# Virtual Makerspaces: Merging AR/VR/MR to Enable Remote Collaborations in Physical Maker Activities

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We present a mixed-reality system for remote collaborations, where collaborators can discuss, explore, create and learn about 3D physical objects. The system combines Hololens augmented reality, 3D Kinect cameras, PC and virtual reality interfaces, into a virtual space that hosts remote collaborators, and physical & virtual objects.

When talented people have access to fabrication tools and expertise, incredible inventions can be manifested to solve local and global problems. Because of this, the "maker movement" is a growing phenomenon, manifested through the increased number of maker spaces in many affluent communities. However, many talented individuals lack access to resources in their local communities, and collaboration opportunities with remote experts are wasted due to the limitations of current teleconferencing systems. We present a mixed-reality (MR) system for enabling remote collaborations in the context of maker activities, that allows groups of students and instructors to discuss, explore, create and learn about physical objects. The system combines augmented reality (AR) headsets, 3D cameras, PC and virtual reality (VR) interfaces, into a virtual space that contains multiple remote students, instructors, physical and virtual objects. Remote students can see a real-time 3D scan of the on-site user's physical environment, and the virtual avatars of other students. The system can support learning and exploration by showing virtual overlays on real objects (ex: showing a physical robot's sensor data or internal circuitry) while responding to real-time manipulation of physical objects by the on-site user; and can support design activities by allowing remote and local participants to annotate physical objects with virtual drawings and virtual models. This platform is being developed as an open-source project, and we are currently building applications with the intention to deploy in hybrid makerspace classrooms involving on-site and remote students.

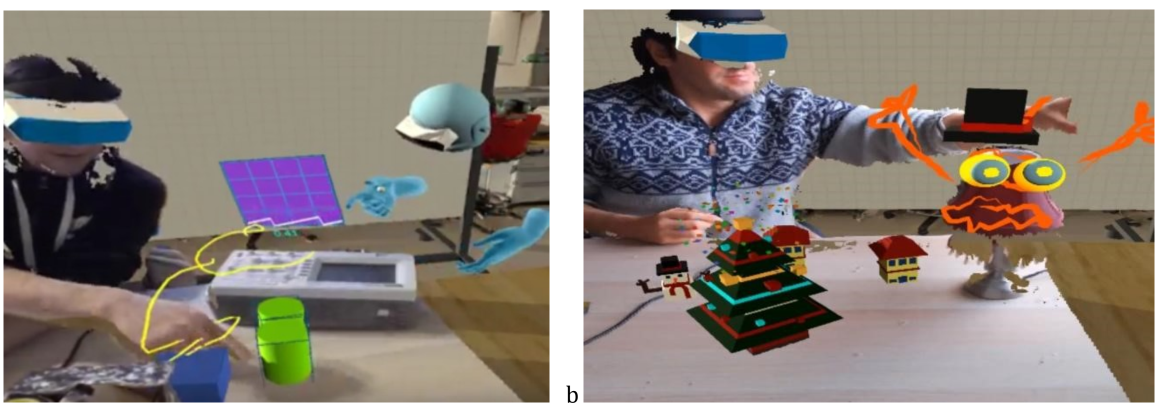

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**Figure 1.** Views from the perspective of a remote user, observing the on-site user and a VR user discussing modifications to a physical oscilloscope device (a), and collaborating with the on-site user to modify a lamp into a Christmas village monster (b).

CCS CONCEPTS • Human-centered computing → Human computer interaction (HCI) → Interaction paradigms → Mixed / augmented reality; • Applied computing → Education → Collaborative learning

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**Additional Keywords and Phrases**: maker spaces; collaborative learning; remote education; mixed reality

## 1 INTRODUCTION

When talented people have access to fabrication tools and expertise, incredible inventions can be manifested to solve local and global problems. For example, in the last decade we have seen teenagers invent test strips that diagnose cancer on the spot [1], low cost prosthetic limbs [2] or Alzheimer detectors [3]. Having access to tools and expertise does not just increase the ability for people to develop the STEM workforce, but it can also bring new life and ideas into century-old problems. However, there is an inequity in who can innovate. There are lots of creative, smart, and driven people who do not have access to the resources and expertise of people to help them bring their ideas to life. Some communities do not have the awareness, means, or support to engage in designing solutions to local problems. Although they may have talented individuals, this talent gets wasted without opportunities to connect to tools and expertise. Our project is designed to connect people and resources regardless of their physical locations, so that local communities can make use of remote experts and remote fabrication facilities, to design solutions involving physical materials.

