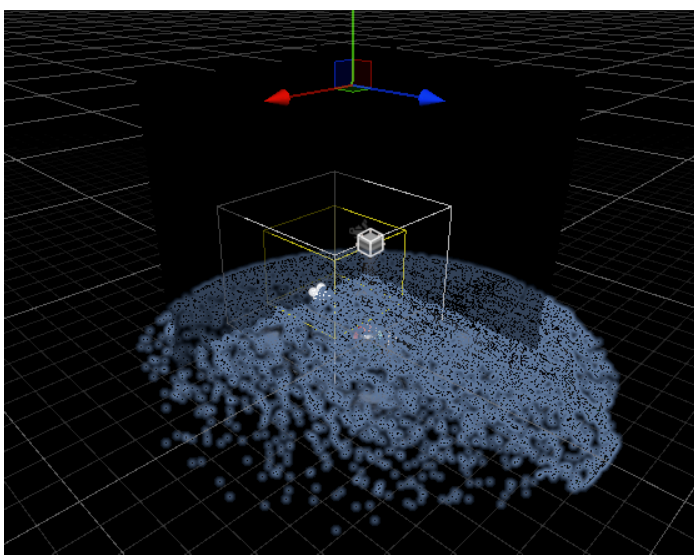

Figure 2.12: Physarum Particles in Unity Scene Window

2.5 - Time Management

In order to create a timeline that moves *A Garden Dream* through its three sections, we created a script called TimeManager which controls the timing of the narrative. TimeManager takes in values in the inspector window that control the timing of the experience's key parts. This way, it is easy for us to test out different lengths for each part of *A Garden Dream* without changing the code. Figure 2.13 shows how TimeManager appears in the inspector window, with each value representing the number of seconds that part of the experience lasts.

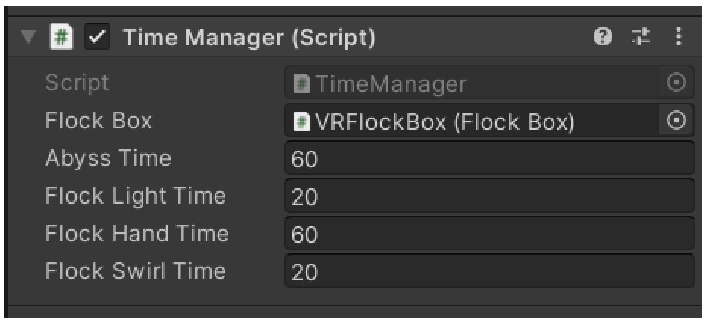

Figure 2.13: TimeManager Inspector

One of the primary jobs TimeManager handles is toggling GameObjects in our scene on or off. Some objects, such as the binaural beat speakers or the flocking moths, are only present for specific parts of the experience. For example, the Abyss sequence requires the floor mandala and four binaural beat speakers. When the TimeManager triggers the Abyss sequence, it enables these objects via Unity's 'SetActive' function (see Code 2.4), and then once it transitions to Ground, it disables them after waiting for the desired time interval (in this case, abyssTime).

```
IEnumerator startAbyss(){
        currentGState = GameState.ABYSS;
        print("ABYSS");
        //Fade in mandala
        mandala.SetActive(true);
        //start binaural beats by enabling speakers
        nSpeaker.SetActive(true);
        sSpeaker.SetActive(true);
        eSpeaker.SetActive(true);
        wSpeaker.SetActive(true);
        //After a set amount of time, transition to ground
        yield return new WaitForSeconds(abyssTime);
        StartCoroutine(startGround());}
```

Code 2.4: startAbyss()

During the Ground sequence, the flock of moths needs to shift between different behaviors in order to move to different points in the scene. TimeManager handles changing the flock's behavior at the desired time intervals and then finally disabling all flocking behaviors and removing the flock from the scene. As explained previously, the leader moth has four different behaviors that it cycles between: Light, Hand, Swirl, and DoNothing. We can control what behavior objects the code uses via the inspector window as shown in Figure 2.14, so throughout development we can swap out different versions of each behavior easily and test which ones best suit the project's vision.

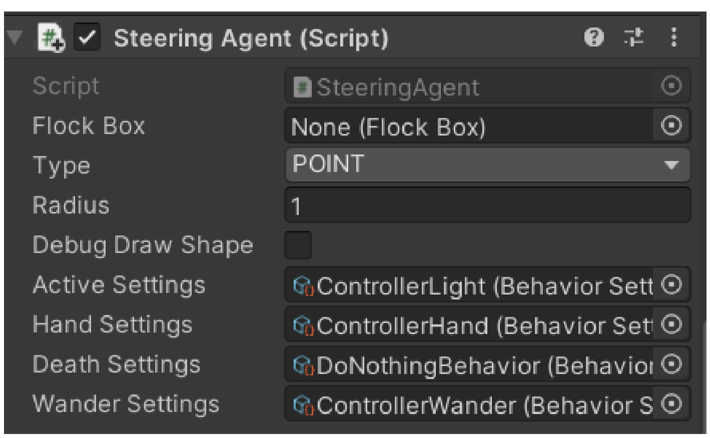

Figure 2.14: Leader Moth Behaviors

TimeManager simply sets the leader moth's active settings to whichever behavior the scene needs at designated times. Follower moths will naturally follow the leader wherever it goes because of how their behavior works, and only need a behavior change when they need to halt in midair, where they get the same DoNothing behavior as the leader. Code 2.5 shows how the TimeManager swaps between behaviors. To change the behavior of the leader moth, we call the first object in the list of agents and change its 'activeSettings' parameter, and to change the behavior of the whole flock, we loop through each object in the list and do the same.

Finally, in order to allow the moths to fall to the ground, we must disable FlockBox as it prevents gravity from affecting the agents. Since we can no longer access the FlockBox's list of agents, accessing the individual agents is a little more difficult. Since our flock still exists as an object in the scene with the agents as children, we now have to loop through the list of children to disable the agents' audio and animation and enable their gravity as shown in the last five lines of Code 2.5.

```
//Generate Flock
flockBox.gameObject.SetActive(true);
//Let agents flock around the light for desired time.
yield return new WaitForSeconds(flockLightTime);
//Now, change the leader moth behavior so it is attracted to the user’s hand.
//Follower moths will automatically follow.
flockBox.agents[0].activeSettings = flockBox.agents[0].handSettings;
//Let agents flock around hand for desired time.
yield return new WaitForSeconds(flockHandTime);
//Let agents disengage from hand and swirl around scene
for (int i = 0; i < flockBox.agents.Count; i++){
   //iterate through the agents and set all behaviors to WanderBehavior
   flockBox.agents[i].activeSettings = flockBox.agents[i].wanderSettings;}
//Let agents swirl for desired time.
yield return new WaitForSeconds(flockSwirlTime);
//Moth ‘death’ sequence
print("KILL!");
//change flock agent behavior to 'donothingbehavior', stops their movement
for (int i = 0; i < flockBox.agents.Count; i++){
   //iterate through the agents and set all behaviors to DoNothingBehavior
   flockBox.agents[i].activeSettings = flockBox.agents[i].deathSettings;}
//wait a moment, then disable the FlockBox code and drop the moths to the ground
//NOTE: FlockBox must be disabled for gravity to affect agents
yield return new WaitForSeconds(0.5f);
flockBox.GetComponent<FlockBox>().enabled = false;
//turn on moth gravity and allow them to fall
foreach (Transform child in flockBox.transform){
  child.GetComponent<AudioSource>().enabled = false; //Disable the audio
  child.GetComponent<Animator>().enabled = false; //Disable the animation
  child.GetComponent<Rigidbody>().useGravity = true; //Make moth fall
  child.GetComponent<SphereCollider>().enabled = true; //Moth collides w/ground}
```
Code 2.5: TimeManager Changing Flock Behavior

3.0 - Playtesting and Iterative Design

To gather data about how users outside of the study team interact with and feel about *A Garden Dream*, we conducted playtesting sessions with WPI students. Playtesting lasted for three days during Week Seven of the project from Wednesday, December 8th through Friday, December 10th. A recorded session of a playtesters' experience can be seen with this link or by clicking the image below. We had fourteen playtesters in total, and all were WPI undergraduate or graduate students.

Figure 3.1: Playtester in the headset

3.1 - Study Protocol and Ensuring Safety

Prior to playtesting our project, we required participants to complete a pre-screening survey in order to ensure that they had no existing health conditions that could impair their ability to safely use virtual reality. See Appendix C for the full list of pre-screening questions and terminating conditions. Once we ensured that a student passed our pre-screening questions, we gave them a list of playtesting times to choose from and they officially became one of our playtesters.

We conducted testing in the WPI Global Lab (Innovation Studio 221) where we connected the Oculus Rift S headset to a VR-supported desktop PC. We sectioned off a 3'x3' space in the lab free of any obstacles to use as our VR playspace. Since we implemented movement in *A Garden Dream* with the VR joysticks, we did not expect users to need to move more than one foot at a time, however we allocated the extra space for safety purposes in case some users moved more. When playtesters entered the lab, they completed the COVID-19 Risk Mitigation Strategy and Informed Consent Agreement forms (see Appendix B) in order to ensure they understood the study and any risks virtual reality may present. Once we obtained consent from the playtester, we began the study. First, the playtester put on the Oculus Rift S and headphones and took the controllers while we started the application on the PC. The playtester then experienced the application from start to finish, lasting approximately 3-4 minutes. Afterward, we asked the playtester to complete a post-experience survey (see Appendix D) that asked questions about their time in the virtual reality space.

3.2 - User Feedback

3.2.1 - Areas of Improvement

We received feedback from all playtesters about areas to adjust to improve the user experience. This consists of visual design components, interactive components, and timing suggestions. Some user feedback provided complaints about the flock leader moth on the user's left hand being distracting and we also noted that most users were right handed and instinctively raised their right hand first to interact with the moths. We decided to make this moth invisible to prevent this confusion and distraction, and also changed the leader to be on the right hand controller. Additionally, users were confused about what the moths were doing, what they were supposed to do, and what the objects actually were. This confusion is distracting for playtesters because while they are trying to concentrate and enjoy the experience, they end up overwhelmed with these additional details that confuse them. To mitigate these confusions, we suggested adjusting the controllers to light up when the moths are approaching them so users can better understand what is controlling the moths or to provide a guided tutorial to inform users about their purpose in the experience. Users also expressed confusion about their ability to jump over the pool, and its purpose. In the Unity development environment, the pool was able to function as expected, but failed once the build of the project was created. We were unsure of how to fix this error but would recommend looking further into the contents of the pool to better understand how it works and why it only persists in the development environment. A large concern of the development team was how users would respond to the timing and duration of the experience. Due to the inconsistency of time preferences, we would recommend the ability to allow a user to decide if they wish to proceed to the next scene or remain in one they are currently in. While these are the largest areas of improvement for the experience, more information and raw data can be found in Appendix D.

Problem	**Method(s) of Improvement**	**Supporting Evidence**	**Completion Status**
Flock leader moth is distracting and/or confusing to users	Leader moth should be transparent	Three playtesters reported the leader moth's position on their hand as a glitch.	Complete
Users tend to favor their right hand, moths are attracted to the left hand	Moths should be attracted to the right hand instead of the left	Playtesting coordinators needed to tell some playtesters to use their other hand	Complete
Some users do not notice the moths are flocking to their hands	Hand models could glow once the moths become attracted to them. OR Offer users a 'how to play' style instruction list either digitally or physically.	Playtesting coordinators needed to tell some playtesters how to interact with the moths	Incomplete
Users can 'jump' over the pool, potentially causing motion sickness.	Modify object collider to a cylindrical collider	One playtester reported motion sickness due to 'jumping' over pool	Incomplete
Users want varying time preferences for how long they want to be in each scene.	Allowing the user to decide if they wish to remain in the current scene or if they want to proceed to the next scene.	Five participants requested for shorter timing, five participants requested for longer timing, two participants requested no change, one participant was indecisive	Incomplete
Users are unsure what the objective or purpose of the experience is.	Providing more of an activity or objective in the experience for the user to complete.	Three playtesters reported that they felt that in the experience they were unsure of what to do at times	Incomplete

3.2.2 - Positive Criticism

After we received feedback from the playtesters, we gathered a collection of positive feedback. Due to the novelty of VR, the majority of users were excited to try the experience and interact with the headset. Playtesters normally felt at ease when using the experience and enjoyed the calm atmosphere. While playtesters were confused at times, they still felt like they were in a relaxing environment, which aligns with the experience goal of the project. Out of fourteen playtesters, eight reported there was no difficulty interacting in the VR space. The majority of playtesters enjoyed the music, with eleven out of fourteen playtesters saying the music composition was either enjoyable or very enjoyable. Common words used to describe the music were, “calm, relaxed, captivating, and nice”.

