Design in the Public Square: Supporting Assistive Technology Design Through Public Mixed-Ability Cooperation

MARK S BALDWIN, University of California, Irvine, USA
SEN H HIRANO, Colytix, USA
JENNIFER MANKOFF, University of Washington, USA
GILLIAN R HAYES, University of California, Irvine, USA

155

From the white cane to the smartphone, technology has been an effective tool for broadening blind and low vision participation in a sighted world. In the face of this increased participation, individuals with visual impairments remain on the periphery of most sight-first activities. In this paper, we describe a multi-month public-facing co-design engagement with an organization that supports blind and low vision outrigger paddling. Using a mixed-ability design team, we developed an inexpensive cooperative outrigger paddling system, called CoOP, that shares control between sighted and visually impaired paddlers. The results suggest that public design, a DIY (do-it-yourself) stance, and attentiveness to shared physical experiences, represent key strategies for creating assistive technologies that support shared experiences.

CCS Concepts: • **Human-centered computing → Accessibility theory, concepts and paradigms**; **Empirical studies in accessibility**; **Accessibility design and evaluation methods**; *Accessibility technologies.*

Additional Key Words and Phrases: Assistive Technology; Visual Impairment; Design; Participatory Design; Co-Design; Disability

ACM Reference Format:
Mark S Baldwin, Sen H Hirano, Jennifer Mankoff, and Gillian R Hayes. 2019. Design in the Public Square: Supporting Assistive Technology Design Through Public Mixed-Ability Cooperation. *Proc. ACM Hum.-Comput. Interact.* 3, CSCW, Article 155 (November 2019), 22 pages. https://doi.org/10.1145/3359257

1 INTRODUCTION AND BACKGROUND

In the two weeks leading up to the CSCW deadline, a hashtag appeared across social media and went viral, #AbledsAreWeird. The hashtag started by @Imani_Barbarin was created to enable people with disabilities to share stories about interactions with those without disabilities that they found awkward, offensive, or "weird." These tales ranged from entertaining and amusing anecdotes to horrific and insulting stories filled with fear and loathing. The tongue-in-cheek idea of this hashtag and associated posts is that "ableds" (short for able-bodied) are "weird" or different and not those with disabilities. The stories gave people with disabilities a chance to describe the interactions of the world that they experience. The so-called social model of disability [40] notes that disabilities are interactional—the result of a mismatch between physical bodies,

Authors' addresses: Mark S Baldwin, University of California, Irvine, Irvine, CA, USA, baldwinm@uci.edu; Sen H Hirano, Colytix, Los Altos, CA, USA, sen@colytix.com; Jennifer Mankoff, University of Washington, Seattle, WA, USA, jmankoff@cs.washington.edu; Gillian R Hayes, University of California, Irvine, Irvine, CA, USA, gillianrh@ics.uci.edu.

2573-0142/2019/11-ART155 $15.00
https://doi.org/10.1145/3359257

the built world, and social constructs. Disabilities are experienced through interactions with the physical and social world, and while social interactions and disability experiences can be shared, these interactions are more often othering and problematic. One might then ask what the role of shared assistive technology can be in changing this dynamic. In this work, completed long before the #AbledsAreWeird hashtag and associated stories, we explored this precise issue. By publicly developing a technology for blind outrigger canoe paddlers, we were able to test the boundaries of cooperative design as well as community-based research. By intentionally co-designing a shared, mixed-ability assistive technology in public settings, we were able to explore the ways in which sighted and blind technology users working together created an improved experience that neither could create alone, thus providing a roadmap for potential future cooperative assistive technology design and development.

Technology can be a powerful enabling force through which blind and visually impaired individuals experience parts of the sighted world that might otherwise not be available to them. These assistive technologies help people manage a variety of everyday tasks at home, at work, and during leisure. Assistive technologies are more often viewed as individual tools to support an individual experience [48] than shared tools [6, 11, 28]. However, just as students in a class who know about a child's disability are likely to be more welcoming [37] and how people view wearable technology more favorably when they know it is assistive [36, 43], cooperation between people with and without disabilities can tremendously improve not only technology design but also experiences for both involved [51].

