

The REACH System: Boundary Spanning's Support of Distributed Collaborative Making

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ABSTRACT

Attempting the hands-on activities typical of makerspaces without in-person expert facilitation can lead to frustration and decreased engagement. This study aims to explore the collaboration affordances of REACH, a novel communication device that allows users to share gestures around a common artifact while in separate locations. Using a modified version of the divergent collaborative learning mechanisms framework (DCLM), this paper highlights the affordances of REACH to support students in collaboratively engaging in joint attention and boundary spanning perception and action, even when they are physically disparate.

CCS CONCEPTS

• **Human-centered computing** → Collaborative and social computing; Collaborative and social computing systems and tools; • **Applied computing** → Education; Collaborative learning.

KEYWORDS

Constructivism • Making • DCLM • Collaboration • Distributed Intelligence

ACM Reference Format:

Casey Smith and Mike Tissenbaum. 2023. The REACH System: Boundary Spanning's Support of Distributed Collaborative Making. In *FabLearn / Constructionism 2023: Full and Short Research Papers (FLC 2023)*, October 07–11, 2023, New York City, NY, USA. ACM, New York, NY, USA, 6 pages. <https://doi.org/10.1145/3615430.3615443>

1 INTRODUCTION

For over two decades researchers have been studying the maker movement and its abilities to help students learn and meaningfully connect to STEM ideas and practices. While making can be accomplished nearly anywhere, the notion of a physical makerspace has grown with the movement as a workshop with tools, materials, and an enthusiastic community where makers gather, share ideas, and learn from one another [10]. Despite their potential, access and achieving a sense of belonging in makerspaces is often more difficult for individuals who do not see their cultural knowledge and practices reflected in them [3]. In the literature review below, we will examine the identity of participants as *makers* as mediated by

the physical environments of *makerspaces*. We will then explore our attempt in addressing challenges of scaffolding remote making sessions through the introduction of REACH (Remote Embodiment for Augmented Collaborative Help) which allows users to co-gesture around physical and projected objects while in geographically separated spaces.

2 BACKGROUND

With deep roots in constructionism, the maker movement in education revolves around building things and then sharing that work with others [10]. While traditional educational systems often value a single form of knowledge, maker-focused education is often more focused on learners developing their STEM identities [6]. Maker culture has shown potential “to augment rather than replace familiar and powerful practices that the students already possess” [2]. In this view, the maker identity is not a new identity altogether but rather one that recognizes a student's agency in the physical spaces they inhabit but also the unique experiences and “funds of knowledge” every new maker brings to the table [14].

If the making is centered around engagement and reflection with other makers using relevant real-world examples, it can provide benefits for both the tutors and the tutees [16]. If the tutor and tutee are peers, then conceptual understanding is improved when students teach one another [4]. If working with peers is important in supporting STEM related learning gains, then it's necessary to find a community to increase the likelihood for those types of interactions. Making activities are therefore often done with others in a single physical makerspace as a “community of practice” where participants have freedom to explore topics that matter to them through creative activity and the sharing of information [13].

More than just a container for activities, a makerspace should reflect the socio-cultural elements of the physical environment to make technology supported activities effective. This echoes work in distributed intelligence that posits that the “intelligence” of a space is distributed amongst the learners themselves, but also shared with the physical environment and any technological supports it contains [15]. The support structures of a physical space can facilitate collaboration if open to natural movement, free communication, and observation of peer work [7].

If the physical environment has a role to play, and the decentralization of the learning process during making is potentially productive, it becomes necessary to support makers when the knowledge they are seeking is not available locally. If there is not a makerspace in the community, makers may need other avenues of support to preserve some of the positive affordances of in-person interaction.