3.2.3 - Debugging/Errors

Throughout development, there were errors that remained consistent and took large portions of time to debug. The most persistent error throughout the project was the pool implementation. The pool presented in the middle of the scene was supposed to have stereoscopic video playing, which caused us to transfer to the High Definition Render Pipeline (HDRP) from the Lightweight Render Pipeline (LWRP). The pool had a collision box that caused the user to “jump” over the object, rather than preventing the user’s path, which was confusing to the user and unexpected behavior. Additionally, the stereoscopic video only worked in the development environment but did not work properly when the project was built. After transferring to HDRP, there were compatibility issues when trying to implement different packages and assets. Some of our assets like the moth object and hand controller had to be readjusted or removed due to these compatibility issues. After transferring to the HDRP, the moth object was glitching and could only be seen on one side because the object was an assigned texture on a plane. To fix this, we connected two planes together so the moth would be seen on both sides. When transferred to the HDRP, the hand controllers glowed bright pink. In order to fix this, we had to change the texture of the controllers to one that was compatible with the pipeline. Another issue that was persistent was adjusting the flocking algorithm so the flock would move in an expected pattern. Due to the specifications of the assigned parameters, the flock would either appear too clumped together, not have either distance from each boid, or would not have a flocking appearance. After adjusting and testing the parameters and behaviors identified in Figure 2.6, we were able to find a flocking implementation that satisfied the expectations. The physarum also caused a challenge during the end of development. When trying to implement packages of physarum, we ran into issues trying to adjust the customizability in its shape and appearance. Oftentimes, the physarum would spawn in a fixed environment or shape, unable to adjust its parameters. Other times, the physarum packages were incompatible with our project due to the HDRP or other packages already implemented. In order to overcome these issues, we eventually found a package that was compatible with the HDRP and were able to flatten the object on top of the bottom plane in the scene. The physarum spawn at the end of the Ground scene after the moths die. The physarum grows on top of the floor and users can experience the simulation and growth.

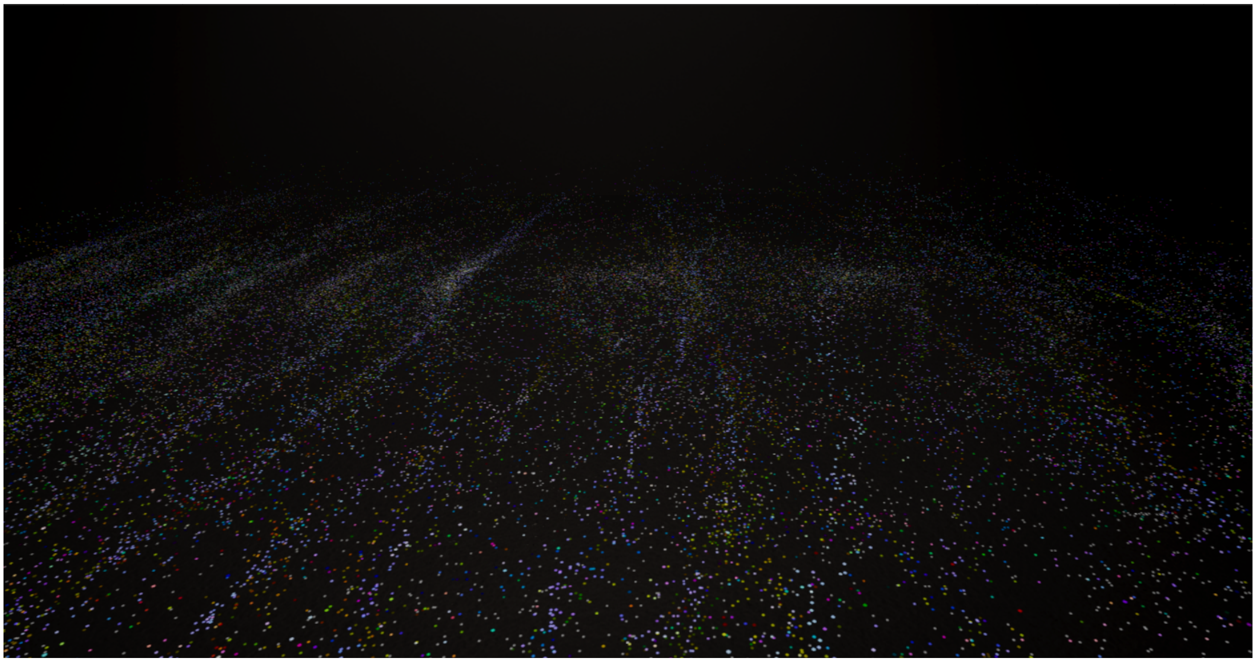

Figure 3.2: Physarum Growth on the Floor of the Experience

4.0 - Postmortem

4.1 - What Went Wrong and What We Would Do Different

The primary obstacle we faced this term was in finding a consistent work space with the equipment we needed. For the first three weeks of the project, we did not have a PC with the right software or graphics card to work on the VR aspects of *A Garden Dream*, which limited us in what we were able to accomplish during that time. We were able to secure WPI's Global Lab as our workspace at the beginning of Week 4, and are very grateful to the staff for helping us get Unity set up on their computer. If we were to do a project like this again, our first priority would be to find a suitable workspace as early into the project as possible.

Something else we felt caused some trouble during the term was the scope of the project. From the start, we committed ourselves to a lot of goals that might have been possible for two seasoned Unity developers to complete in seven weeks, but are much more difficult for two beginners. We spent a lot of time simply learning how to use Unity and virtual reality, as neither of us had much experience with either, and we did not factor in how much time this would take while scoping out the project. In retrospect, we may have been able to prevent ourselves some stress in the last couple weeks of the project had we picked smaller goals and worked toward refining them early on and then added more to the project if we had the time.

There were some problems we encountered while learning Unity regarding finding proper resources to study from. Unity was first released in 2005 and releases new updates frequently, so it was difficult for us to find specific, reliable information for the newest version of Unity. Many of our Unity-centric difficulties stemmed from the rendering pipeline we decided upon with our sponsor at the beginning of the project: the HDRP. As opposed to the standard pipeline, the HDRP is more visually in line with what Sims wants for his final version of *A Garden Dream*, but what we did not know when selecting this pipeline is that many of its features are still being developed. Because of this, we had to cut one part of the project that did not work with HDRP: the closing scene, which would have utilized Oculus' passthrough camera technology to return the user to the real world at the end of the experience. Looking back, we should have stuck to the standard rendering pipeline for the purposes of this prototype so that we could complete more sections of the project.

Finally, we encountered some unforeseen difficulty in getting IRB approval to playtest *A Garden Dream*. While we began the process early in the project timeline, we were unaware of how much we had to take into consideration when working with virtual reality equipment. We had meetings with the IRB throughout the term to ensure that our playtesting protocol was safe and that we were preventing our subjects from getting motion sickness. While playtesting ran smoothly and we gathered meaningful feedback from each participant, we did not leave ourselves much time to incorporate that feedback into the final version of *A Garden Dream*. Had we been more thorough with our protocol early on, we may have been able to get playtesting done earlier in the project.

4.2 - What Went Well

For the project, we decided to utilize a 9 to 5 work schedule, the only exceptions being our weekly sponsor meetings on Monday and Thursday evenings. This dedicated work time helped us to stay focused while we were together and to try and complete as much as we could each day before our 5PM deadline. Additionally, it aided us in maintaining a work-life balance that is sometimes difficult to achieve during a normal term.

We also found that meeting with our sponsor twice a week benefitted the project, as we were able to set weekly goals on Monday and show our progress and get feedback on Thursday. Regularly meeting with Sims also ensured that he was informed of everything we completed and made progress on and gave him the opportunity to provide advice and suggestions each step along the way. Additionally, we utilized Discord to ensure that all members of the project had reliable communication with one another whenever needed. Small questions and comments that could not wait for the next sponsor meeting found a home in our server and allowed us to progress quicker than if we had held off and presented them a few days later.

We definitely would not have made as much progress this term without our two part-time team members: Laurie Mazza and John Frazia. With Laurie working on technical art and John on audio implementation, we were able to learn from them and focus more on how these aspects of the project integrate with our technical development work. Laurie and John were also a great help with getting us situated with Unity and sharing their knowledge of interactive media design and virtual reality.

Once we found the Global Lab as our consistent work space, our workflow increased. We did not need to spend time during the day moving to a new space or hunting for an empty table, and the lab provided equipment that was suitable for our work in virtual reality.

Next, we found that the playtesting sessions we completed in Week 7 ran smoothly and gave us ample feedback to provide our sponsor. All of our participants were great to work with and provided meaningful and interesting insight into the project. It was rewarding and exciting to see our peers react to the project we had put a term's worth of work into.

Finally, we are very proud of the work we completed this term. We were able to finish full prototypes of the first two sections of *A Garden Dream*: Abyss and Ground, and began work on a third: Earth. Working with new tools like Unity and the Oculus Rift S was very rewarding and allowed us to extend our programming knowledge to a new field that neither of us had worked in before. We are excited to see what the future has in store for virtual reality as a platform, and what *A Garden Dream* will become in the coming years.

References

Artificial vr locomotion—controls and user input. (n.d.). Oculus for Developers. Retrieved December 3, 2021, from https://developer.oculus.com/resources/artificial-locomotion-controls/

Bourg, D. M., & Seemann, G. (2004). AI for game developers (1st ed). O'Reilly.

Carl, R. (2010, January 14). Terry riley's in c. NewMusicBox. https://nmbx.newmusicusa.org/Terry-Rileys-In-C/

Cruz-Neira, C., Sandin, D. J., & DeFanti, T. A. (1993, September). Surround-screen projection-based virtual reality: the design and implementation of the CAVE. In Proceedings of the 20th annual conference on Computer graphics and interactive techniques (pp. 135-142).

Daniela, L., & Aierken, Y. (2020). The educational perspective on virtual reality experiences of cultural heritage. In New Perspectives on Virtual and Augmented Reality (pp. 22-37). Routledge.

Dey, T., Karnauch, A., & Mockus, A. (2021, May). Representation of developer expertise in open source software. In 2021 IEEE/ACM 43rd International Conference on Software Engineering (ICSE) (pp. 995-1007). IEEE.

Frank, T. (2016, February 20). Can music be designed to enhance your brain's performance? College Info Geek. https://collegeinfogeek.com/brain-enhancing-music/

González-Zamar, M. D., & Abad-Segura, E. (2020). Implications of virtual reality in arts education: Research analysis in the context of higher education. Education Sciences, 10(9), 225.

Idaho ATP. (n.d.). How is "ICT" different from "AT"? Idaho Assistive Technology Project. Retrieved December 14, 2021, from https://idahoat.org/services/resources/ICT

Keane, M. (2016, April 18). Japanese courtyard gardens. Kyoto Journal. https://www.kyotojournal.org/gardens/tsubo-niwa-japanese-courtyard-gardens/

Kersting, M., Steier, R., & Venville, G. (2021). Exploring participant engagement during an astrophysics virtual reality experience at a science festival. International Journal of Science Education, Part B, 11(1), 17-34.

Reedijk, S., Bolders, A., & Hommel, B. (2013). The impact of binaural beats on creativity. Frontiers in Human Neuroscience, 7, 786. https://doi.org/10.3389/fnhum.2013.00786

Reynolds, C. (2001, September 6). Boids (Flocks, herds, and schools: A distributed behavioral model). http://www.red3d.com/cwr/boids/

Reynolds, C. W. (1987, August). Flocks, herds and schools: A distributed behavioral model. In Proceedings of the 14th annual conference on Computer graphics and interactive techniques (pp. 25-34).

Ribeiro, A. (2021, January 12). Vr locomotion: How to move in vr environment. Circuit Stream. https://circuitstream.com/blog/vr-locomotion/

Sajwan, M., Gosain, D., & Surani, S. (2014). Flocking behaviour simulation: Explanation and enhancements in boid algorithm. International Journal of Computer Science and Information Technologies (IJCSIT).

Appendices

Appendix A: Study Protocol and Research Methods

Purpose of Study: To obtain user feedback in order to determine if experience goals are being achieved, identify user interaction bugs on the Oculus Rift S, and identify methods for design and development improvement.

Project Description: This experience is designed to provide users with the ability to navigate a VR world that utilizes spatial sound based on user interaction from an Oculus Rift S. The experience is intended to be a calming and immersive world where the user's feedback is responded to with different plant life and other external agents. User feedback includes hand movements observed through the Oculus controllers and physical movement in the designated play area. The users would be able to provide constructive feedback on what they thought of the experience, areas of weakness, and what they enjoyed.