In this work, we set out to first understand the experience of blind and low vision outrigger canoe paddlers as a powerful example of access to leisure activities regardless of physical constraints. Working with an organization that takes blind and low vision paddlers on group outings in a six-person outrigger canoe (OC6) for both recreation and competition, we quickly saw a need for solo paddling. Competitions typically involve the use of an OC6 with a sighted steerperson, allowing up to five visually impaired persons to participate. To prepare for competitions, however, training in an one-person outrigger canoe (OC1) is critical to developing strength and technique. As such, we focused our investigation on supporting blind and low vision paddlers using an OC1. For example, visually impaired paddlers typically must either rely on a multi-person canoe or respond to simple audible directives (*e.g.,* left, right, watch out) called out from a support boat—neither of which match the training conditions of sighted paddlers. In addressing these challenges, we take the interdependent approach to assistive technology design [10], with an eye towards the ways that working together on both the design and the experience of such technology could drive additional awareness and engagement across the boundaries of the sighted and blind paddler communities.

Following a multi-month participatory design experience with both sighted and blind paddlers and several rounds of prototype iterations and development, we tested our multi-modal multi-user system with blind and sighted paddlers. In this paper, we present the results of our design experience in three major themes. First, public cooperative design and development of assistive technologies is possible, requires engagement from both sighted and blind communities, and increases awareness of the disabled experience within the surrounding community. Second, this particular approach owes its success to its deployment within an established community accustomed to modifications and DIY approaches to their canoes, suggesting a particularly relevant type of target for future similar endeavors. Third, the physicality of the multi-modal design created additional challenges and opportunities for both blind and sighted co-designers and users, suggesting new design possibilities and constraints for assistive technology researchers.

2 RELATED WORK

2.1 Opportunities for Blind and Low Vision Fitness

Achieving desired health and fitness outcomes remain an ongoing challenge for the visually impaired community [4]. Limited opportunities [42], dependence on others [23], and lack of generalizability outside of educational environments [17] pose barriers to most outdoor activities. Although organizations like the United States Association of Blind Athletes [39] and the International Blind Sports Federation [13] promote a variety of sports adapted or designed specifically for visually impaired participants, as Rector et al. found in their investigation of "eyes-free" exercise, opportunities for *rigorous outdoor activity* remain an ongoing challenge for assistive technology research [46].

Water sports provide a safe environment for physical activities with the proper equipment and supervision [41], yet until recently [32, 55], have received little attention from the assistive technology community [16]. In activities like paddling (*e.g.,* rowing, kayaking, or canoeing), one likely reason for this is the complexity required to ensure safe navigation on the water for blind or low vision paddlers. Current efforts, to the extent that they exist, depend on either extensive training and preparation [9, 55]; complex, customized technological enhancements [32, 55]; or in the case of multi-person canoes, a team of mixed-ability athletes. Projects like Microsoft's Soundscape Kayaking Scavenger Hunt [32], which paired blind and sighted paddlers in kayaks to navigate through a series of GPS waypoints using 3D sound, can be a very powerful experience. However, they do not support the realities of leisurely paddling (*e.g.,* navigating among other objects in the water) nor training on the water (*e.g.,* drills and maneuvers). Enabling a blind or low vision paddler to safely paddle in a canoe alone, as far as we know, has not been explored from an assistive technology design perspective.

Drawing on conversations within the disability community, Bennett et al. encouraged assistive technology researchers to consider the "interdependent" relationship within mixed-ability groups in their work [10]. By embracing interdependence, issues like error free automated navigation and exception handling can be handled as a separate case from enabling access to activities. As a historically communal activity, interdependent engagement holds a prominent role in outrigger paddling. Paddlers frequently rely on each other for support, producing a natural environment to explore mixed-ability assistive technology design.