While some asynchronous characteristics of a community of practice translate to online settings, technologies for synchronous exchange for the hands-on portions of typical making activities

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FLC 2023, October 07–11, 2023, New York City, NY, USA

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ACM ISBN 979-8-4007-0896-1/23/10...\$15.00
<https://doi.org/10.1145/3615430.3615443>

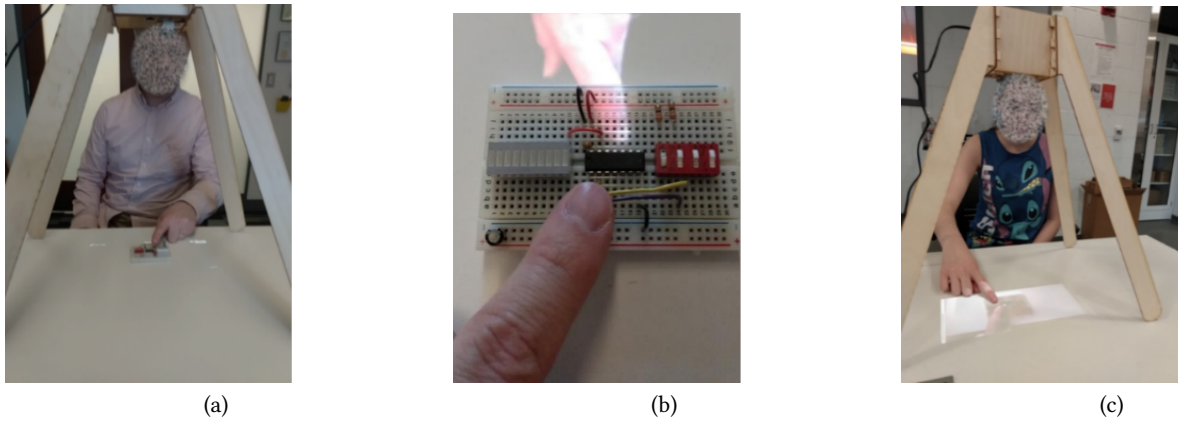


Figure 1: REACH in Use: (a) Student Viewpoint, (b) Projected Gesture, and (c) Mentor Viewpoint.

pose challenges. In an in-person setting, physical artifacts provide a joint frame of reference that multiple people can interact and gesture around, which helps listeners with comprehension and provides additional information into their mental representations of problems [9]. To accommodate these physical and embodied affordances in remote interactions, researchers have experimented with projector-camera systems using custom built hardware such as IllumiShare [12]. Such systems use cameras and projectors to augment the physical space and provide the synchronous communication and negotiation required of collaborative learning as well as a mutual orientation to a shared space via a combination of talk and gesture [5]. As the complexity and cost of these systems have become more accessible, we have developed a novel projector-camera system (REACH) that can be constructed with resources and knowledge typical of makerspaces.

To understand the utility of REACH for distributed collaborative maker activities we pose the following research question: In what ways does REACH impact distributed collaborations during remote making sessions?

3 METHODS

The data for this study comes from a one-day maker activity within a larger 10-day summer camp in which the researchers were developing curriculum and getting design feedback for a collection of collaborative technologies to foster distributed collaboration between makerspaces in two states. The camp met daily for three hours and focused on STEAM activities introducing microcontrollers, LEDs, motors, and sensors that students could use to develop projects of significance to them. Students were given short making examples and guided through mind map and brainstorming activities to prompt design of personal projects that were shared publicly with friends and family on the last day of camp.

3.1 REACH

REACH relies on a projector and camera positioned above a work surface to project and capture a small work area. A user places an artifact under the projector (Figure 1a) and the artifact is projected

onto the second user’s work area (Figure 1c). Users can co-gesture around physical and projected objects in either space (Figure 1b) thus grounding their cognition in the physical environment [1]. The 1:1 mapping of the projected, horizontal workspace with the physical environment takes advantage of natural user interactions as if the remote users were sitting next to one another.

3.2 Participants

There were 16 participants (10 boys and six girls) at the camp from local community groups that served Black and Latinx middle school students. Three camp counselors were present throughout the activity but interacted minimally once the students started. Six researchers guided the activity and provided prompts and scaffolding as needed.