Study Protocol: Playtesting will take place in the Global Lab (IS 221) where the Oculus Rift S headset will be connected to a desktop PC. Playtesters will be given a 3'x3' space in the lab free of any obstacles to use the VR headset in. Users are not expected to walk around more than ~1ft at a time as movement in the experience is controlled by the VR controller joysticks. When playtesters enter the lab, they must complete the Informed Consent Agreement, COVID-19 Risk Mitigation Strategy, and Prescreening Study Instrument. Based on their answers in the Prescreening Study Instrument, the student researchers will determine if it is safe for the playtester to participate in the study. Individuals prone to motion sickness, who are unable to stand for extended periods of time, or who have photosensitive epilepsy may not be able to safely use VR. They will then put on the headset, headphones, and take the controllers while the student researchers start the application. Playtesters will have a maximum of 20 minutes to complete the experience. After completion, the playtesters will complete the Post Experience Study Instrument. Only one playtester will be in the space at a time and will complete all necessary forms on the desktop PC in the lab.

Appendix B: COVID-19 Risk Mitigation Strategy and Informed Consent Agreement

COVID-19 Risk Mitigation Strategy

Investigator: Jennifer deWinter, Charles Roberts, Elaine Chen, Madeline Perry, John Frazia, and Laurie Mazza
Contact Information:
- Group Alias: gr-kyoto-vr-mqp-b21@wpi.edu
- Individual Emails: jdewinter@wpi.edu (x6679), cdroberts@wpi.edu, echen2@wpi.edu, mmperry@wpi.edu, jfrazia@wpi.edu, lmazza@wpi.edu

Title of Research Study: Kyoto VR: A Garden Dream
Sponsor: WPI, Atticus Sims of Kyoto VR

Introduction: You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

At WPI, our primary responsibility related to research is to protect the safety of our research participants. COVID-19 refers to the Coronavirus that is being spread across people in our communities. We need to provide you with important information about COVID-19, and to tell you about ways your study participation might change because of COVID-19 related risk.
If you are considering joining a study at this time or are currently enrolled in a study, it is important that you consider the following information to determine if study participation is right for you at this time.

How is COVID-19 spread?
COVID-19 is a respiratory virus spread by respiratory droplets, mainly from person-to-person. This can happen between people who are in close contact with one another (less than 6 feet). It is also possible that a person can get COVID-19 by touching a surface or object (such as a doorknob or counter surface) that has the virus on it, then touching their mouth, nose or eyes.

Can COVID-19 be prevented?
Current ways to minimize the risk of exposure to COVID-19 include "social distancing" which is a practice to decrease the potential for direct exposure to others who may have been exposed to COVID-19, for example by avoiding large gatherings or refraining from shaking hands with

others. It is important to understand that since study participation may include increased travel outside of your home and increased exposure to others within a research site it may increase your exposure to COVID-19. At this time, there is no vaccination to prevent COVID-19 infection.

What are the risks of COVID-19?
For most people, the new coronavirus causes only mild or moderate symptoms, such as fever and cough. For some, especially older adults and people with existing health problems, it can cause more severe illness, including pneumonia. While we are still learning about this virus, the information we have right now suggests that about 3 of 100 people who are infected might die from the virus.

Who is most at risk?
Individuals over 60 and with chronic conditions such as cancer, diabetes and lung disease have the highest rates of severe disease from the infection.

What do we do to minimize risk for research participants?

A. All in-person research will take place on the WPI campus.
B. Participation in the study will be strictly limited to WPI students and faculty authorized to attend campus in-person.
C. Research visits will strictly abide by all official WPI COVID-19 protocols in effect at the time of the test session. These protocols specify campus-wide standards for COVID-19 mitigation, including (but not limited to):
    - Visitors allowed on campus
    - Required vaccination status of visitors
    - Masking requirements
    - Social distancing requirements
    - Maximum room occupancy requirements
    - A summary of the latest WPI protocols is maintained at this URL: https://www.wpi.edu/we-are-wpi
D. Regardless of current WPI protocols, all test administrators and subjects will be required to wear a face mask at all times during the test session.
E. Test subjects will visit the research site only once, and only long enough to review the Informed Consent Agreement, participate in the test, and respond to the research survey.
F. Only one participant will be allowed in the space at a time. The participant and the researchers will maintain a six-foot distance from one another unless the participant needs assistance with the equipment. Once the researcher finishes helping the participant, a six-foot distance will be reestablished.
G. The location where study subject visits take place will have hospital-approved hand sanitizer readily available for use before and/or after the test session.

H. All physical equipment, including the VR headset, controllers, headphones, computer mice, and keyboard handled by subjects during the test will be thoroughly sanitized with alcohol wipes after each test session.

If you have further questions about COVID-19 and your participation in research, please talk to your study team.

Informed Consent Agreement for Participation in a Research Study

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Investigator: Jennifer deWinter, Charles Roberts, Elaine Chen, Madeline Perry, John Frazia, and Laurie Mazza

Contact Information:

- Group Alias: gr-kyoto-vr-mqp-b21@wpi.edu
- Individual Emails: jdewinter@wpi.edu (x6679), cdroberts@wpi.edu, echen2@wpi.edu, mmperry@wpi.edu, jfrazia@wpi.edu, lmazza@wpi.edu

Title of Research Study: Kyoto VR: A Garden Dream

Sponsor: WPI, Atticus Sims of Kyoto VR

Introduction: You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study: The purpose of this study is to obtain feedback on the project in order to facilitate design improvements and find/address operational bugs.

Procedures to be followed: Playtesters will enter the Global Lab (IS 221) one participant at a time. You will wear the Oculus Rift S headset which will be connected to a desktop PC. You will be given a 3’x3’ space in the lab free of any obstacles to use the VR headset in. You will be allocated approximately ~1ft at a time as movement in the experience is controlled by the VR controller joysticks in their hands. After playtesting, you will complete the questionnaire on the desktop PC in the lab. Members of the research team will be present in the space at the desktop PC to answer all questions and concerns that you may encounter during the experience.

1. When you enter the lab, you must complete the Informed Consent Agreement and the COVID-19 Risk Mitigation Strategy.
2. You will put on the headset, headphones, and take the controllers by hand.

3. You will enter a virtual reality experience lasting a maximum of 20 minutes. You may stop the experience at any time if you feel uncomfortable or unwell by informing the research team.
4. After completion, you will complete the Post Experience Study Instrument on a provided computer in the lab.

Risks to study participants: Individuals who do not pass the pre-screening survey will not be allowed to participate in the study as they may not be able to safely use a virtual reality headset. Some users may report motion sickness and headaches during or after using virtual reality equipment. If a participant wears glasses and feels any discomfort, please let the researcher know. If a participant begins to feel unwell during the experience, they may stop at any point by informing the research team. The participant may use chairs provided in the space to sit down before leaving if they need to. The experience will be paused on the computer and the individual will remove the headset and take time to rest. If necessary, the researchers will be able to provide water or anything the individuals request within reason.

Benefits to research participants and others: You will have an opportunity to enjoy and comment on a new VR experience under active development. Your feedback will help improve the experience for future players.

Record keeping and confidentiality: Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: There is no foreseeable risk of injury associated with this research study. Nevertheless, you do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, please contact the research team at our group alias gr-kyoto-vr-mqp-b21@wpi.edu, or any of our individual emails listed above. You may also contact the IRB Manager (Ruth McKeogh, phone 508 831-6699, email irb@wpi.edu) and/or the Human Protection Administrator (Gabriel Johnson, phone 508-831-4989, email gjohnson@wpi.edu).

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

____________________________________ Date: ____________________

Study Participant Signature

____

Study Participant Name (Please print)

_____________________________________ Date: ____________________

Signature of Person who explained this study

Appendix C: Advertising to WPI Student Body and Playtesting Pre-Screening Questions

Subject: Virtual Reality Playtesting Opportunity

Body:
Hello everyone!

This is Madeline and Elaine, and we are seniors working on our MQP. For our project, we are creating a virtual reality audio-visual experience and are looking for students interested in playtesting!

A playtesting session would take around 10-15 minutes maximum to complete, and involves putting on a VR headset, playing through our project, and answering a short series of questions about your experience. More information about the exact steps of the study can be found here: [LINK TO STUDY PROTOCOL]

In order to guarantee the safety of participants, all individuals interested in this study must complete our pre-screening survey. If you pass the screening, we will reach out to you with more information about setting up a time to come and complete the playtesting session.

The screening survey can be found here: [LINK TO PRE-SCREENING QUALTRICS SURVEY]

Thank you so much for your interest!
Elaine Chen
Madeline Perry

Pre-Screening Survey:

Are you 18 or older?

- Yes
- No [TERMINATE]

Are you comfortable with VR Equipment?

- Yes
- No [TERMINATE]

Are you prone to feeling dizzy?

- Yes [TERMINATE]
- No

Are you prone to feeling lightheaded?

- Yes [TERMINATE]
- No

Are you prone to feeling nauseous?

- Yes [TERMINATE]
- No

Do you have a history of low blood pressure or fainting?

- Yes [TERMINATE]
- No

Do you have a history of vertigo?

- Yes [TERMINATE]
- No

Are you currently pregnant?

- Yes [TERMINATE]
- No

Have you ever used VR (Virtual Reality) or AR (Augmented Reality)?

- Yes
- No

Please select the option that best corresponds to your current state of vision.

- I have normal vision and do not require the assistance of glasses or contact lenses.

- I have normal-to-corrected vision for both eyes and require the assistance of glasses or contact lenses which I own.
- I have normal-to-corrected vision for one eyes and require the assistance of glasses or contact lenses which I own.
- I am blind in one or both eyes. [TERMINATE]

Please select the option that best corresponds to your current state of hearing.
- I have normal hearing and do not require the assistance of hearing aids or other hearing devices.
- I have normal-to-corrected hearing for both ears and require the assistance of hearing aids or other hearing devices which I own.
- I have normal-to-corrected hearing for one ear and require the assistance of hearing aids or other hearing devices which I own.
- I am hard of hearing. [TERMINATE]

Are you highly prone to motion sickness? (From travel, heights, roller coasters etc.)
- Yes [TERMINATE]
- No

Have you ever had a brain injury that resulted in memory loss or unconsciousness?
- Yes [TERMINATE]
- No

Do you have difficulty standing for long periods of time?
- Yes [TERMINATE]
- No

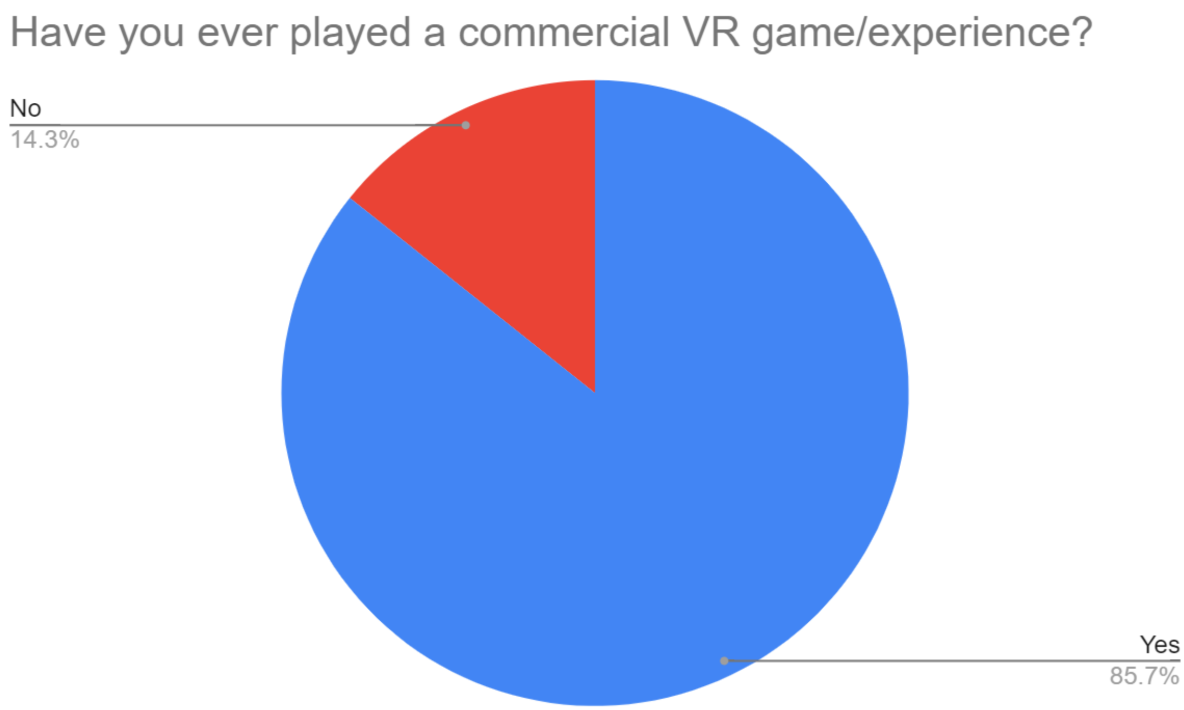
[If none of the terminating conditions are met] You have passed our prescreening questions and are eligible for participating in our playtesting session. Please provide your email below so we can reach out with follow up information. Thank you!
[Short answer response]

