REACH Projector: Remote Embodiment for Augmented Collaborative Help

Casey Smith, Mike Tissenbaum
cjsmith0@illinois.edu, miketiss@illinois.edu
University of Illinois at Urbana-Champaign

Abstract: Maker activities help students connect to STEAM content through hands-on activities that emphasize the roles of mentors, peers, and in-person interaction with physical artifacts. Despite the positive affordances of these activities, they do not translate well to online settings. Without immediate in-person feedback mechanisms, unstructured making activities may lead to frustration and decreased engagement. How do communities help students develop identities as future engineers if local help and mentorship is not available? The proposed study aims to address challenges of scaffolding collaboration during remote maker sessions through investigation of a novel projection device that allows users to talk and share gestures around a common physical artifact while in separate locations.

Students face an evolving world that expects new skills and creative ways of approaching problems. Meeting the needs for interdisciplinary collaboration and understanding of societal impacts requires students to have experience in engineering and design, which makerspaces are well suited to provide (Blikstein, 2013). However, effectively scaffolding collaboration in makerspaces remains a challenge, particularly if a local making expert is not available in the same physical space. The lack of co-located space and artifacts limits opportunities for interactions between makers and immediate feedback from experts, students, and their peers (Jayathirtha et al., 2020). This work aims to address the challenges of supporting remote making collaboration through the development of a novel communication technology that allows users to share embodied interactions around a common artifact while in separate locations. Through this work, we aim to understand how such technology infrastructures impact collaboration during remote making sessions.

Connecting in-person affordances to remote communication

Collaborative making, much like collaborative learning, is not a single mechanism or method, but rather a social contract informed by multiple components. The setting, institutional constraints, and provisions for guidance increase the probability of certain kinds of interactions. These interactions trigger additional learning mechanisms that enable peers in the group to influence each other's cognitive process via synchronous communication and negotiation (Dillenbourg, 1999). Within makerspaces, collaboration is a key factor in supporting students to troubleshoot, act as near-peer mentors, and develop their STEAM identities through interaction with physical artifacts (Halverson & Peppler, 2018).

Much of the current discourse in education around design thinking and makerspaces has its roots in constructionism (Papert, 1991). In Papert's view, the physical artifact helps the learner remain in-situ with the knowledge they are grappling with in a specific environmental context. There is general understanding of the unique affordances of physical artifacts as "shared objects of thought" that offer grounding for multiple collaborators interactions, observations, and manipulations (Kirsh, 2010; Roth, 2001). Through this lens, researchers can see the powerful role that collaboration plays in maker-focused learning. However, when students, peers, and mentors are not co-located, being able to engage in tangible, embodied, and often physically proximal, collaborations is difficult, if not impossible. Therefore, researchers need to examine the potential for digital tools that can reduce the spatial barriers between collaborators while still supporting the kinds of rich interactions we know to be beneficial for collaboration. In response, the authors introduce the REACH projector, a two-way communication device custom built to explore the possibilities for remote gesturing around physical and projected objects. Below, we describe the REACH projector and its anticipated benefits for collaboration, followed by an outline of the ways REACH supports students in physically disparate embodied real-time collaboration.

Through this pilot work we hope to explore preliminary findings, student experiences, and further areas of inquiry, including: 1) Are there common features of activities that would be compatible with the affordances provided by the REACH projector? and 2) How does the finite working envelope of the REACH projector mediate the types of gestures that are used? As previously noted, one commonality may be activities that would otherwise require technical, domain specific language for which there is no other good substitute without the visual cues the projector system enables.

Remote Embodiment for Augmented Collaborative Help (REACH) projector

The REACH projector uses a pico-video projector and camera positioned above a work surface to project and capture a notebook paper-sized image. A user places an artifact on the work surface (see Figure 1a) and an audiovisual (A/V) link projects the artifact on a second user's setup (see Figure 1c). The cameras capture everything happening in both spaces, creating mirror images of hand gestures and interactions with the artifact while users collaboratively discuss it (see Figure 1b). This allows students to share embodied gestures via the A/V link while simultaneously grounding cognition in the physical environment (Alibali & Nathan, 2012).

