The Bee Box

Combining Mixed Reality and Tangible User Interfaces for Collaborative Storytelling for Education

QIANYI CHEN

UC Berkeley, qianyi.chen@berkeley.edu

AKASH MAHAJAN

UC Berkeley, akash_mahajan@berkeley.edu

ELI PLEANER

UC Berkeley Graduate School of Education, epleaner@berkely.edu

YUTING WANG

UC Berkeley, kathytw@berkeley.edu

YIYAO YANG

UC Berkeley, a-y@berkeley.edu

We explore the design of meaningful collaborative pathways between physical and digital environments. To demonstrate this design potential, we have constructed the Bee Box, a mixed reality, nature-based educational storytelling experience meant to be interacted with by two players. The Bee Box consists of a physical, miniature garden box with real soil and moss, and a virtual rendering of this garden box to be explored within a VR headset. The player at the physical board takes the role of a gardener, while the player in the VR environment takes the role of a bumblebee. The task of the two players is to collaborate towards enabling the bumblebee to pollinate the garden and live within a healthy ecosystem. This experience is enabled technologically by bidirectional sensor-based feedback, in which actions done on the physical board result in meaningful changes in the virtual environment, and vice versa. We contend that such a mixed reality design has many potential applications, including other educational domains as well as within therapeutic and social computing contexts.

CCS CONCEPTS • Collaborative and social computing • Education • Interaction Design

Additional Keywords and Phrases: Augmented Reality, Virtual Reality, Mixed Reality, Nature-Based Learning, Embodied Learning

1 INTRODUCTION

What is it to be embodied in a hyper-digitalized world? How do we design meaningful interactive pathways between physical and digital environments? What unique affordances do these multi-modal, mixed reality pathways provide? And what does it mean to collaborate in different "realities"?

We explore these questions in the context of a collaborative nature-based educational experience. This design experience is meant to demonstrate unique affordances of such a mixed reality environment, acting as a case study for one of many potential applications of this emerging technological space. Our intention for this case study is to explore the possibilities and challenges around designing successful, collaborative mixed-reality environments.

As virtual reality becomes more prevalent, it has been criticized as a form of immersive escapism [8]. Though motion tracking software often enables a more embodied form of experience than traditional video games, the fundamental disconnect between the virtual and the physical space directly limits the richness of one's experience within virtual reality. There is a sense of magic that is lost, upon removing a virtual reality headset, seeing that the world around you has not changed, despite the incredible virtual journey you may have found yourself on. We aim to maintain this sense of magic, and augment it, in the form of a technological dialogue between virtual and physical spaces.

Regarding affordances of virtual reality, our design highlights the attribute of scale: placing the virtual reality user's perception in a different scale than the player at the physical board. Digitally rendered environments enable this in a way that is not easy in physical spaces. In doing so, scale becomes an element of story-telling: as scale affects perception, perception affects identity, and one feels that they are not playing themselves anymore. The perceptual paradigm is new, foreign, and exciting. Beyond this excitement, this novel perceptual paradigm supports the development of empathy, as a player finds themselves seeing the world in ways that they have never seen before.

In sum, our design seeks to blur the lines between the physical and the digital, creating a technologically permeable membrane for multi-modal exploration. Actions that take place in the physical board result in meaningful changes in the virtual space, and vice versa. Players must work together, seeing the world in radically different ways made possible only through emergent technology.

2 Related Work

While in many VR and AR experiences the player interacts with only digital content, tangible user interface (TUI) [3] can add physicality to such digital experiences. According to Thomas [7], being able to use physical objects as input devices plays an important role in engaging the player in the game. One such physical input is a marker that can be recognized by the computer. For example, Jumanji Singapore, a board game system consisting of a tangible board, VR world, and AR world, uses physical cubes with markers on the surface of each side. When the player rotates the cube, similar to rolling a die, the marker is read as input and triggers changes in the game. In the case of Jumanji Singapore [9], one cube is used as a die to determine how many steps the player can go forward and another cube handles more complex input such as the navigation of the player in the VR world. Since the marker is customizable, a variety of information can be sent from the tangible part to the virtual environment in AR or VR.