Appendix D: Playtesting Post-Experience Survey

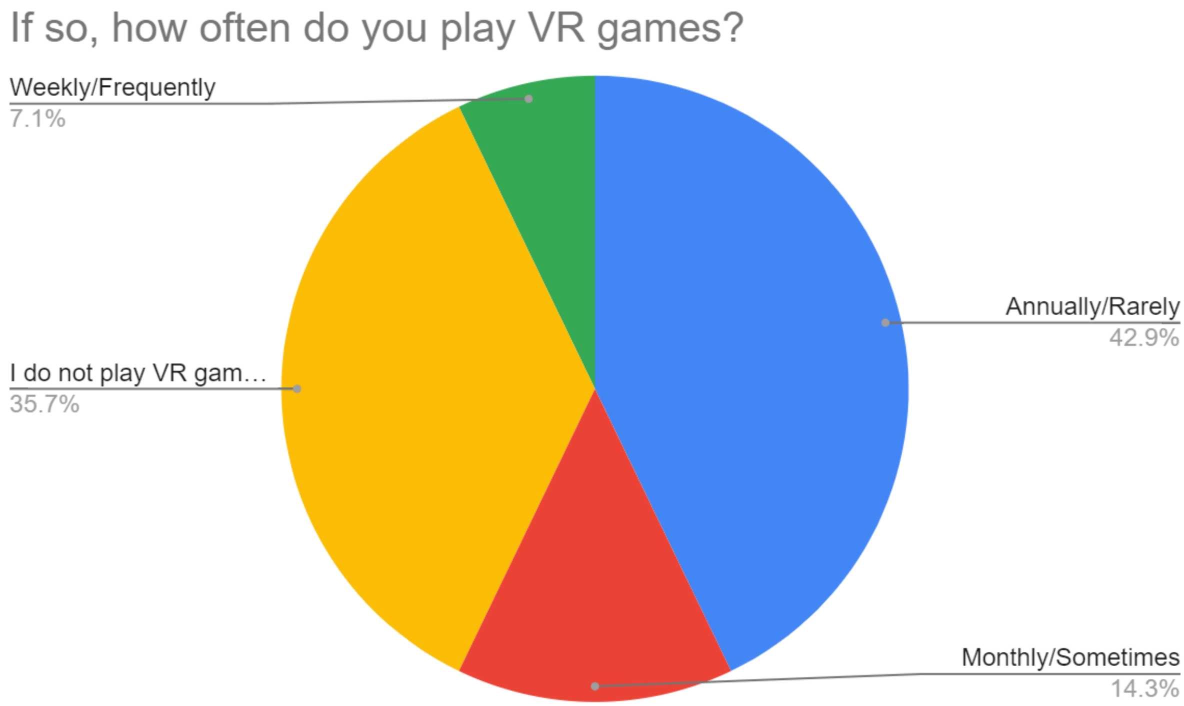
1. Have you ever played a commercial VR game/experience?
2. If so, how frequently do you play VR games?
    - Daily/Very Frequently
    - Weekly/Frequently
    - Monthly/Sometimes
    - Annually/Rarely
    - I do not play VR games.
3. What emotions did you experience while you were in the VR space?
4. On a scale of 1-4, how relaxed did you feel during the experience?
   [Likert Scale 1-4] 1 = Not Relaxed, 4 = Very Relaxed
5. Did you have any difficulty interacting with the VR space?
6. How did the music make you feel?
7. Some parts of the music composition are procedurally generated. Please rate your thoughts on the music.
   [Likert Scale 1-4] 1 = Not Enjoyable, 4 = Very Enjoyable
8. What are your thoughts on the timing of the experience?
9. Did you come across any glitches or bugs that we should be aware of?
10. In general, do you have any feedback on improvements that could be made to this VR experience?
11. How much did spatialized sound have an impact on your experience?
    [Likert Scale 1-4] 1 = Little Impact, 4 = Large Impact
12. Did you feel motion sickness at any point during the experience?
13. If so, please elaborate how you experienced this motion sickness or when during the experience you felt it. (If you did not experience motion sickness, please respond with N/A)

Appendix E: Playtesting Results

Question 1.)



Question 2.)


If so, how often do you play VR games?
Weekly/Frequently
7.1%
Annually/Rarely
42.9%
I do not play VR gam…
35.7%
Monthly/Sometimes
14.3%

Question 3.)

What emotions did you experience while you were in the VR space?

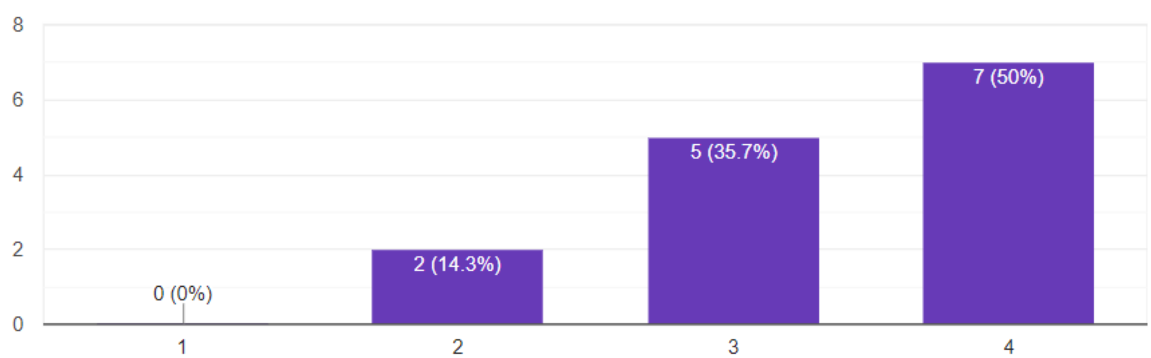
14 responses

- Intrigue
- Calm/Curiosity
- Curious and slightly confused
- empty
- curiosity mainly, seemed calm
- A lot of confusion. I was not really sure what to expect or what to do. There was no guidance on what to do either, so I just felt misguided and unsure of how to react to my surroundings.
- wonder, confusion, intrigue
- calm, relaxed, chill, vibez
- calm, curious
- I felt calm and relaxed, especially with the sounds. At times where I thought there was nothing to do, I panicked a bit because I felt like something was going to jump scare me.
- Joy, excitement, confusion
- Kinda calm feeling!
- Calm and curious
- Calm, curiosity

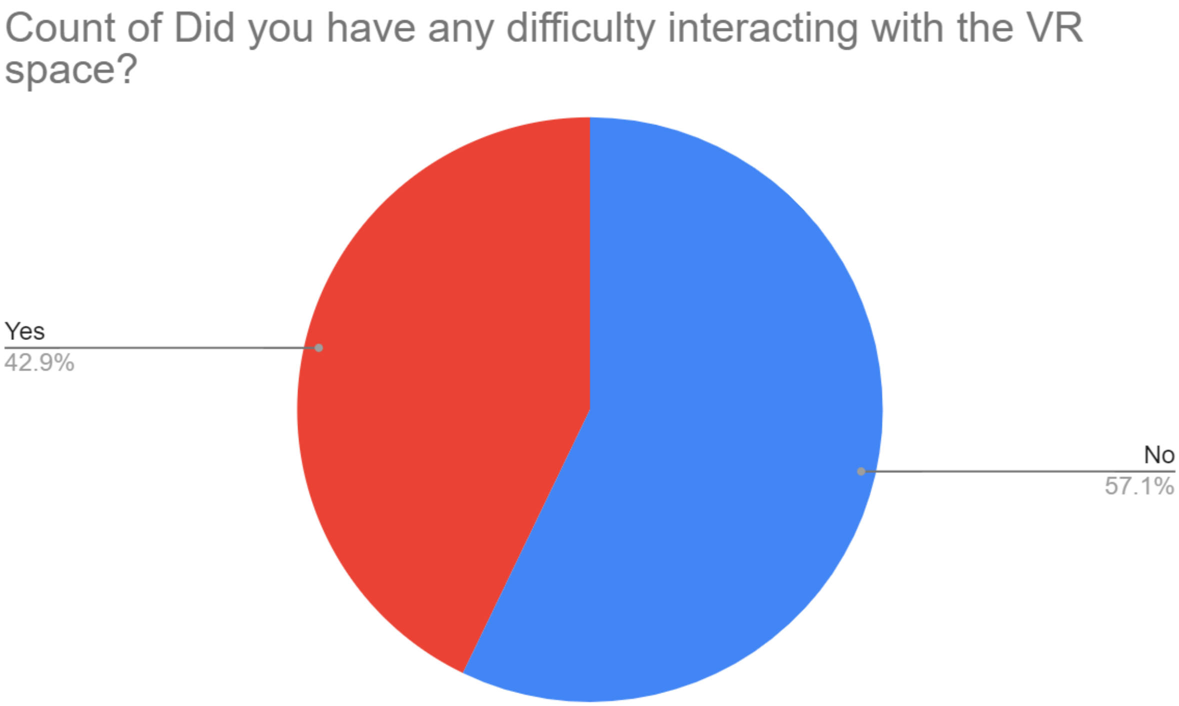
Question 4.)

On a scale of 1-4, how relaxed did you feel during the experience?

14 responses



Question 5.)



Question 6.)

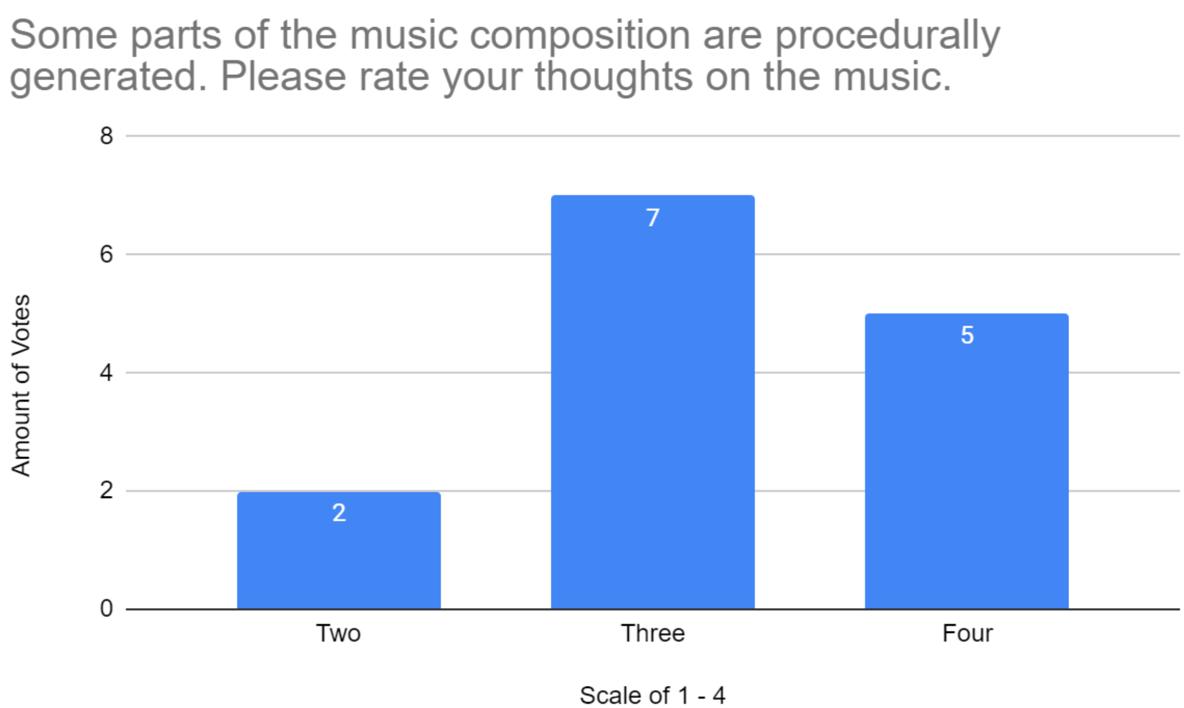
How did the music make you feel?

14 responses

- Calm
- calm but alert
- Empty
- okay
- the music was nice, generally calm. i could see how the second scene may be a bit high pitched if someone had hearing problems
- I did not pay attention to the music too much. I felt like it matched the atmospheres perfectly, though. In the first world, the music was very low and made me feel a bit unsettled as there was not a lot of stimuli to react to. In the second world, the music made me feel on edge because I thought I was going to have to fight something as it felt like a boxing match.
- light and magical
- love the synth, low tones were great, I dont know what the progression of the synth or soundscape was, but I definitely wanted to hear more.
- alert but relaxed

- The music helped a lot to calm me down. However, it felt like music from a horror movie. In general, I really enjoyed it and it helped calm me down a lot, especially after a long day.
- contemplative
- The music was calm and relaxing! Like sitting and drawing outside or something like that.
- Great volume and placing and panning was not intrusive
- Captivated

Question 7.)