2.2 Designing Assistive Technologies for Fitness

In our review of fitness-related assistive technology research, the needs, goals, and objectives of users are identified through traditional research methods such as surveys, interviews, workshops, and experiments [2, 5, 34, 45]. While valuable as research contributions, these methodological approaches make it unclear how interventions will perform over time. In a longitudinal follow-up study [47] to their lab-based intervention [45], Rector et al. acknowledged this limitation and note that long-term real-world deployments serve to better illustrate the potential of fitness-oriented assistive technologies [47]. Drawing upon existing practices from disability studies and participatory design, Mankoff et al. argued that deep, long-term engagement between researchers and disabled individuals can lead to positive results that benefit everyone involved [30]. Furthermore, real-world deployments serve to mitigate the disparity between researchers and subjects of differing abilities [57], and acknowledged that users with disabilities are experts of the assistive technologies that they use [51]. However, as Kane et al. pointed out, deployments within organizations risk small, repetitive participant pools [24]. In our work, we sought to mitigate some of these risks through public-facing, inclusive design sessions.

2.3 Public and Participatory Assistive Technology Design

While design practices like participatory design do bring users into the design process [35], researchers need to adapt to the abilities of their target audience [3]. According to Morrison et al., in a multi-workshop study using "tactile ideation techniques", blind participants struggled with the ideation process while prototyping with physical objects in a participatory design setting. Despite enjoying the process of manipulating tactile objects, participants with less vision were taxed "in a way that did not encourage ideation", highlighting the challenges for researchers to bring blind and low vision users into the design process effectively [33].

One way to engage blind and low vision participants in participatory design is to draw from the multiple levels of expertise within existing communities [56]. Cooperative design or co-creation/co-design—a subfield of participatory design—positions designers, researchers, and users equally as experts of their own experience [49]. Co-design principles are grounded by the principle that individuals contribute according to their own creativity and ability. Success, according to Sanders and Stappers, is dependent on not pushing individuals beyond their own level of interest [49]. In the work presented in this paper, we build upon the principles of co-design by situating a mixed-ability design team within a public setting, similar to the work of Teal and French on Designed Engagement [54] in which participants are drawn through the public setting, rather than recruitment. In addition to the ability to uncover insights that exist outside the boundary of a design team, Teal and French suggested that public engagement through design serves to build empathy with the public as they become active participants in the design process.

2.4 Awareness and Disability

Public-facing assistive technology co-design holds promise as a method for increasing positive attitudes towards disability. Though the Americans with Disabilities Act [38] has brought access to vital services for the disability community, negative stereotypes and awareness towards people with disability pervade contemporary culture [50, 58]. It is generally accepted that increased exposure can positively affect attitudes towards disability, but the mechanisms for supporting contact are less understood [8, 53]. Exposure alone does not appear to sufficiently promote positive attitudes in mixed-ability groups [25]. Rather, prolonged, meaningful contact between mixed-ability groups is required to create sustained positive outcomes. Keith et al. argued that influential contact that is perceived as "equally cooperative and pleasant" is necessary for positive change in awareness [25]. Sports, in particular, are regarded as powerful activities for changing societal perceptions on the capabilities of people with a range of disabilities [12, 14]. However, to the best of our knowledge, factors related to perception and awareness within sporting activities have only been observationally studied, with a dearth of research exploring mixed-ability sport engagement.

3 METHODS

Our study was conducted at the Newport Aquatic Center, a facility dedicated to supporting paddle-based water activities such as rowing, kayaking, paddle boarding, and outrigger canoeing. The Newport Aquatic Center serves as a home for numerous external organizations, including Makapo—an organization that focuses on providing paddling opportunities for individuals with visual impairment. Over a ten month period from January to October at the Newport Aquatic Center, we used a participatory design approach over 13 sessions to iteratively develop CoOP, an assisted steering system for one-person outrigger canoes (OC1).

Fig. 1. A Makapo paddler in a one-person outrigger canoe (OC1) with the final version of CoOP attached.

3.1 The CoOP System

Although CoOP itself is not the focus of this paper, in this section we provide a brief description of CoOP to provide context for the results and discussion that follow. To work around the challenges faced by Makapo, we developed CoOP, an assistive system through which the rudder (*i.e.,* steering) of an OC1 is remotely controlled by another person (*e.g.,* a coach), freeing blind and low vision paddlers from managing directional control and enabling increased focus on technique.

CoOP sits on top of the rudder (see Figure 2) and manipulates it using special motors (*i.e., common servos*), which are "plug and play" with a standard handheld RF transmitter. In the current version, CoOP is attached to the OC1 using a GoPro Suction Cup Camera Mount (see Figure 3) [22].