3.3 Task Design

The electronics breadboarding task was designed to provide a simple, but authentic, learning activity that could be completed by novices in ~15 min. Two flashcards with instructions introduced one of two circuits: One for lighting an LED with a pushbutton switch, and another for dimming an LED by turning a potentiometer. Students were arranged into three groups. Two students did the exercise sitting across from one another at a table. The other two groups, one with four girls (Figure 2) and one with four boys, used REACH to communicate with one another remotely. The flashcards were divided between group members in a jigsaw format. Once students became experts on their circuit, the flashcards were removed and they shared how to construct their circuit with the other half of their group, with two groups communicating via REACH.

3.4 Data Collection and Preparation

The primary data records for this study are audio visual recordings. The two REACH video feeds show the overhead view of the shared workspace with the physical artifacts and gestures. Zoom video conferencing recordings captured the verbal and facial exchanges between students as they collaborated. Two wide angle video views were included to gauge users’ relative positions around



Figure 2: Four girls using REACH to collaborate remotely during circuit building activity.

each REACH and capture interactions with instructors. The six separate video feeds for the REACH groups were then synchronized using their audio channels to provide a mosaic view of the collaborative exchange, transcribed using the rev.com captioning service, and imported into the ELAN software package for further analysis.

3.5 Analysis

After all data was reviewed and transcribed, the girl’s REACH group (Figure 2) was selected due to the richness of the exchange. The 34-minute video mosaic for this group was transcribed manually to correct errors made by the transcribing service and segmented into a total of 880 conversational turns for coding. The Divergent Collaboration Learning Methods (DCLM) framework was selected to investigate the mechanisms of collaborations facilitated by REACH [18].

There are two codes uniquely relevant to our analysis below, namely Boundary Spanning Actions (BSA) and Boundary Spanning Perceptions (BSP) shown in Table 1. In the original DCLM study, a BSA meant reaching across the multi-touch table to actively engage in another user’s space [18]. In this study the other user’s space

is geographically remote, so BSA is used to denote when a user actively and physically interacts with a projection from the remote user’s workspace. Similarly, BSP is when a user watches and learns from another user by observing a local projection from the remote user’s workspace. Due to the role BSP and BSA play in establishing joint attention, they are key in supporting the distributed intelligence of the remote making space and collaborative gesturing with REACH.

A set of subcodes were also used to note features not present in the DCLM framework: the use of proper (PN) or descriptive names (DN) when referring to circuit components; when students used row and column coordinates (CD) to indicate location on the breadboard; when they described placement by descriptive locations (DL); a “checking in” code (CI) to distinguish between the student thinking out loud and inquiring about each other’s progress; gestures (G1) that occurred in the workspace of REACH as a potential embodied aid to collaboration; and, off topic (OT) talk.

We coded a nine minute segment, consisting of 235 conversational turns, that covered the complete exchange of the first circuit design and was particularly active and emblematic of the overall collaborations that took place. Three passes were made discussing and resolving individual interpretations of the DCLM framework with each pass. Sufficient interrater reliability was achieved in the third pass ($\kappa = 0.77$) and all remaining disagreements were resolved through discussion.

4 FINDINGS

Of the 235 conversational turns analyzed, there were six instances of Boundary Spanning Actions (BSA), 44 instances of Boundary Spanning Perception (BSP), 22 of joint attention and awareness (JA) and 32 of gesturing (G1). In the findings below we examine three cases that highlight the collaborative affordances of REACH coded using the DCLM framework.