Question 8.)

What are your thoughts on the timing of the experience?

13 responses

- I was a bit confused on the timing for the first part, I felt like I should be doing something or going somewhere and couldn't figure out what (though that may differ for people who are not accustomed to VR and needing time to get controls/movement down)
- The ending when the leaves all "died" was a little bit too sudden and almost felt like a bug
- very well timed
- they timing felt okay, i think my time in each of the two scenes may have been a bit long

- The first world felt very short while the second world felt very long. I felt like I was in the VR for a good amount of time -- again, I was not really sure what to expect, so I had no expectations for the length of time I would be in the experience. I felt like I was in the second world for much longer than the first because I was actually interacting with something. The leaves get moving around and I was not sure what to do, so it made it feel much longer.
- I was a little confused about how long things were supposed to go and what I was supposed to do, but overall it felt like I had enough time to interact in the second part, but the first part I was a little lost on what to do in the first part and wish I had more time to explore
- I wanted to be in there longer, is there a set time limit, I was only in the experience for 5-10 minutes
- I was a little bit lost at the beginning in the circle and it felt like it lasted a little too long (or i didnt understand it was a meditation circle)
- I thought the timing of the experience was a good amount. Maybe something a but longer -- 15 minutes -- would drastically help my anziety levels to calm me down. In terms of the time of day that I had this experience, it was great. My stress levels decreased after a long day of meetings and work.
- the beginning was a bit long, but once the leaves came it was well timed
- I think the first part was a bit long? Maybe? I was confused for a bit until it faded out, but otherwise it was fine!
- It was good
- The first space was shorter than I would have liked it to be. I wish I had a bit more time to explore it after figuring out the controls.

Question 9.)

Did you come across any glitches or bugs that we should be aware of?

14 responses

- One of the butterflies was stuck to my left hand. Not sure if that was a feature or not
- Choppiness of boids - and they seem to react to my right hand a bit? They're still fun to play with though
- The moth in my hand was glitching the entire time so it was distracting from the whole experience
- Butterflies clashed within eachother
- the falling leaves/butterfly things seemed to glitch out a bit in their motion. they jittered around a lot and moved strangely. They also had a tendency to bunch up together. I also found it very difficult to interact with the leaves but one accidentally fell into my hand? Not sure if that was meant to be intentional?
- I do not remember any bugs.

- I was walking out of bounds, so that was less a bug as much as a break from immersion. sometimes the butterflies would also glitch onto my hands before fluttering off, which detracted from realism
- not that I was aware of.
- the in-game ground felt a little out of sync with the irl ground
- No, I do not think so.
- Not that I could see
- I don't think so? I feel like the way the leaves moved and bunched up around my left hand was intended, so I believe that was fine.
- Nothing I am aware of
- I didn't see any glitches or bugs.

Question 10.)

In general, do you have any feedback on improvements that could be made to this VR experience?

14 responses

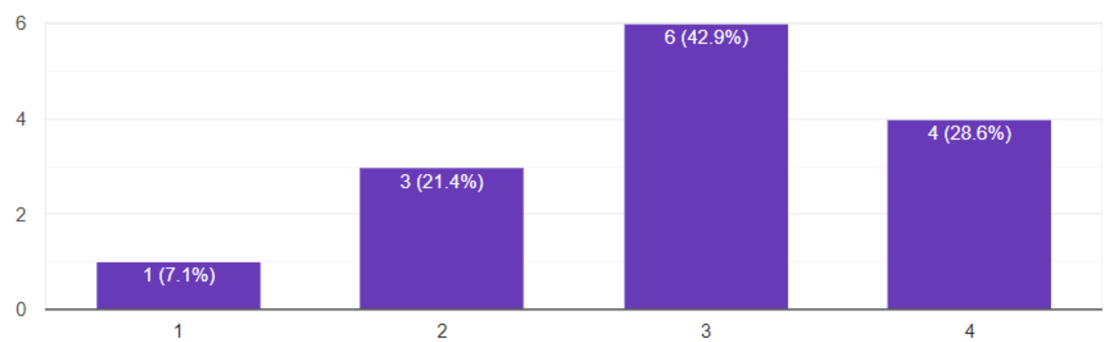
- The beginning part with the elevation change in the middle felt weird to walk on without the joystick since I would trip over myself because of my brain thinking it was a staircase in real life
- some light particle trails on the boids might be a cheap way to make it more visually dynamic, and distract from the specifics of the boids movement
- More moths? I wasn't sure what I was expecting when walking into the space and did not know where to look at until pointed out. But I can see this as a later stage of development for the environment that might be outside the scope of the project. It was very promising overall.
- Imporve the Loudness of sounds and levels.
- the music transition from scene 1 to 2 was a bit jarring, smoothing that audio may be beneficial. also maybe some sort of intro scene just explaining the motion controls on the joysticks.
- I do not have any feedback. Ideally, I would have liked a more objective-based experience, but I am not sure of this project's goal, so that might not be an appropriate change.
- The volume could be a little louder personally, and the differentiation of frequencies could be a little larger for my poor tone hearing
- I wanted to be able to watch the animations, without having to interact with them.
- audio queue/sound effect when leaves spawn in
- Maybe the experience should include some activities to do during it. It felt awkward to just explore.
- I don't think so, it seemed really cool and fun.

- Maybe shorten the first portion a bit? Otherwise, I liked how it is, it felt fun to play around with the leaves and watch them follow my hand.
- The hands were a little reflecty but besides that everything worked great!!
- At the end of the second segment, the leaves float motionless near the bottom of the area. I would have found it more enjoyable if the leaves had faded out while hitting the bottom of the bound instead.

Question 11.)

How much did spatialized sound have an impact on your experience?

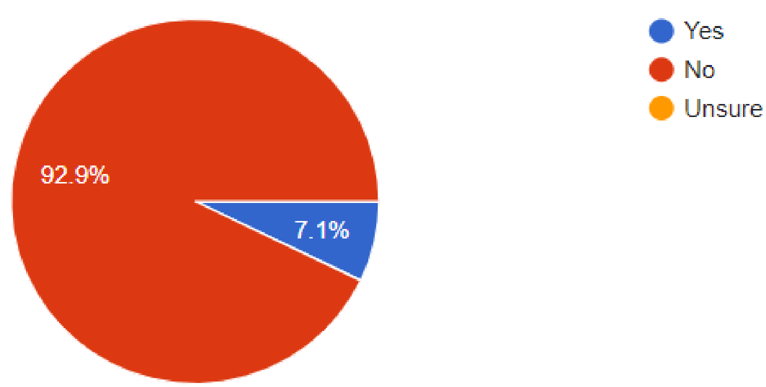
14 responses



Question 12.)

Did you feel motion sickness at any point during the experience?

14 responses



Question 13.

If so, please elaborate how you experienced this motion sickness or when during the experience you felt it. (If you did not experience motion sickness, please respond with n/a)

14 responses

- Mild sensory mismatch while standing on center platform (floor is further than my feet, so if I am looking down while moving around it is a bit disorienting/dizzying)
- I didn't feel sick but the right stick turning felt a little bit choppy so I didn't use it. If I had used it instead of turning my head I might have felt more sick
- n/a (x12)

Appendix F: Project Schedule

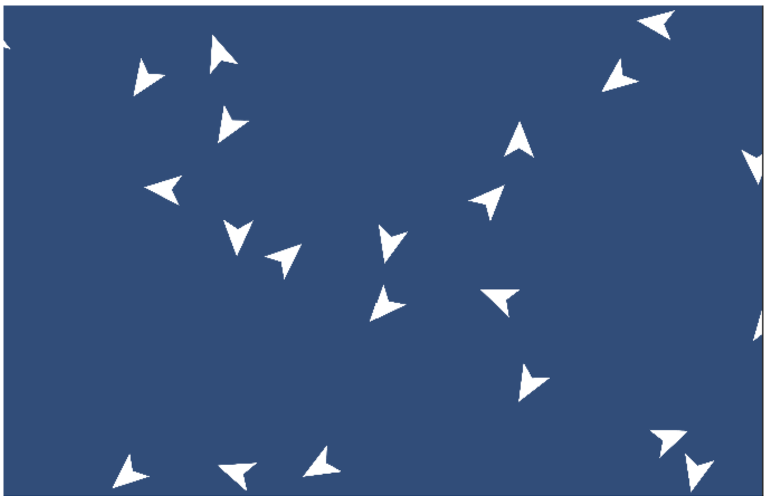
PROJECT TITLE	Tsuboniwa: A Garden Dream							
ADVISORS	Professors Jennifer deWinter, Charles Roberts							
TEAM MEMBERS	Elaine Chen, John Frazia, Laurie Mazza, Madeline Perry							
Key:	Complete		Debugging/Revision		Current Work		Prep Work	
Date	**WEEK 1**	**WEEK 2**	**WEEK 3**	**WEEK 4**	**WEEK 5**	**WEEK 6**	**WEEK 7**	**WEEK 8**
Prep								
Logistic work - Creating schedules, discussing minimum viable product	Complete							
Unity Tutorials	Current Work	Complete						
Securing Equipment	Prep Work	Current Work	Current Work	Complete				
Development								
Flocking Implementation	Prep Work	Current Work	Current Work	Debugging/Revision	Complete			
Flocking Behavior		Prep Work	Current Work	Current Work	Current Work	Current Work	Debugging/Revision	Complete
VR Integration			Prep Work	Current Work	Complete			
Audio Development		Prep Work	Current Work	Current Work	Current Work	Current Work	Debugging/Revision	Complete
Narrative/Scene Development				Prep Work	Current Work	Current Work	Debugging/Revision	Complete
Playtesting								
Alphafest Demo			Current Work	Complete				
IRB	Prep Work	Prep Work	Current Work	Current Work	Current Work	Debugging/Revision	Complete	
Official Playtesting						Prep Work	Complete	
Paper								
Planning	Prep Work	Prep Work	Current Work	Debugging/Revision	Complete			
Writing				Prep Work	Current Work	Current Work	Current Work	Complete

Appendix G: Project Gallery

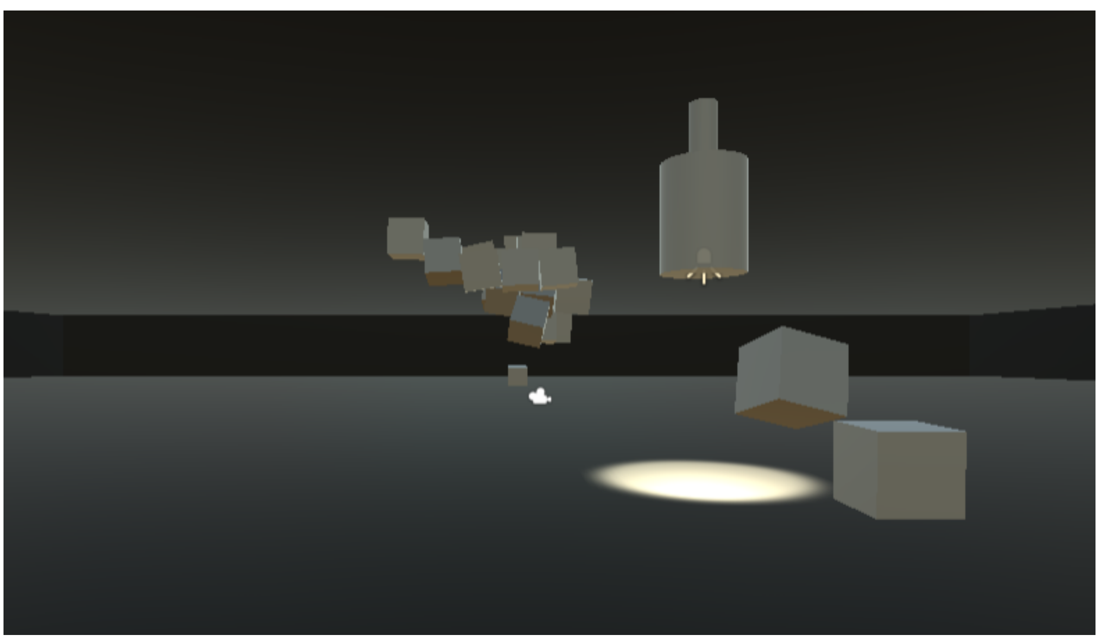
Additional photographs and screenshots taken over the course of the term.