Another way of mapping input from the tangible element is using data obtained from physical sensors. For example, Inner Garden [5] utilizes biometric data gathered from Electroencephalography (EEG) as input to control the water level of the virtual environment, which is projected on a physical sandbox. Furthermore, Inner Garden utilizes physical avatars placed on the board. The location of these avatars are tracked and used as another type of input to coordinate the location of the player in the VR environment.

VRBox [2] and VR SandScape [6] use a sandbox setting similar to Inner Garden, further exploring the interaction dynamics between tangible and virtual spaces. Compared to Inner Garden, where the player can only change the shape of the environment, VRBox affords the player more creative freedom by providing virtual objects in the VR environment for the player to drag and place on the scene. VR SandShape investigates the interactions between two players in a tangible sandbox system and VR environment, where each player has control over either the VR side or the tangible side. This introduces myriad interactions between the two environments, and necessitates communication and understanding between players.

In collaborative experiences, a tangible object has been used to physically represent one player in a virtual space. In Piumsomboon's work [4], the tangible interface is a 360-camera that can be moved by an AR user. The camera's view is also shared with a VR user. In addition, this study introduced a multi-scale collaboration between two users, called Giant-Miniature Collaboration (GMC). Two players in the collaboration have different scales of avatar and therefore observe the environment from different perspectives. Therefore, the dynamic between two users in this setting includes the differences in scale and the power of control, which introduces different perceptions of the environment and novel problem-solving dynamics.

Our work contributes to investigating the value of having tangible interaction in mixed reality collaborative gameplay, and how multiple scales and perspectives of players bring important dynamics in collaborative and educational contexts..

3 Design Overview

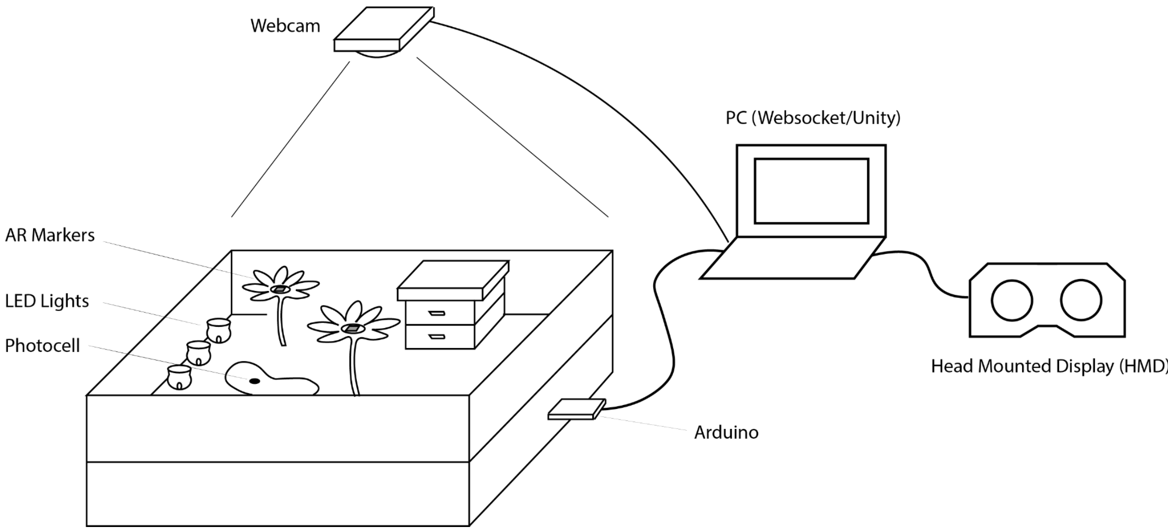

Figure 1: Design of the Bee Box interaction system.