Human Computer Interaction (HCI) researchers have been developing projector-cameras systems for remote collaboration for many years using both custom built hardware such as IllumiShare (Junuzovic et al., 2012) as well as commercially available systems like the ShareTable application for the HP Sprout (Unver et al., 2016). Thus far, the complexity and cost of these systems has prevented large-scale adoption. In order to situate this technology meaningfully in makerspaces, care was taken to design a projector system that could take advantage of prototyping capabilities and knowledge that would likely be familiar to maker communities. Hardware components were chosen for relatively low cost and their ability to be manufactured using commonly available tools in makerspaces such as soldering irons, 3D printers, and LASER cutters. The cost of construction was kept low in the hope that it would increase the likelihood of co-participation with other communities of makers as the study progresses.

The electronics hardware for the REACH system consists of four major components: a projector, an embedded computer, a camera, and a small, printed circuit board to interface with the projector. The projector is a 640x320 pixel DLP projector, with an LED light source, developed by Texas Instruments for the mobile market. To remove the need for complex electronics development, REACH utilizes this projector in the form of a DLPDLCR2000EVM evaluation board (ti.com) developed for interfacing to the BeagleBone Black single board computer. Unfortunately, the BeagleBone platform does not have the performance required to handle a two-way video stream with image processing so REACH utilizes a Raspberry Pi (RPi) 4 (raspberrypi.com) single board computer and a simple custom printed circuit board (PCB) to interface between the RPi and the projector. This PCB serves a secondary purpose in providing correct orientation of the RPi and projector for mounting in the stand as well as exposing extra inputs and outputs (I/O) from the RPi expansion header for future use. The camera system utilizes the RPi Camera v2.1 using a Sony 8MP Sensor.

All software components utilized in the project are open source and freely available. The Raspberry Pi Raspbian operating system (raspbian.org) is an actively developed open-source Linux distribution based on Debian. As such, it is a convenient platform for development and supports most major languages and tools for development. The application is a two-way video exchange written in a combination of Python (python.org) and Go (golang.org) with four major sections: image capture, image processing, network channel, and image display. Image capture is managed through the high-performance video framework provided by the VidGear library (abhitronix.github.io/vidgear). The PiGear API included in this library provides convenient access and fine control of the Raspberry Pi camera. Image processing and display is managed via the popular open-source computer vision library, OpenCV (opencv.org). The OpenCV library is currently used for cropping, scaling, and panning as well as selective masking of foreground images when projecting the mentor's gestures back to the physical artifact at the student's station. This processing is important to minimize visual feedback loops that can lead to distracting visual artifacts. The network protocol for the video exchange relies on Web Real Time Communication (WebRTC) like most modern video conferencing systems (webrtc.org). WebRTC development in the open-source landscape often focuses on applications designed to run within browsers. With the limited processing power of the Raspberry Pi, this is not ideal because the browser is resource intensive and not required for any other purpose. An open source WebRTC stack written in the Go language called Pion (pion.ly) is used to implement the video channel without need for a browser. Exchange of tokens for security and address exchange is managed through a XMPP (xmpp.org) exchange server for simple link initiation.

Designing for remote embodiment

The REACH projector helps mediate remote collaboration exchanges and aids users in orienting themselves to a shared problem and communication prior to establishing a shared domain specific language (Roth, 2001). By leveraging projected gestures onto a shared artifact to augment the physical space, REACH attempts to preserve the embodiment affordances of in-person exchange. The shared gesturing support at the heart of REACH serves as an aid to this real-time collaboration at a distance. The communication via audio link also supports these gestures. Recent work has shown that gestures help listeners with comprehension (Barsalou, 2008) in addition to providing the speaker additional information in their mental representation of the shared problem (Goldin-Meadow, 2011). Further, Black et al. (2012) shows that these embodied physical experiences can form the grounding for later symbolic learning.

These findings are important in making a case that hands on activities and support have benefits for students even after the activity is completed. If in-person instruction is not possible, REACH provides a channel to support mental pathways and methods in transformational ways by leveraging the existing work around gesturing in-person. By projecting the artifact and student gestures while simultaneously projecting the mentor's hands back onto the student's artifact, the projector enables both participants to extend their embodiment onto a remote environment. We believe these shared projections will be particularly useful in allowing the participants to communicate about the physical object being projected in ways that would be nearly impossible with voice alone, or through one-way communications streams (e.g., simply holding up an object to a webcam).