4.1 Case 1: Seeking Clarification Locally while Looking Remotely

This case shows an example of REACH supporting divergent collaboration in the form of boundary spanning perceptions and actions that do not require the active and joint attention of the other participant. This episode in Table 2 is prompted as an instructor asks Imani to help Kayla build the button LED circuit and suggests that they compare their circuits using the REACH system. Kayla and Imani have already made an attempt, but Kayla’s LED is not lighting

Table 1: DCLM Codes + Sub Codes

CDIS Code	Mechanisms of collaborative discussion	DIVC Code	Mechanisms for enacting divergent collaboration	SUB Code	Description
MS	Making Suggestions	JA	Joint Attention and Awareness	PN / DN	Proper / Descriptive Name
AS	Accepting Suggestions	BSA / BSP	Boundary Spanning Action / Perception	CD / DL	Coordinates / Descriptive Location
CL	Clarification	NR	Narrations	G1	Gesture
NG	Negotiation	MO	Modeling	CI	Checking In
SH	Seeking help	GA	Goal Adaptation	OT	Off Topic

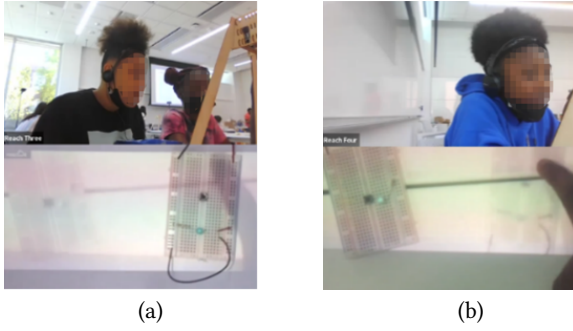


Figure 3: BSP & BSA in Case 1: (a) Kayla’s breadboard placed under REACH, and (b) Imani interacting with the projection.

up when she pushes the button, so she’s placed it under REACH at Imani’s suggestion as shown in Figure 3a.

On seeing Kayla’s circuit projected onto her workspace, Imani compares it to her own and asks an instructor why the button is “way over there” while pointing to the projection in Figure 3b. Even though Kayla is distracted at this point and does not respond verbally, Imani is still able to achieve divergent collaborative goals via her perceptions of Kayla’s work across the boundary spanned by REACH and interact with the local projection to seek clarification from a local instructor.

4.2 Case 2: Seeking Help from Afar

The second pattern involves help seeking using REACH to enable joint attention around physical artifacts. Here, the students are engaged in peer-to-peer collaboration and have established some momentum building the first circuit with the LED and the button. The interaction in Table 3 begins with Kayla seeking help with the next step of the circuit construction.

In response, Imani holds up a wire (Figure 4a) as an example and tells Kayla to find one. After some trial and error with where to hold the wire, Kayla sees the green wire projected in her workspace

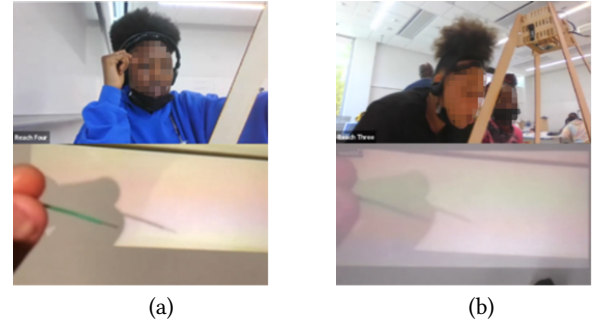


Figure 4: BSP and JA in Case 2: (a) Imani holding up a green wire under REACH, and (b) Kayla observing the projection.

(Figure 4b) and proceeds to search through her parts for a match. Despite never using the words “green” or “wire”, both participants have joint attention on the same object, even though one is gesturing with the physical object and the other is perceiving it as a projection on her workspace.

4.3 Case 3: Rapid Debugging

This final sequence illustrates rapid debugging and repairs supported by shared orientation and joint attention through REACH. There are several quick exchanges involving debugging wire placements, however this one was selected as most of the verbal exchanges were coupled with boundary spanning perceptions. The interaction in Table 4 comes at the end of Imani instructing Kayla on how to build the LED button circuit and begins with Imani using REACH to show Kayla where to connect the final wire. Twenty seconds after this segment, Kayla would push the button and the LED would light.