Makerspaces are open spaces with DIY approaches [4], where people can create unique artifacts in teams, can learn about the inner workings of physical objects, and develop creative solutions to problems in their communities. However, a major limitation is that participants must be physically present to take part in making activities. These spaces are currently available in affluent communities and university settings, which have resources to provide fabrication tools and staff. However, they are inaccessible to talented individuals in less fortunate communities; we intend to democratize access so more people can make use of these spaces, thus creating lost opportunities for innovation and workforce development.

Our system addresses this inequity by allowing users to collaborate with others remotely, in order to engage in designing, creating, and learning about physical artifacts. Traditional collaboration technologies such as Zoom and Skype are good for remotely connecting people across space through 2D screens, but they are not designed to support educational activities where peers physically manipulate physical objects [5]. The combination of technologies like VR, 3D real-time capture and rendering, and AR have the potential to bring geographically dispersed people together in a shared workspace [6], [7]. Remote assistance systems have been developed to enhance spatial understanding in live-video collaborations by allowing remote experts to guide on-site workers, for example by attaching drawings on remote physical objects, or guiding attention by pointing or gesturing [8], [9]. However, these systems are not designed for creative design or for learning about physical objects; instead, these solutions are usually used in asymmetric collaboration scenarios where a local user follows the instructions given by a remote user. In this project we integrate technical innovations in AR, VR, and 3D scanning, for the context of makerspace collaborations. We aim to create a platform where on-site and remote users can contribute to a shared creative process, through features that facilitate communication, design and learning about physical objects.

## 2 VIRTUAL MAKERSPACE SYSTEM

We have developed a system that allows students and instructors using different hardware platforms (desktop computer, augmented reality and virtual reality) to collaborate in a virtual 3D space that merges physical and virtual objects (Figure 2). This system design was informed by discussions with physics teachers and makerspace coordinators. This is currently a platform on which different applications can be developed. We will be performing user studies to understand what activities are valuable to implement for remote maker education. In this section we describe features and some possible uses of the system.

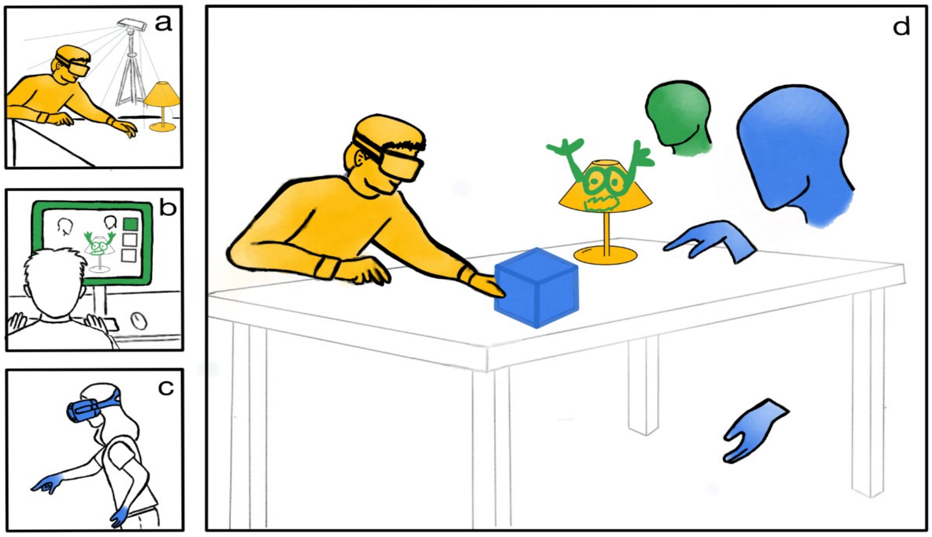


**Figure 2.** The system combines content from three types of users: A person using AR headset on-site in the makerspace (a); their body and physical workspace are tracked by a 3D depth camera. A remote desktop user using mouse and keyboard, currently drawing in green (b). A remote VR user whose head and hand positions are tracked (c). All users inhabit the same virtual space and see physical objects, virtual objects, and virtual annotations (d).

### 2.1 **Users**

The system is designed to support collaborations between an on-site user interacting with at least one remote users in the same 3D virtual environment.

**On-site users** (Figure 2a) are people who have access to a makerspace with physical fabrication tools and materials. The system currently supports one such user, who is expected to be a student or instructor. Their workspace consists of a 3D camera (Kinect DK) which looks at their workspace, scanning the user's body and any physical objects placed in the workspace. These users also wear AR headsets (Hololens2), through which they can see other virtual avatars of users who are connected remotely, virtual objects overlaid on the physical objects in the workspace, and virtual annotations.