Our work, Bee Box, is a mixed reality play space for multiple people to learn collaboration through play. As shown in Figure 1, this system includes two parts: a tangible board and a digital environment. The tangible board consists of physical objects which can be moved by the player, and electronic outputs such as LED lights, and electronic inputs such as photorecells. The digital environment is built with Unity for the VR player to interact with using Head Mounted Display (HMD).

In this prototype, we carefully chose a garden as the theme in order foster collaboration and nature-based awareness. Both the tangible board and the virtual environment in VR portray a scene of a garden using either physical materials or digital assets. The player on the tangible board side plays as a gardener, and the role of the VR player is a bee in the garden. As the bee is small in size, the VR player was able to explore the environment in a different way than the tangible board player. This difference in scale utilizes the affordances of VR, helping develop empathy through embodiment experiences [1]. Furthermore, the difference in perspective between the two players helps create incentives for communication, as each player has unique capabilities in their respective environments.

We designed tasks and instructions in this system to be exploratory and open-ended. For example, one objective is for the gardener to plant flowers in the physical garden, which will allow the bee to collect pollen in the virtual environment. We do not directly communicate this objective, and intend for this to be inferred through exploratory dialogue between the two players, as they evaluate the objects available to them. As another example, the bee requires a small pond to drink from, and needs to communicate this need to the player in the physical board, who has water but does not initially know what to do with it.

The tangible board and the VR environment are in synchronization via marker-based location tracking and two-way serial communication between Arduino and Unity, enabling both sides to receive real-time feedback from the other. For example, when the tangible board player completes several tasks, the VR side receives this information in real-time and triggers changes in the VR environment, and vice versa. This two-way communication brings huge potential for the two players to have sequential interactions and collaborations.

4 Prototype Implement

4.1 Tangible Board

Figure 2 shows the structure of our AR box. The box is composed of two layers, which separate into two independent open boxes with the same dimension (length: 15'', width: 13'', height: 4''). The top layer is used to hold the physical garden, and the base layer is used to store the Arduino boards. The box is made of 1/8'' acrylic sheets. We cut the acrylic sheets using a laser cut machine and glued the pieces together using superglue. In order for the wires to go through, we cut holes (diameter: 0.5'') on the bottom of the top box. The location of the holes was chosen based on the placement of sensors and objects. We also cut two holes (diameter: 1'') on the two sides of the bottom box for the cords that power the Arduino boards.

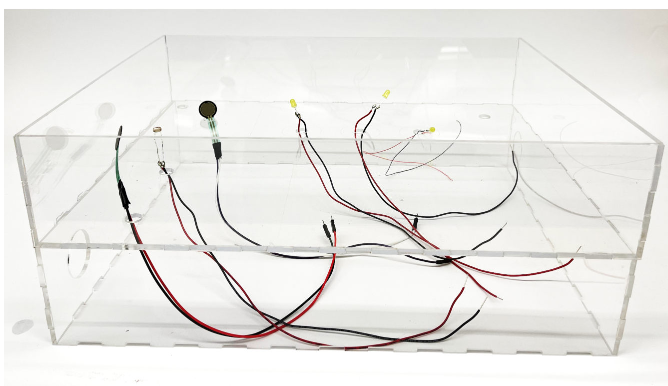

Figure 2: Structure of the boxes with photoresistors and LED lights.

The garden is placed in the top box, with its structure illustrated in Figure 3. The garden contains three main layers from top to bottom — moss, soil, and plastic wrap. Moss is laid on the surface to mimic grass in the garden. The soil layer has a depth of 3'', and it mainly serves to support and hold the objects we use, such as 3D printed flowers. We chose to use plastic wrap as the bottom layer to prevent soil from dropping to the base box, while also allowing wires to pass through.