Kayla looks at the projection in her workspace (Figure 5a) and tries to duplicate the circuit but still has questions. Imani attempts to elaborate with a descriptive location based on a number of “squares”. Getting a little frustrated, Kayla places her breadboard under REACH so Imani can have a look and gestures to the area

Table 2: Seeking Clarification Transcript

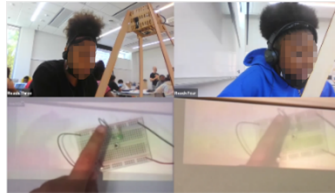
Time	Speaker	Transcript	CDIS	DIVC	SUB
0:07:47	Instructor	Tell her to put her circuit here so that you can see it.	MS	-	G1
0:07:51	Imani	Put your circuit right here.	AS, MS	-	G1
0:07:55	Kayla	What?	CL	BSP	-
0:07:55	Imani	Put your circuit right here.	MS	-	G1
0:08:03	Imani	Yeah, I can’t see it, but....	-	NR	-
0:08:05	Instructor	You can see it a little bit, right?	-	-	CI
0:08:09	Instructor	So, tell her what she’s doing right, and what she’s doing wrong.	MS	-	-
0:08:13	Instructor	Okay? So, help her out. . . help her make the exact same circuit that you have, okay?	MS	-	-
0:08:17	Imani	Okay. Why is that button all the way over there?	AS, CL	BSA, BSP	G1, PN
0:08:20	Instructor	Why’s there a button?	CL	-	-
0:08:20	Instructor	Cuz they’re building it on the same thing.	CL	-	-
0:08:22	Imani	Yeah. . .	-	NR	-

Table 3: Seeking Help Transcript

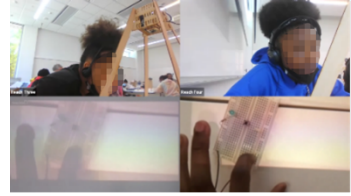
Time	Speaker	Transcript	CDIS	DIVC	SUB
0:12:53	Kayla	Ok what’s the next one?	SH	-	-
0:12:55	Imani	Get one of these.	MS	-	G1
0:12:58	Kayla	I can’t see it.	-	BSP	-
0:12:59	Imani	These.	-	JA	G1
0:13:01	Kayla	Oh okay.	AS	BSP	-



(a)



(b)



(c)

Figure 5: Rapid Debugging using REACH**Table 4: Rapid Debugging Transcript**

Time	Speaker	Transcript	CDIS	DIVC	SUB
0:13:28	Imani	You see it right here?	CL	BSP	G1
0:13:33	Kayla	Wait, what? Who do I skip it to?	CL, NG	-	-
0:13:36	Imani	Just skip one... this...one of those squares... skip one.	CL, NG	-	DL, G1
0:13:43	Kayla	Like this? Look.	CL, NG	BSP	CI
0:13:46	Kayla	Right there.	-	BSP, JA	G1
0:13:46	Imani	Where’s that?	CL, NG	BSP, JA	-
0:13:51	Imani	Don’t put it on, put it...put it on the other side.	MS, NG	BSP, JA	DL
0:13:55	Imani	Where positive is first.	CL, NG	BSP, JA	DL
0:13:56	Kayla	On this side?	CL, NG	BSP, JA	G1
0:13:57	Imani	Yeah... Where positive is first and negative is last.	CL, NG	BSP, JA	DL
0:14:01	Kayla	Wait, show me what yours look like.	NG, SH	BSP, JA	-
0:14:03	Imani	You see right here? Positive is first and negative is last.	CL, NG	BSP, JA	DL, G1

that’s giving her trouble in Figure 5b. Now that both of their attention is on the same part of Kayla’s circuit, Imani sees the issue and offers a suggestion to fix it. Kayla then gestures to clarify the suggestion. Imani confirms verbally but Kayla asks to see Imani’s circuit again and Imani complies, pointing to the correct wiring she just described in Figure 5c.