Flocking Progress

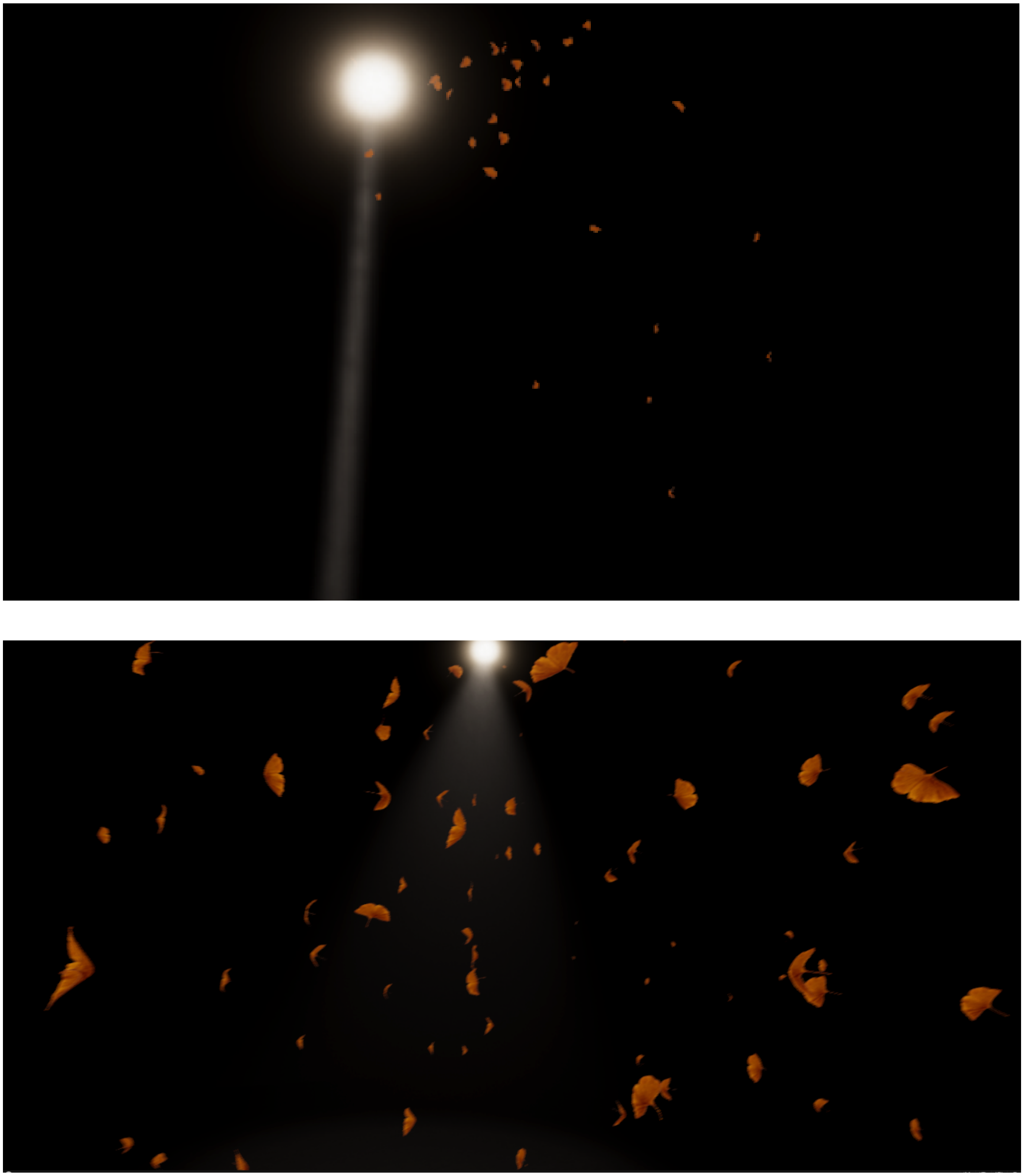
Our flocking algorithm went through many iterations, both in the code and visually.



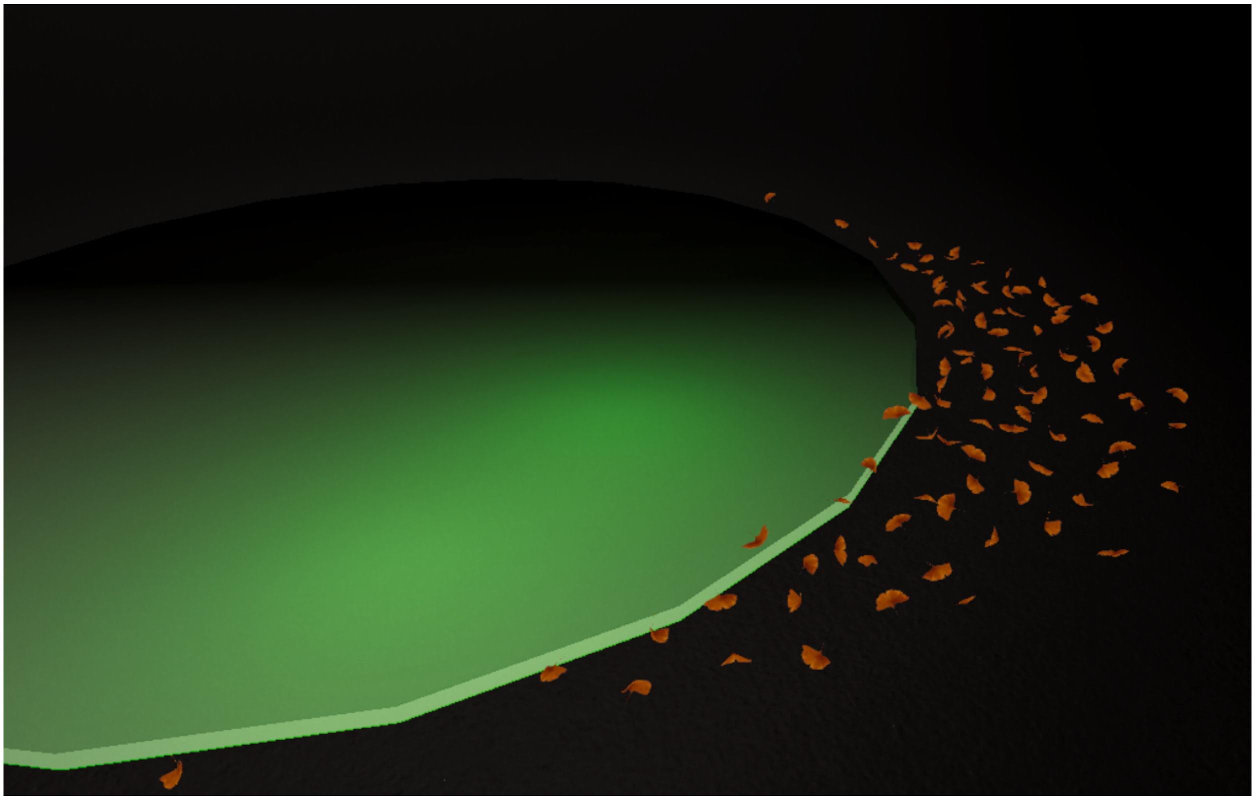
Week 1 2D flocking implementation using sprites on a plane.



Earliest 3D flocking implementation, done with cubes.

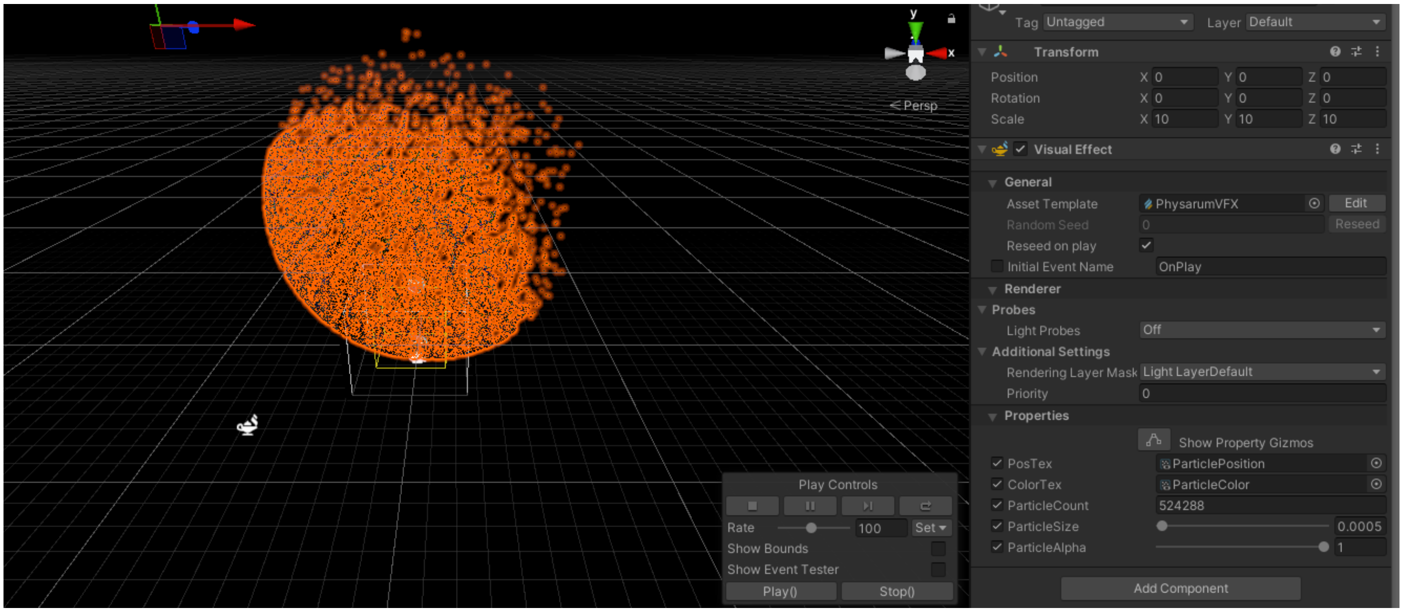


Final 3D flocking implementation using the animated leaf asset Atticus Sims provided.