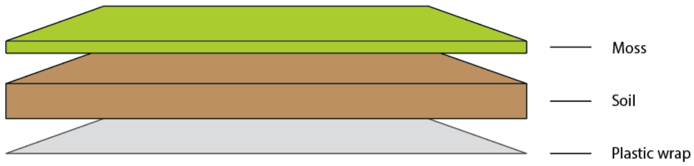

Figure 3: 3 layers of the garden: moss, soil, and plastic wrap

As shown in Figure 4, the garden is composed of three 3D printed honey jars with LED lights, a 3D printed beehive, a piece of mud (Play-Doh), a 3D printed water jar, and three 3D printed flowers. All 3D printed objects were printed using a resin 3D printer. We embedded three photoresistors below the beehive, mud, and water jar to detect the presence of these objects. The initial setting of the physical board is shown in Figure 5.

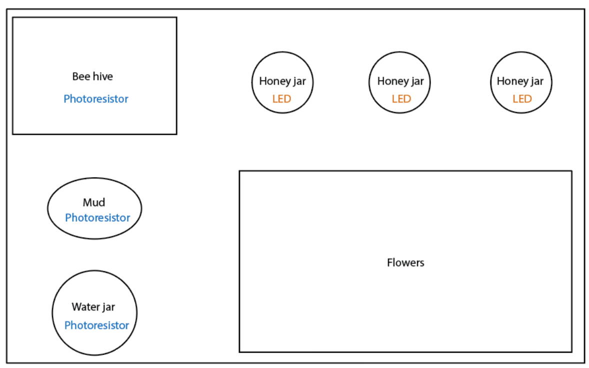

Figure 4: Floor map of physical garden

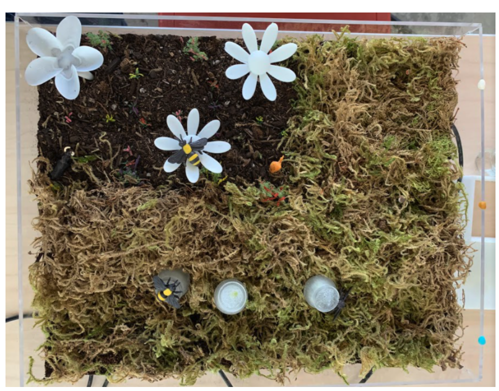

Figure 5: Initial setting of the box without the beehive, mud, and water jar

4.2 Virtual Reality Environment

The virtual environment in VR (Figure 6) is a digital version of the garden. We modified low-poly 3D models from Sketchfab. The environment consists of ground covered with grass, a bee hive, and flowers, which are digital representations of the objects on the tangible board. When the scene initiates, the VR player is placed near the flower. As they explore around, they will see instructions pop up that instruct them to complete several tasks. Based on the completion states, the VR user will see different models appear in the scene, including a honey jar and an area of mud. Since the VR player plays the role of a bee in this garden, the scale of the player is adjusted in order to provide an immersive, embodiment perspective.

Figure 6: VR Environment

4.3 Connecting Tangible Board to Virtual Reality Environment

4.3.1 Sensor Communication Between Tangible Board and Virtual Reality Environment

Using an Arduino, we mounted photoresistors to the tangible board to be used as analog inputs (range: 1-1023), in order to detect the presence of placed objects such as the beehive, mud or water jar. A threshold was set for each of the objects (depending on their opaqueness) to map the action of placing the objects on the board into the virtual environment. As the photoresistor values depend upon the ambient lighting of the environment, we calibrated them for each exhibition location.

Furthermore, Each honey jar contains an LED, which lights up after the VR player reaches the beehive and has "collected" honey. For future iterations of this board, We intend to explore mapping the location of the VR player in the virtual environment to a grid of LEDs as output on the physical board, thus extending the collaborative quality of the participants.

The bi-directional communication between Arduino and Unity was implemented using Ardity, which allows us to build a thread-safe queue to transfer data across COM ports. Arduino and Unity transmit on the Serial ports and listen for messages by invoking the right handler.