CoOP was designed to be low-cost, taking a do-it-yourself (DIY) approach to development. Additionally, designs were informed by a desire to avoid complicated, difficult to acquire, or expensive components. We selected off-the-shelf parts whenever possible and designed custom parts for fabrication on low-end 3D printers, making the total cost for a fully functional system less than $250—which is considerably less than many assistive tech equipment.

3.2 Design and evaluation of CoOP

Project development took place in thirteen cooperative sessions from January to October 2018. Sessions were held at the Newport Aquatic Center with a core group (n=15 including the first and second author, see Table 1) for roughly two to three hours each, for a total of 34 hours on-site working with over 23 people whom were in Makapo or around the Newport Aquatic Center. Participation in sessions was opportunistic, sessions were scheduled around having enough participants from the core group who were available, and various others at the Newport Aquatic Center came in and out of the session areas as they desired. Because of the nature of people's availability, some members are more heavily represented in the results.

Each session involved an iterative evaluation of our prototype and post-evaluation interviews. In total, we conducted 34 hours of sessions including semi-structured (n=5) and *ad hoc* (n=3) interviews, focus groups (n=2), and evaluations of the prototype (miles=26). Interviews and focus groups were audio recorded when possible, otherwise notes were taken. The natural progression of the project ranged from planning to real world operation, which we categorize in detail below.

Table 1. This table details members of the core design team for CoOP. They are organized by role within the design team and their visual and organizational affiliations. Identifiers are assigned using their role, visual status, and a numerical indicator.

Identifier	Role	Vision	Organizational Affiliation
ResearcherS1	Researcher	sighted	UCI
ResearcherS2	Researcher	sighted	UCI
DirectorLV1	Director, Coach	low vision	Makapo
PaddlerLV1	Paddler	low vision	Makapo
PaddlerLV2	Paddler	low vision	Makapo
PaddlerB1	Paddler	blind	Makapo
PaddlerB2	Paddler	blind	Makapo
PaddlerB3	Paddler	blind	Makapo
PaddlerS1	Paddler	sighted	Makapo
PaddlerS2	Paddler	sighted	Makapo
CoachS1	Coach	sighted	Makapo
CoachS2	Coach	sighted	Makapo
SpecialistS1	O&M Specialist	sighted	Makapo
SupportS2	Support Boat	sighted	Newport Aquatic Center
TechnicianS3	Boat Repair Technician	sighted	Newport Aquatic Center

3.3 Preliminary Sessions: 1,2

Preliminary sessions consisted of informal meetings with Makapo to gain a better understanding of the problem space. Because our research team had no experience with outrigger paddling, the first session was primarily spent discussing the details of the activity. We identified common goals, philosophies of enabling technology, and learned about skill sets. The second session was spent exploring the type of canoe we would be utilizing for the project. Through our exploration of the canoe we identified guidelines and constraints of canoe modification, learned basic canoe operation, and agreed on a strategy for implementation. The research team spent the three month period leading up to the third session developing a low-fidelity prototype based on the data collected during the preliminary sessions. The photographs and measurements of the canoe that were collected informed preliminary system design. Preliminary designs were first sketched on paper, followed by implementation using 3D modeling software, and finally physical creation (see Figure 2) using a combination of 3D printed and off-the-shelf parts.

3.4 Evaluation Sessions: 3-11

The evaluation sessions commenced a four month period of iterative prototype development and testing. Sessions typically occurred every other week depending on participant availability and time constraints surrounding prototype development. Sessions were attended by stakeholders from the primary author's institution, Makapo, and the Newport Aquatic Center (see Table 1). Due to the public space in which prototype evaluation was conducted, we also received solicited and unsolicited insights from nearby paddlers and Newport Aquatic Center employees. Evaluation sessions consisted of an iterative cycle of fit and *in situ* tests to refine the design.

The physical dimensions of the outrigger canoe constrain any assistive technology designs. At roughly ten feet in length, transferring the OC1 between our design lab and the Newport Aquatic Center was not practical. Additionally, Makapo was actively using the OC1 during our development

Fig. 2. A close-up of version three of the CoOP system mounted to the rudder assembly and the transmitter used to control the rudder (right corner).

phase, further complicating any plan to work off-site with the OC1. The OC1 that we used for testing was stored on a rack located outside. At the beginning of each session the canoe would be removed from the rack and placed on stands in a public area where incoming and outgoing paddlers cared for their canoes.