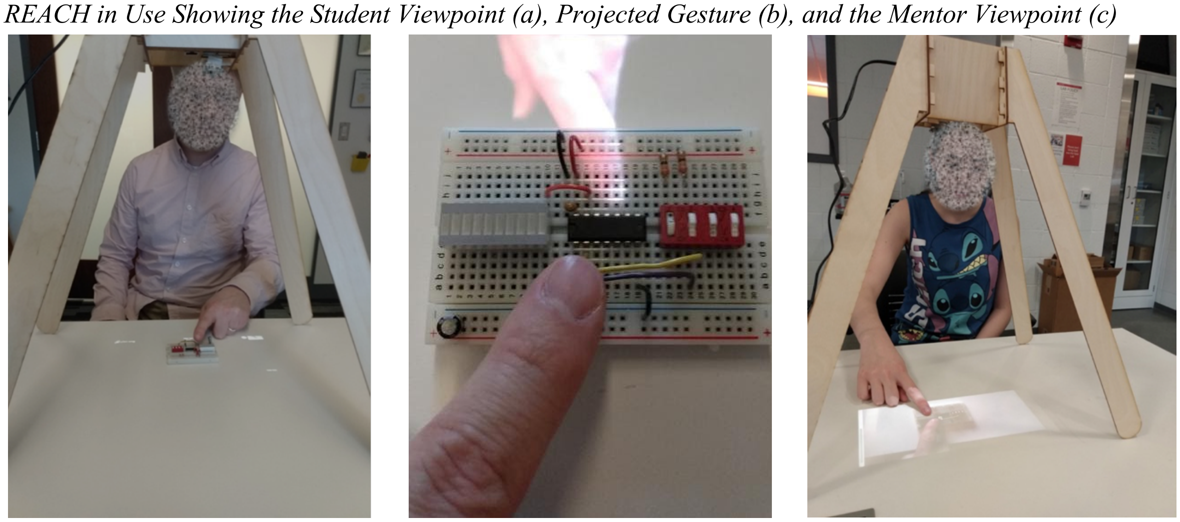
Designing for augmented collaborative help

REACH uses projections to augment the physical space in a way that mimics the experience of sitting across the table from a collaborator, thereby adding little overhead to learning in using the device. These interactions become increasingly important when problems are encountered and support for immediate, synchronous, and gesture-based feedback is required.

One particularly interesting observation from early trials is how closely moments of debugging and repair during a simple circuit building activity mimic those of in-person sessions of troubleshooting and repair reported in work with interaction analysis (Jordan & Henderson, 1995). In work on social interactions, Roschelle (1992) analyzed students' mutual orientation to a shared physical space through a combination of talk and gesture, along with other manipulatives, to troubleshoot and repair a problem in an in-person setting. REACH is designed with relative transparency to human interaction in mind as an extension of that work. We anticipate that this transparency of use will ease the frustrations of helping students with remote making sessions and support perseverance for completion of difficult tasks.

Despite designing for support mechanisms similar to in-person interactions, there are still some clear differences. For example, the projections allow for the hand gestures of both the student and the mentor to occupy the same physical space. While clearly not possible in an in-person interaction, this feature of the REACH projector is particularly useful in the establishment of a shared spatial orientation. In early testing, a student was able to insert the wire directly through the author's projected finger. Certainly not something you would want to try in-person! These early trials raise the question of what other useful shifts in perspective might be helpful in augmenting the collaborative experience that are simply not possible in a shared physical space?

Figure 1
REACH in Use Showing the Student Viewpoint (a), Projected Gesture (b), and the Mentor Viewpoint (c)



(a) (b) (c)

Demonstration

To demonstrate the affordances of the REACH projector, a presentation with videos of the system being used in a maker activity will illustrate how it supports joint orientation to a shared problem space as well as immediate synchronous communication and repair efforts. By engaging with the CSCL community, we hope to explore opportunities for this technology and gain insights into potential methods of evaluation.

Future development

Six projector units are currently constructed, and software development continues to improve the user experience for our next round of pilot studies planned for late Spring 2022. Ongoing tasks include development of background subtraction methods so that projected images are not re-transmitted between the projectors. Efforts are also underway to optimize the frame rate and image quality for the limited resources of the Raspberry Pi. These pilot studies are a key step in working towards a full study in early Summer 2022. Design-based research methodologies (Barab & Squire, 2004) are being used to iterate the projector design based on lessons learned from pilots and student feedback on their experience of using the REACH projector.

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