5 DISCUSSION

This work aims to extend the framework of DCLM to include study of divergent collaboration when users are participating from afar. Our findings suggest multiple patterns of interactions similar to collaboration around physical artifacts in a shared physical space suggesting that REACH may serve as a bridge between distributed intelligences across physical locations and users by preserving some of the affordances of in-person exchanges. This work shows how REACH can uniquely support specific forms of DCLM among distributed learners, particularly boundary spanning and joint attention.

5.1 Boundary Spanning

This study shows the importance of supporting physically distributed students to engage boundary spanning collaboration. In Case 1, we see Imani talking to an instructor and asking questions while gesturing to Kayla’s circuit projected from her workspace in Figure 3b. Even though Kayla is distracted, Imani is still able to use the information provided by Kayla’s circuit. In Cases 2 and 3, where BSP is more often coupled with collaborative discussion, there are frequent pauses where the shared visual workspace offers information as students compare the remote projection to their local circuit. Boundary Spanning Action (BSA) occurs less frequently, however in Case 1 Imani grounds her gestures around the projection of Kayla’s circuit as an example of BSA that aids her discussion with an instructor. Providing these opportunities for peripheral participation gives users the chance to see what others are doing before becoming engaged in the activities of the larger group.

While support for legitimate peripheral participation seems possible with these results, more work is needed to see how REACH

can be leveraged in a makerspace “community of practice” and to develop activities that model and situate its use during more informal and open-ended making [13].

5.2 Joint Attention

We see a short example of REACH’s ability to provide joint orientation to a shared workspace in Case 2 (Figure 4a) where Imani is trying to show Kayla which wire goes into the circuit next. The event is negotiated via a verbal exchange assisted by boundary spanning perception despite Imani never using the word “wire” or describing it in any way. Once joint attention is achieved, both participants converge on the meaning of “these”, and Kayla can continue building. While this type of show and tell is relatively straightforward, the importance of this exchange is in the ability for two students to communicate and help one another even when they are not using domain specific language to describe the materials or are not physically collocated [17]. Without the support REACH provides, interactions such as these can become tedious and frustrating.

In Case 3, Kayla and Imani debug a wiring issue using talk and gesture, taking turns showing each other their boards with REACH, and pointing to areas of interest in the sequence shown in Figure 5. Gesturing is generally understood as an embodied, nonlinguistic resource integral to communicative practices that ensure participants in the discourse are talking about the same thing. This case highlights the importance of the joint spatial orientation REACH provides. Research on collaboration around multi-touch tables has shown that large work areas can decrease joint attention if users are spread out without proper scaffolding [8]. Even so, collaborations can still be productive if there are opportunities for boundary spanning [18]. In Case 1, we see how REACH offers opportunities for user perception to span into another user’s space for collaboration. However, the small workspace of REACH funnels users into one-on-one exchanges and limits the types and viewability of gestures versus many students around a tabletop. While perhaps not ideal, studies have indicated that some system constraints can focus collaboration [11]. In Case 3 we see a period of sustained joint attention which may be due, in part, to this effect.

6 CONCLUSION

The REACH projector showed promise in supporting most mechanisms of collaborative discussion in the cases described above. This suggests that REACH can support multi-modal channels of communication and shared understanding that move beyond the user’s local environment. While this activity was shorter and more proscriptive than traditional maker activities, which may encourage a richer set of divergent goal adaptations, the results are encouraging for future REACH designs to support productive divergent collaboration in more open-ended and constructionist learning environments.

Despite some limitations, users were able to effectively use REACH with little help due in part to the naturalistic mode of interaction of talking about an item sitting between them. Two students that were not sitting together, who had never used a breadboard, with little domain specific language, using a novel technology, had the following exchange inside of 15 minutes: “Ok, now

try to press the button.”, “Oh! It turned on!”, “Period.” followed by laughter. These kinds of exchanges are important for effective collaboration and socialization and hold promise for future REACH implementations.

ACKNOWLEDGMENTS

This research is supported by grants from the NSF (2048833) and the Institute for Inclusion, Diversity, Equity & Access at the University of Illinois Urbana-Champaign (GIANT2021-04).

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