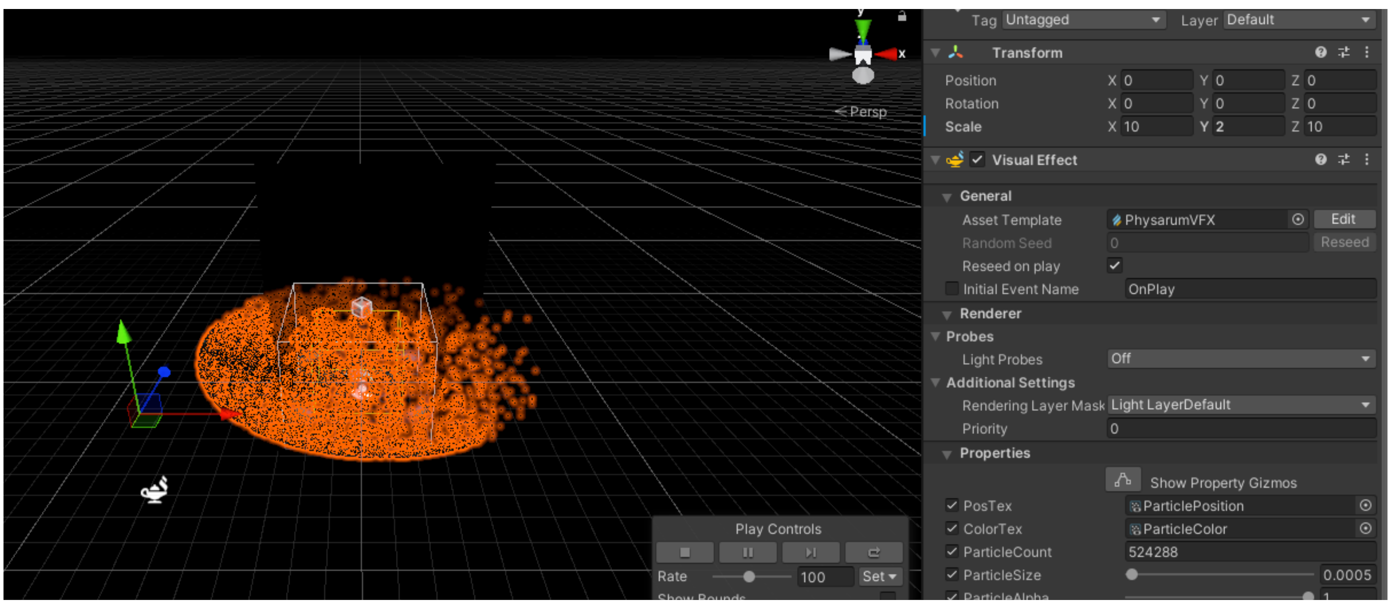


Moth death

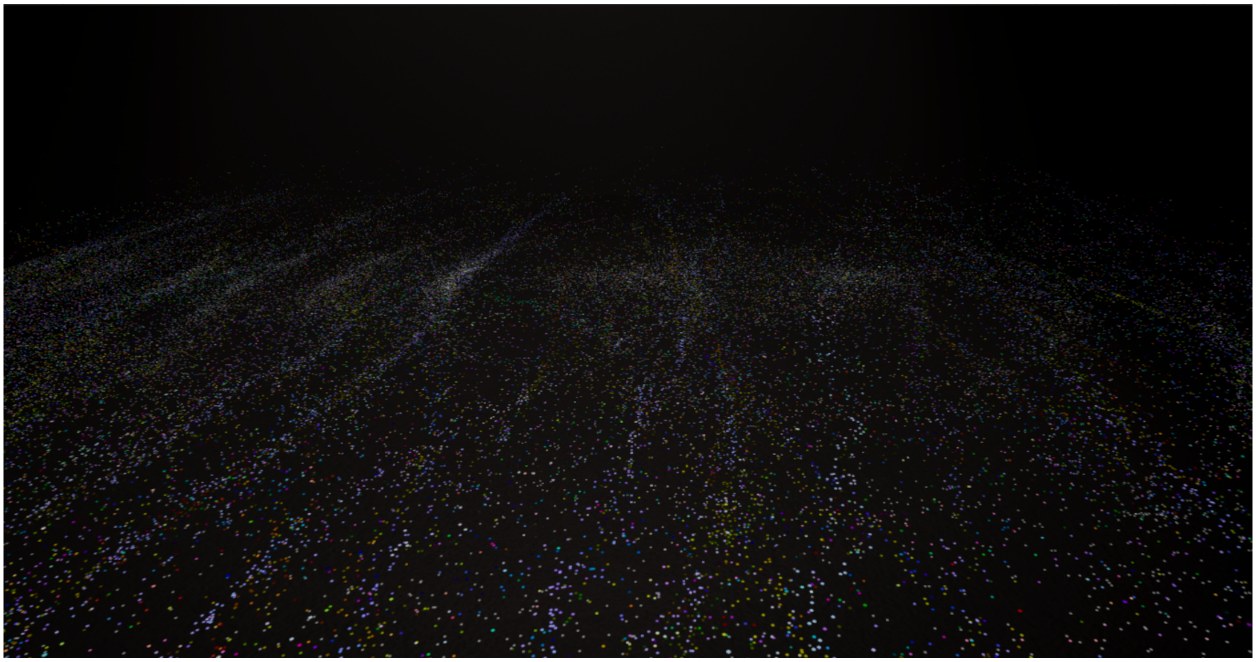
Physarum Progress



Before adjusting the vertical size of the sphere



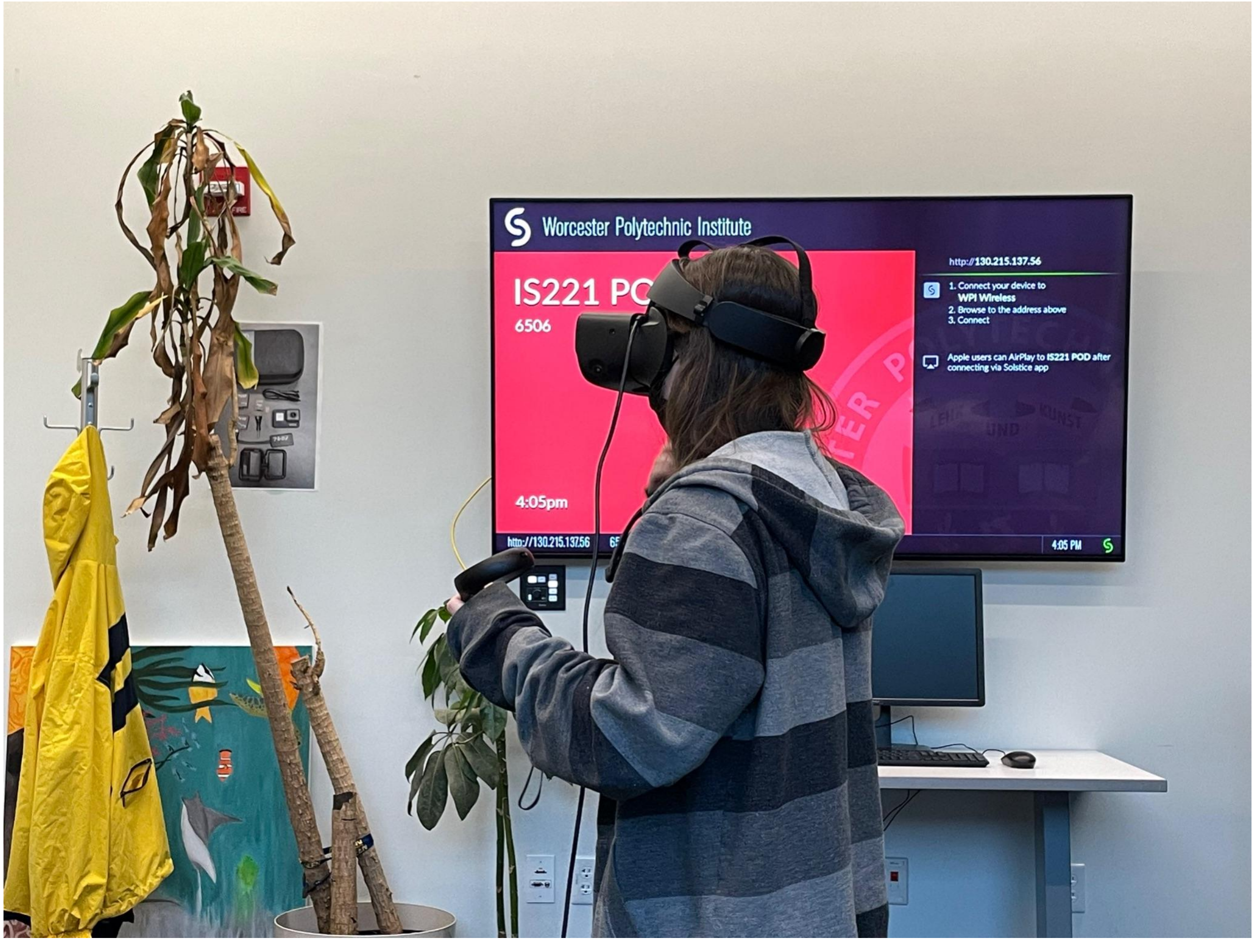
After adjusting the vertical size of the sphere



Physarum implemented in experience

Team Photos

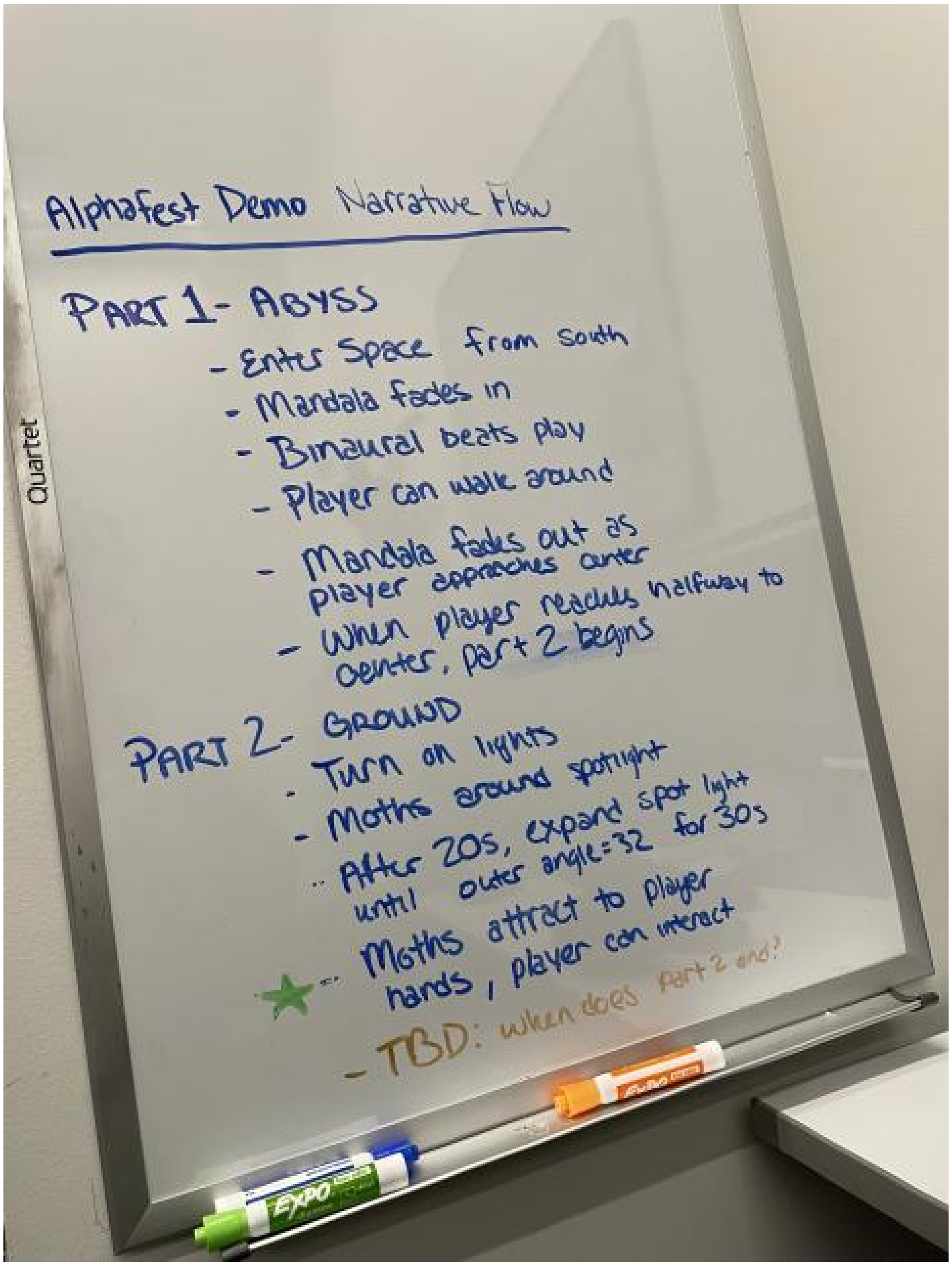
A typical afternoon in the Global Lab.



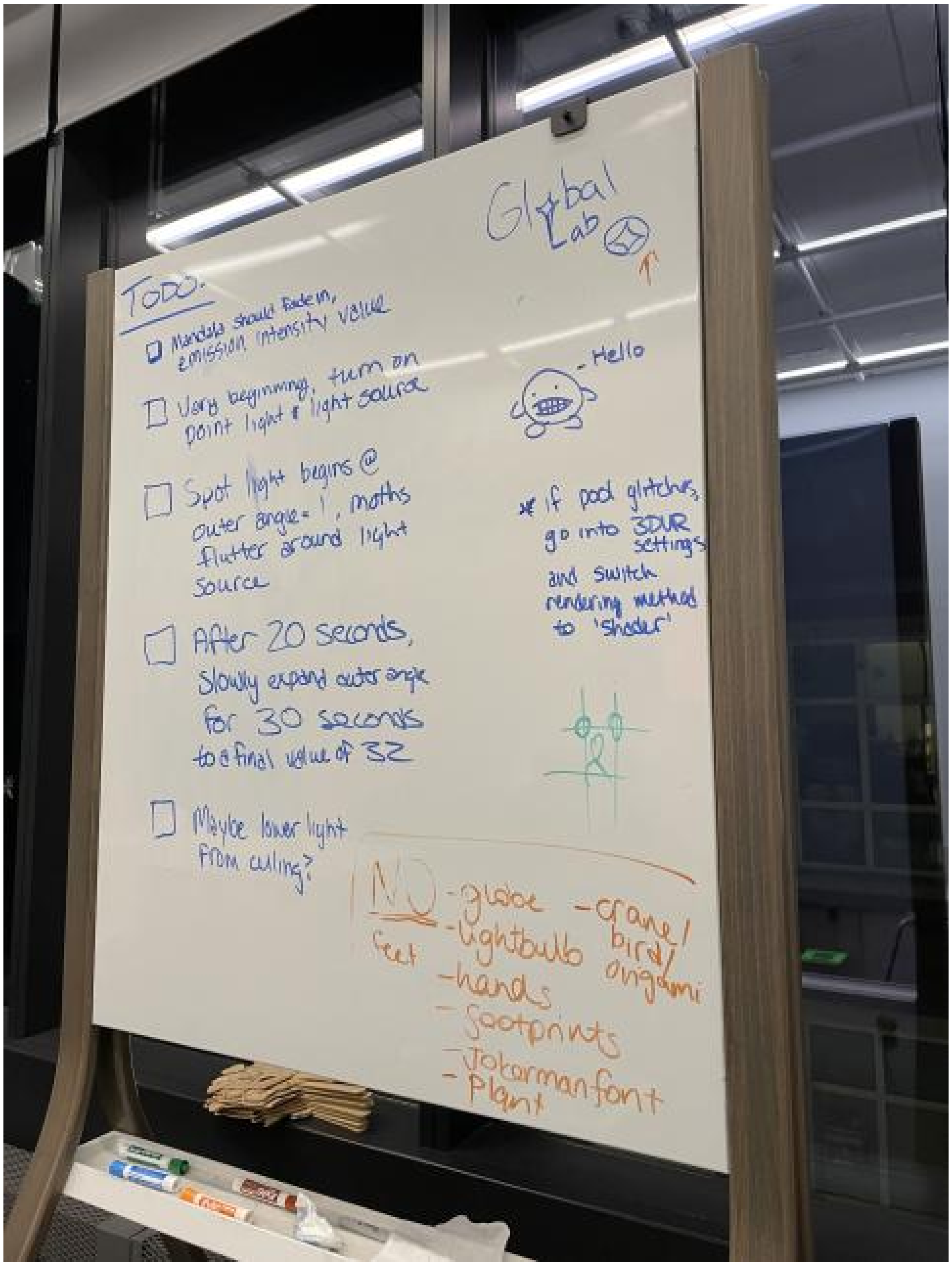
Madeline testing the experience to find any bugs or errors.