4.3.2 Marker-Tracking Communication Between Board and Virtual Reality Environment

Marker-based object tracking is a low-tech, scalable approach for translating physical locations in digital spaces. Marker-based tracking involves generating a barcode or pattern (QR codes are one common example) that computer software will recognize in a physical space. We used AR.js's marker-based toolkit in conjunction with A-Frame to track physical markers in a 3-dimensional digital space. A-Frame and AR.js are built in Javascript and run in the browser, utilizing the browser's API to access the device's built-in camera.

Our VR rendering engine was built in Unity, which exists separately from the browser. Thus, we needed a real-time communication stream between the marker-based tracking taking place in the browser, and the rendering engine in Unity. To accomplish this, we turned to websockets, a data streaming protocol that is language- and platform-agnostic. We created one central Node.js server that uses Socket.io in order to emit and receive messages between the marker-tracking client in the browser and the VR rendering client in Unity.

As new marker locations are found, the browser transmits their coordinates to the server, which then transmits the coordinates to Unity. When a marker is lost, that event is transmitted in a similar way. In order to successfully transmit and receive the coordinates, we transferred these data packets as JSON strings. This enabled cross-platform communication without challenges around platform-specific data structuring.

Markers were tracked using an external camera, allowing us to set up the viewport in an ideal location that would not be possible with a laptop camera. Marker recognition is reliant on high-contrast lighting, and so we set up our physical environment to utilize sharp, direct light, while avoiding soft, ambient light when possible.

5 Evaluation

By organizing a showcase open to everyone, we had different pairs of people interacting with this collaborative game based on their comfort levels with VR headsets and how well they knew each other. Both the players were in the same room and had to share the observations and communicate instructions to each other after each interaction, as shown in Figure 7.

Figure 7: Players in the VR world and on the physical board collaborating together

The VR player as a bee had an open environment and often wandered away, thus missing out on a small change in environment by the player on board. The player at the physical board often had to nudge the VR player to look towards a particular point by referring to the physical board. Initially, the player in front of the physical garden tried to light up the honey jars themselves, realizing later that only the VR player (bee) has the ability to make honey and thus light up the honey jars. Both the players adopted a different style of spatial coding system, with the bee communicating its position in an egocentric way whereas the gardener had an allocentric perspective to the garden. This nudged both participants to be more empathetic while communicating their actions

In cases where there was minimum communication, the VR player was often left surprised by how an object popped up out of thin air. This exploration maps very well to real life where a bee is exploring a big environment, unaware of what lies ahead and often experiences a lot of surprises, whereas humans who can see the complete garden are in better control of their environment. This surprise was often the point which prompted both the players to exchange their places and experience what the other person had seen.

6 Conclusion and Future Work

Our existing research and prototypes have shown that AR, VR and Tangible User Interface can bring novel, meaningfully collaborative gameplay educational environments. These novel interactions are reflected in the following aspects:

– AR and VR can provide users with mixed layers of physical and digital multi-modal information. Compared with traditional board games, the introduction of AR and VR technologies allows players to see information such as clues, triggered events, and changed board state within the same playing area.

– By pairing virtual worlds with a corresponding physical model, we provide opportunities to cultivate empathy in players due to the availability of multiple perceptual perspectives. Interactions not possible in traditional board games become available: players can transition between virtual contexts and through different timelines, change their body scale, and move in ways not physically possible.

– The tangible user interfaces in communication with AR/VR enables interactivity to be closely integrated in a new way. Any physical interaction on the board can give players virtual feedback and trigger real-time changes in the virtual environment, and vice versa.

In all of this, we see great potential for expanding this multi-modal, cross-technological design in other domains. We plan to conduct further user testing with children (> 13 years of age), to understand how they interact and behave in this hybrid environment. We envision this used in classroom contexts as an interactive teaching tool, affording instructors the ability to integrate manipulatives in novel ways while enabling students to experience educational content in more engaging ways. For example, this could be used to teach topics related to the material sciences of biology, chemistry, or physics, with students and teachers collaborating on modeling STEM scenarios.