**Remote desktop users** (Figure 2b) are remote students with access to a PC. They can remotely connect to the virtual space through a thin client app (ex: Google Chrome Remote Desktop; or in the future a dedicated desktop app). On their screen they see a 3D virtual space that contains physical objects from the makerspace user's workspace, virtual content overlaid on the objects, and a virtual makerspace background (created from static 3D scans of a real maker space environment). They can use keyboard and mouse to control a virtual camera and move in the virtual space; can talk to the other users through audio communication; and can contribute through features such as virtually drawing on objects, pointing at objects, creating location anchors, and spawning virtual objects.

**Remote VR users** (Figure 2c) are remote students with access to VR headsets (such as Oculus Quest). They have the same abilities to interact as the PC user, and additional abilities to use their hands to annotate and manipulate virtual objects, and navigate by teleporting. In the virtual space, these users are visible as avatars with virtual hands.

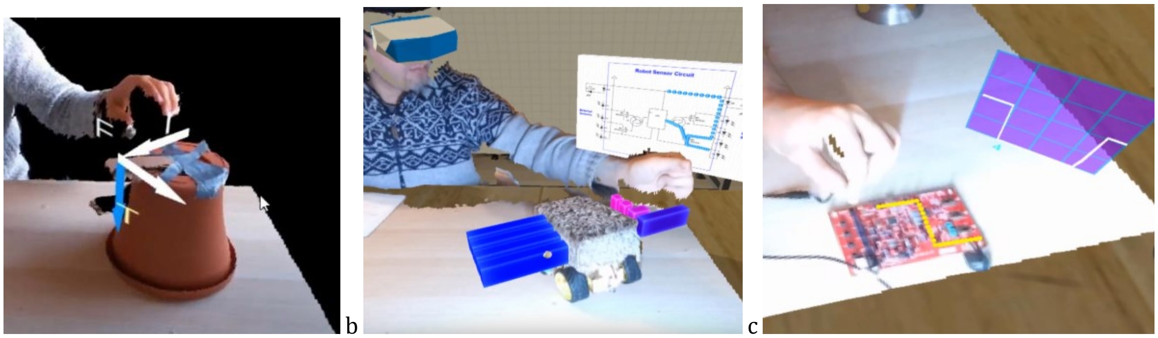

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**Figure 3.** Plant pot with virtual overlays of physics forces (a). Robot with interactive overlays of proximity sensor data and circuit electricity diagram (b). Circuit with interactive overlays of electricity flow and virtual oscilloscope graph (c).

### 2.2 Features for Sharing and Learning

**Sharing physical and virtual objects:** Physical objects from the on-site user's workspace are observed by the 3D camera in real time and rendered into the virtual space as 3D shapes. The remote users can see the on-site user's body and physical objects, and can change perspective looking from different angles to understand 3D organization of objects in the workspace. Virtual objects (ex: physics force arrows, Figure 3a) can be added into the space and become visible to all users (for remote users, these objects become part of the virtual workspace, while for the onsite user, these are visible as AR overlays on the real world objects).

**Overlaying virtual content on physical objects:** This system can overlay visualizations on physical objects, dynamically updated while the physical objects are manipulated in real time. For example, (Figure 3b) shows the on-site user bringing a physical robot equipped with proximity sensors; the system can display virtual overlays on the robot's sensors to visualize their values; and display a circuit diagram next to the robot, that illustrates the inner workings of the robot. As the robot is moved in space, the system tracks the physical object based on computer vision tracking, and ensures virtual overlays remain aligned with the object.

**Controlling virtual overlays from physical objects:** The system can receive information from the real world and use this to update virtual visualizations that are overlaid on physical objects. For example, as the on-site user moves their hands next to the robot, the live sensor information is used to update the sensor visualizations, and to drive visualizations on the internal circuit diagram (Figure 3b). Another example is when the on-site user touches a functioning circuit (Figure 3c); as the real circuit is manipulated, the system receives data from the circuit sensors and visualizes the path of electricity inside the circuit, or shows a virtual oscilloscope next to the circuit.

**Virtually controlling physical objects:** (Although this feature is not implemented currently, we expect it will be implemented by the time of CHI 2021 Interactivity). In the future we expect that the remote users will be able to influence the physical objects, for example using a virtual UI to control the voltage fed to a physical circuit or influencing the inner parameters of the robot sensor program.

### 2.3 Features for Guiding and Designing

**Drawing:** All users can draw in the virtual shared space. For the on-site user and remote VR users, drawing is performed through their fingertips or hand directions which are tracked by the AR/VR headsets. Remote desktop users can use their mouse to draw on the virtual meshes, or on transparent surfaces planar to their camera view. The drawings can be temporary (i.e. fade after several seconds), or permanent. These drawing annotations can be used as part of explanations of how things work (e.g., oscilloscope explanations, Figure 1a), to indicate modifications to physical objects (e.g., lamp modifications, Figure 1b), or as guides for users to perform actions (e.g. Rube Goldberg machine, Figure 4a).