Priority Boards and To-Do Lists

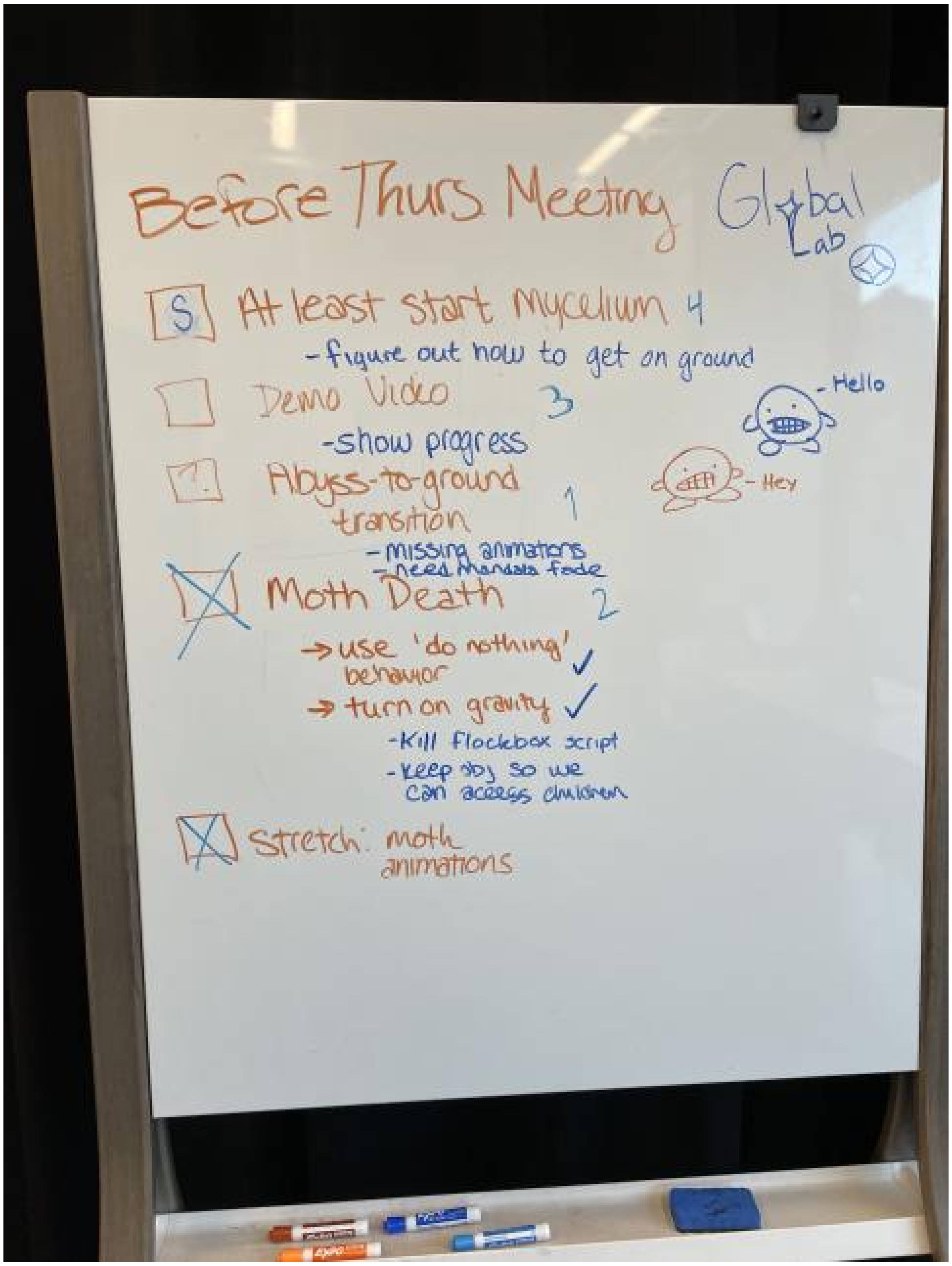
After we started utilizing the Global Lab as our work space, we made use of the white boards in the room to track our progress and goals for each week.



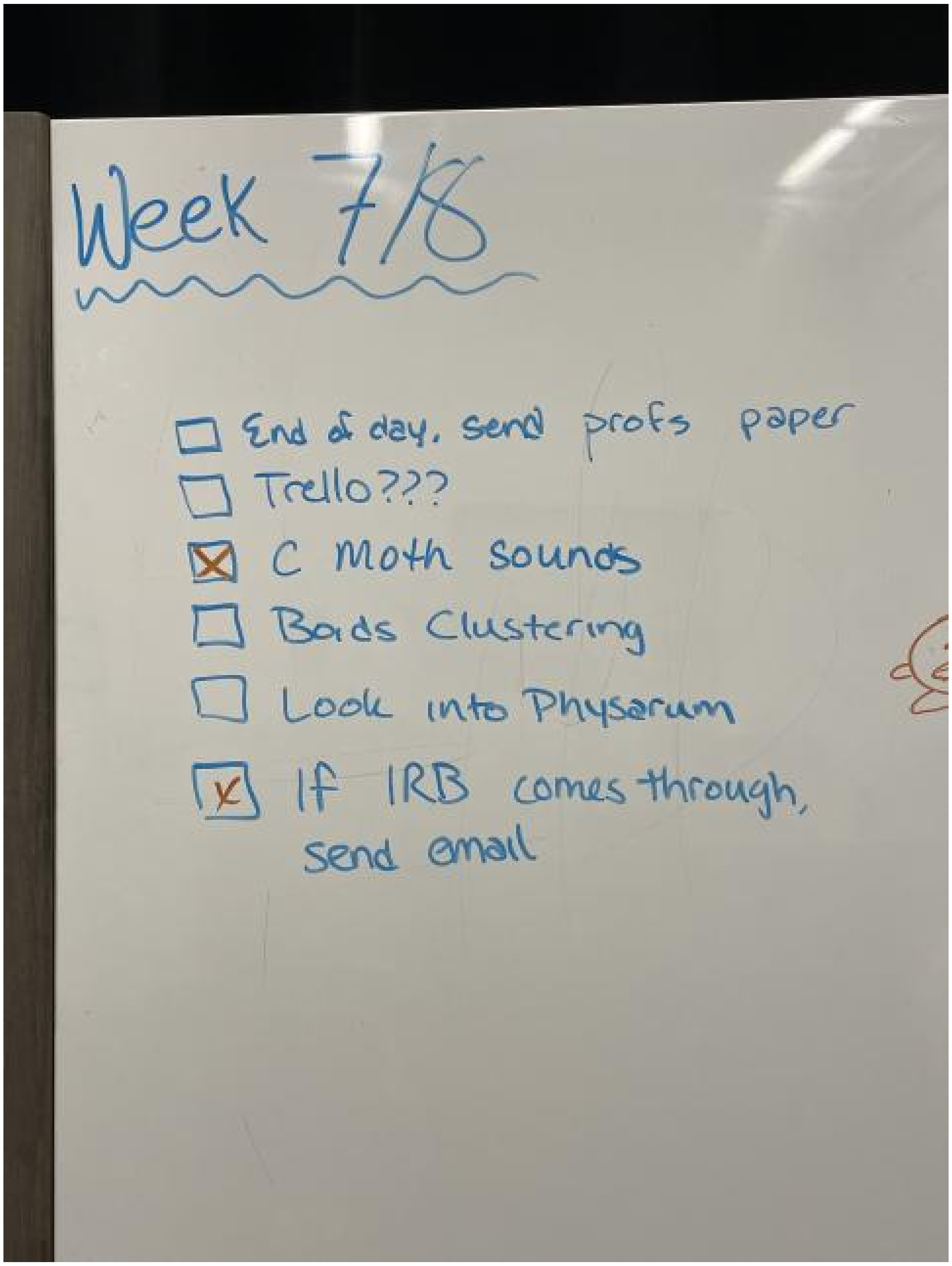
Week 4 Priority Board



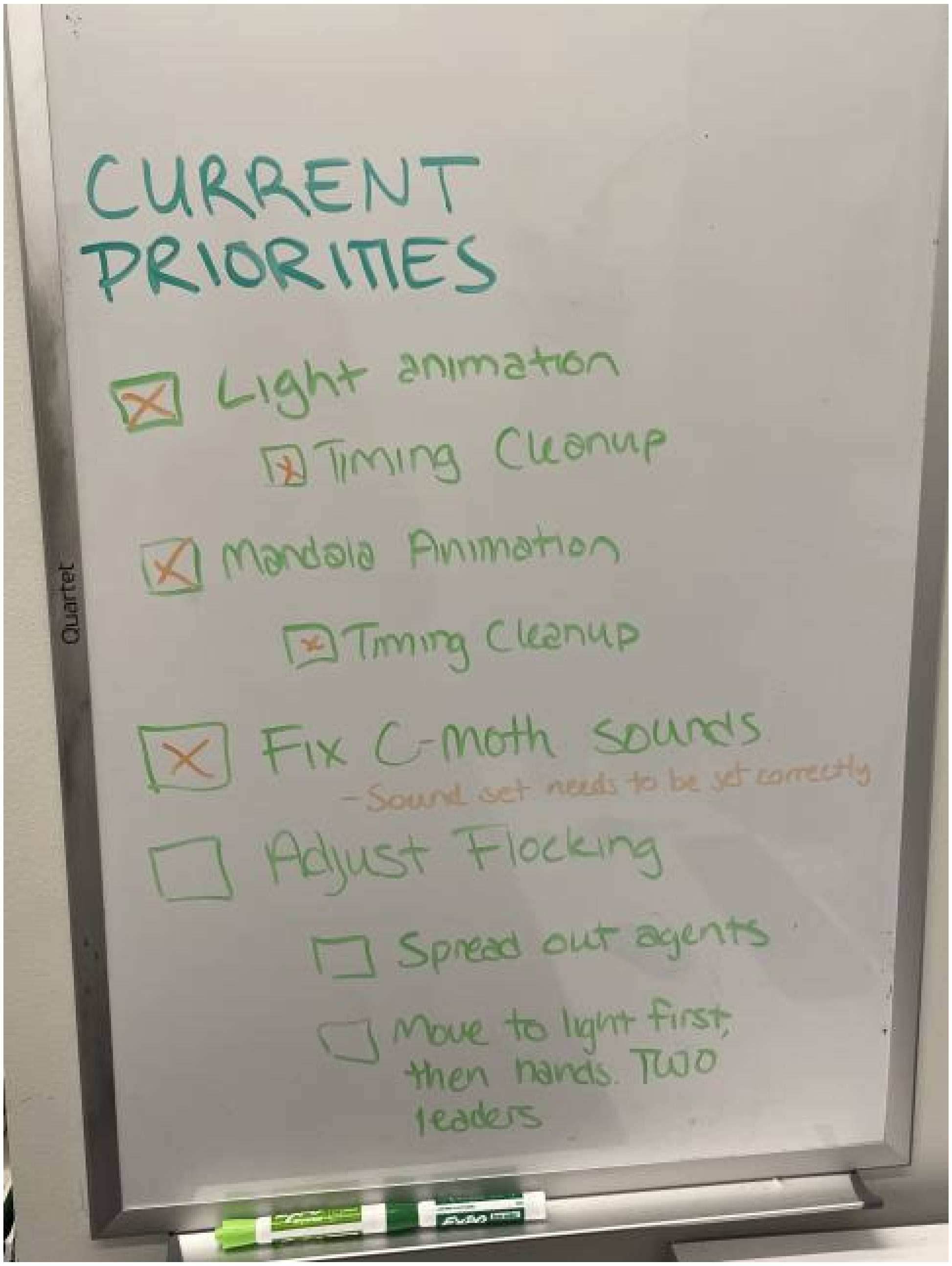
Week 5 Priority Board/Notes (blue only)



Week 6 Priority Board



Week 7 Priority Board



Another Week 7 Priority Board