Furthermore, this form of interactivity may find use in the mental health field, enabling therapists to work with their clients in novel ways. Perhaps an individual, within the virtual space, is in dialogue with aspects of their psyche, represented in a physical space that the therapist uses didactically. Or perhaps this could be used to tell social-emotional stories, supporting positive reframing and enabling cognitive behavior shifts.

Finally, the applications of this design in the arts and entertainment space are plentiful. As our technological approach naturally allows for scaling this experience to many peers at once, it is possible to have a vastly distributed collaborative environment. Many people, all with their own physical spaces, incorporating objects within their surroundings, in connection with others in virtual spaces, experiencing this mixed reality in dramatically different ways. The possibilities are vast and exciting.

ACKNOWLEDGMENTS

We thank Dr. Kimiko Ryokai, Tonya Nguyen, and Zeke Medley for instruction and support throughout the project. We thank Ziqing Li, who made great contributions to the VR and AR algorithms. We thank Lucas Macchiato for emotional support.

REFERENCES

[1] Parastoo Abtahi, Mar Gonzalez-Franco, Eyal Ofek, and Anthony Steed. 2019. I'm a Giant: Walking in Large Virtual Environments at High Speed Gains. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, Paper 522, 1–13. DOI:https://doi.org/10.1145/3290605.3300752

[2] Thomas Fröhlich, Dmitry Alexandrovsky, Timo Stabbert, Tanja Döring, and Rainer Malaka. 2018. VRBox: A Virtual Reality Augmented Sandbox for Immersive Playfulness, Creativity and Exploration. In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play* (*CHI PLAY '18*). Association for Computing Machinery, New York, NY, USA, 153–162. DOI:https://doi.org/10.1145/3242671.3242697

[3] Hiroshi Ishii. 2008. Tangible Bits: Beyond Pixels. In *Proceedings of the 2nd international conference on Tangible and embedded interaction* (*TEI '08*). Association for Computing Machinery, New York, NY, USA, xv–xxv. DOI:https://doi.org/10.1145/1347390.1347392

[4] Thammathip Piumsomboon, Gun A. Lee, Andrew Irlitti, Barrett Ens, Bruce H. Thomas, and Mark Billinghurst. 2019. On the Shoulder of the Giant: A Multi-Scale Mixed Reality Collaboration with 360 Video Sharing and Tangible Interaction. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, Paper 228, 1–17. DOI:https://doi.org/10.1145/3290605.3300458

[5] Joan Sol Roo, Renaud Gervais, Jeremy Frey, and Martin Hachet. 2017. Inner Garden: Connecting Inner States to a Mixed Reality Sandbox for Mindfulness. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (*CHI '17*). Association for Computing Machinery, New York, NY, USA, 1459–1470. DOI:https://doi.org/10.1145/3025453.3025743

[6] Kimiko Ryokai and Yong (Leon) Li. 2020. VR SandScape: Working with Multiple Perspectives in a Hybrid VR/SAR Collaborative Play Space. In *Extended Abstracts of the 2020 Annual Symposium on Computer-Human Interaction in Play* (*CHI PLAY '20*). Association for Computing Machinery, New York, NY, USA, 350–354. DOI:https://doi.org/10.1145/3383668.3419892

[7] Bruce H. Thomas. 2012. A survey of visual, mixed, and augmented reality gaming. *Comput. Entertain.*10, 1, Article 3 (October 2012), 33 pages. DOI:https://doi.org/10.1145/2381876.2381879

[8] Siricharoen, Waralak. 2019. The Effect of Virtual Reality as a form of Escapism. *CONF-IRM*.

[9] Zhiying Zhou, Adrian David Cheok, Tingting Chan, and Yu Li. 2004. Jumanji Singapore: an interactive 3D Board Game Turning Hollywood Fantasy into Reality. In *Proceedings of the 2004 ACM SIGCHI International Conference on Advances in computer entertainment technology* (*ACE '04*). Association for Computing Machinery, New York, NY, USA, 362–363. DOI:https://doi.org/10.1145/1067343.1067403