**Indicating locations:** All users can point in directions or on locations in the virtual space. For the on-site and VR users, pointing is done through their fingertips or hands; while for the remote desktop user, pointing is done through the mouse via camera raycasting. There are several methods of pointing: as a laser beam that has a start and end point; as a short-distance laser beam that simply indicates direction; or as a permanent "arrow" pinned on a location. These features are used to guide peer attention and actions (such as when explaining circuits, Figure 4b).

**Spawning and manipulating virtual objects:** All users can spawn virtual objects that are predefined for each experience. These virtual objects can range from simple geometric shapes, to complex interactive 3D models that respond to virtual physics and inputs from the real world sensors described in Section 2.2. The on-site and remote VR users can manipulate virtual objects through hand actions of grabbing, rotating, moving and scaling. The remote PC user currently cannot manipulate the spawned virtual objects, but in the near future we will implement keyboard-and-mouse features for manipulating the virtual objects. Using these features, the students can discuss modifications to be made to objects, or create hybrid scenes that involve physical and virtual objects (Figure 2b).

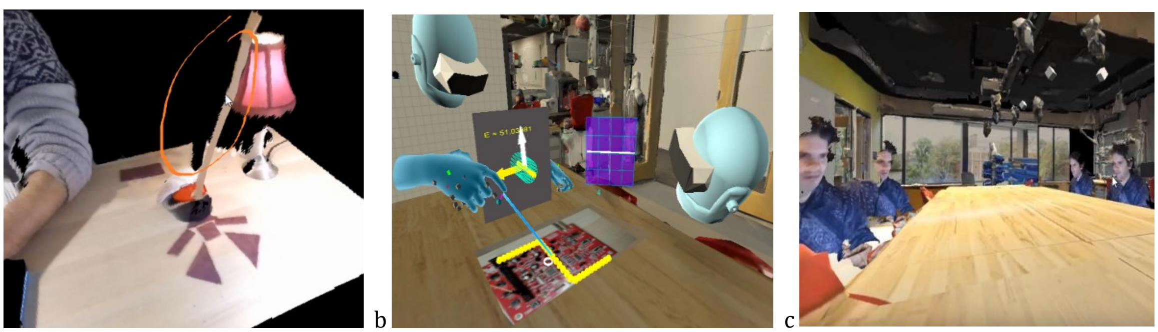
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**Figure 4.** Drawing on a 3D structure of Rube Goldberg machine (a). Pointing at circuit visualization (b). Classroom of multiple 3D scanned individuals (c).

## 2.4 Features for Enhancing Traditional instruction

**Creating 2D and 3D content on virtual whiteboards:** The system can replicate and enhance some aspects of traditional instruction. For example, users can draw on virtual 2D whiteboard surfaces[1]. But it is possible to present complex material such as 3D visualizations on the board, which are interactive and respond to user gestures (for example, a 3D visualization of how ultrasonic signals propagate in relation to voltage supplied to the robot sensors).

**Inserting web-based resources:** In the virtual space, users can bring in documentation from Internet resources, such as websites, images and slideshow presentations. These resources can be helpful as users discuss and collaborate around physical objects.

**Inhabiting different environments**: We use a static 3D model of a makerspace as background to simulate the feeling of being in the real maker space. But this virtual space can be removed to a black background to make the users focus on the objects in the workspace (Figure 3a); or, in the future this will allow multiple people with 3D camera hardware at home, to appear as if they are part of the same virtual environment (Figure 4c)

[1] Virtual whiteboards implementation courtesy of the University of Georgia's Virtual Experiences Lab

## 3 Future work and Limitations

We believe this mixed reality system, which combines 3D cameras, AR, VR and PC hardware, will open opportunities for physical education and innovation across distance, as remote collaborators will be able to engage in maker activities regardless of their physical locations. This system can support generic maker activities such as learning about the internal workings of objects (e.g. ,Figure 3a), brainstorming designs (e.g. Figure 1), constructing physical structures (e.g. Figure 4a), and building community (e.g. Figure 4c). In the near future we plan to perform a structured qualitative study to understand needs of potential users, then to design specific applications and deploy them in physics and makerspace classrooms inhabited by on-site and remote students. This platform is being developed as an open-source project. The project currently is limited by several factors, such as: the use of only one 3D camera for the on-site user, which makes it difficult to visualize shapes behind the visible objects; and, the system is currently limited to only one on-site user, one remote desktop user, and one remote VR user. To ensure a smooth experience for CHI Interactivity participants, participants will take the role of the remote desktop user; although the current system supports only 1 desktop user at a time, we are investigating the possibility of enabling multiple users by the time of CHI Interactivity. In the future we expect that multiple people will be able to be remote through desktop and VR.

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