3.5 Deployment Sessions: 12-14

The final three sessions centered on preparation for a yearly paddling race sponsored by the Newport Aquatic Center. Sessions were attended by a core group that included CoachS1, PaddlerB1, and at least one member of the research team. These sessions provided CoachS1 with the opportunity to learn how to use CoOP, give PaddlerB1 additional training, and evaluate the robustness of CoOP.

3.6 Analysis

In these sessions, we performed repeated member checks and escalating *in situ* testing to continually improve the design of CoOP. We then analyzed our interviews, observations, and field notes using inductive coding and memoing to identify needs and considerations for prototype iteration. Additionally, for this paper, we focus our analysis on the design process, for which the themes that were generated were refined through discussions with coauthors.

4 RESULTS

In this section, we present the results of our field work and design, surrounding the iterative development of CoOP. We demonstrate the various ways that our *in situ* design process fostered investment and interest across the sighted and visually impaired paddling community. Results are presented according to three high-level themes that emerged from our data analysis: 1) public-facing co-design and development of assistive technology; 2) DIY within the context of community; and 3) the physicality of multi-modal design.

4.1 Public-Facing Co-design of Assistive Technology

Conducting the majority of our design research in public at the Newport Aquatic Center served as a convenient location for the team to coordinate as well as allow researchers to conduct evaluations without the need to pull the test OC1 from active use. Although a lab-centered approach may have shortened the iterative design cycle, our thematic analysis revealed that many design decisions were a direct result of the visibility of our work to the general paddling community. In this section, we describe 1) how the public setting for our work afforded solicited and unsolicited feedback, and 2) how multiple levels of expertise contributed to the design and development of CoOP.

4.1.1 Solicited and Unsolicited Feedback. We did not intentionally solicit feedback from the general paddling community, but conducting design and evaluation on the wash deck (*i.e.,* where equipment is washed down after use) at the Newport Aquatic Center exposed the process to a steady flow of paddling enthusiasts. In the second session, our preliminary functional tests on the wash deck caught the attention of a few paddlers working near us. Upon observing that our prototype was unable to turn the rudder, one of the paddlers commented:

> I used to be really into racing RC trucks, spent a lot of money in my youth, you need to get a high performance LiPo battery. They can deliver a lot more power than what you are using. You should also think about looking into a high-torque waterproof servo. – *Session 2, Unsolicited Community Member*

Although receiving unsolicited feedback from the public during an evaluation of a non-functional prototype was unexpected, the input we received prompted a deeper investigation into the capabilities of the radio-controlled watercraft ecosystem, such as discussions with employees at a local hobby store. In the same session, a different community member overheard our discussion on harness mounting strategies and commented:

> You know what would work are those 3M stick pads, the ones that act like Velcro. I have used them to hold stuff to my canoe in the past. – *Session 2, Unsolicited Community Member*

As with the earlier community member, this input prompted a deeper conversation between team members, eventually leading to an entirely different mounting strategy. The team decided that straps wrapped around the hull of the OC1, an approach initially rejected by ResearcherS1 and ResearcherS2 due to concerns over drag in the water, would be an acceptable alternative to adhesive mounts. Recognizing the value of unsolicited feedback, the design team adopted an open design stance, inviting anyone who expressed interest in our work to express ideas. This shift in approach follows what Sanders and Stappers describe as a blurring of roles, where the researcher shifts from translator to facilitator [49]. Embracing the broader community as experts of their own range of experiences, led to valuable opportunities for input and feedback on the current iteration of CoOP. From our field notes during the following session:

> Even with the straps, the fit was still a little bit too loose. One of the paddlers cleaning his canoe next to us suggested that we pick up some pipe insulation foam. He said, "It's cheap, easy to cut, and compresses enough to give you some flexibility [in the design]." – *Session 3, Field Notes*

Even if we could have eventually resolved the various design issues that arose during our early sessions without these inputs, involving the broader paddling community in the process not only expanded how challenges were resolved but also increased community investment in our work. At our sixth session, PaddlerB1 and his father were attaching the harness to the OC1. After struggling to thread the straps into tension clips, an alternative mounting discussion took place:

> As we were cleaning the canoe after our test, PaddlerB1's father asked if I had thought about using a suction cup to hold the harness on to the canoe instead of straps. I expressed concern over durability, but he assured me that the brand of suction mount that he used would provide more than enough resistance to the forces we were experiencing. – *Session 6, Field Notes*

Here, a community member's father, reflecting on his own experiences with suction cup mounts outside of the paddling world, contributed a design insight that ultimately proved to be the right mounting solution for our final iteration of CoOP. His insight drew from both his individual experience (*i.e.,* his knowledge of suction cup mounts) and his collective experience with PaddlerB1(*i.e.,* facing a particular challenge)—a central tenet of the co-design process. Adopting community insight in this way can lead to positive feedback loops between the design team and community members that encourages deeper investment [26]. After integrating the suction cup mount into the design, PaddlerB1's father exhibited increased engagement in the design process, which in turn encouraged the design team to solicit his input on new iterations.

Soliciting feedback from users or the community at large is a critical step in any user-centered design process [1], as it ensures that the product works appropriately for a target audience within a defined setting. But it gains additional value within a public co-design process, allowing for the generation of edge-case scenarios and enabling more holistic design thinking. In preparation for our final prototype evaluations, ResearcherS1 and DirectorLV1 were testing the strength of the new suction cup mount in the water when PaddlerLV1 returned from a Makapo practice:

> During mount testing, DirectorLV1 asked if the harness would float. We detached the system and tossed it in the water. It floated. PaddlerLV1, standing nearby, commented, "If that were to fall off while I was in or near the canoe, there is no way I would be able to see it." DirectorLV1 agreed and suggested wrapping neon green flotation bands (typically used to keep personal items from sinking) around the top of the enclosure. He had one with him so we ran a quick test with CoOP. Both DirectorLV1 and PaddlerLV1 noted that it was much easier to see. – *Session 8, Field notes*

PaddlerLV1 and DirectorLV1 can and do paddle without sighted guidance; yet their reduced visual acuity makes it difficult to differentiate between lower contrast objects. At the time, the CoOP enclosure was being printed with black ABS filament in our lab 3D printer. We switched to neon green filament for the next iteration to increase the contrast between CoOP and the water (see Figure 3). While the use of fluorescent colors for marine equipment is not unusual, PaddlerLV1's unsolicited feedback *in situ* lead us to think about how colors further shaped our design process for CoOP. Color might not be something a designer would think to consider for an assistive device for a blind user. Public and cooperative contexts, however, benefit from such consideration. Too frequently, assistive technologies that are well designed with the primary user in mind, like this one, do not consider other users who may not share the same disabilities as the primary user.

4.1.2 Multiple Levels of Engagement. Receiving feedback from the community proved to be a useful guide for adapting the design, as is the case in public engagement [54] and co-design [49] efforts. We were able to access this level of engagement through our repeated presence in the public community space. For example, in the following excerpt from field notes, we describe the degradation of the 3D printed tiller cap, the mount point that sits between CoOP and the canoe rudder, and the way in which we solved the issue using direct manufacturer expertise:

> Today DirectorLV1 introduced me to a design engineer from one of the canoe manufacturers who was visiting the Newport Aquatic Center. After a brief demo of the system, I expressed some concern over the durability of an ABS tiller cap. We brainstormed on design and material selection for CoOP's custom tiller cap. He suggested adding a particular type of washer for reinforcement. - *Session 5, Field Notes.*

The expertise accessed in this particular case was *ad hoc* and opportunistic. These are not the characteristics of a structured design process that is replicable, drawing attention to the challenges of the overarching DIY approach to some assistive technology. However, it also draws our attention back to the necessity in this case of accessing a dedicated community already engaged in the cooperative leisure activity at stake. In other cases, such dedicated expertise may be less essential to functional design requirements, yet foster idea generation in unexpected ways. For example, in one session from our field notes, an employee from our partner organization was able to address an engineering challenge from her experience working with children with visual impairments:

> Today we asked the Makapo paddlers to attach the CoOP harness to the OC1. Noticing some of the challenges they were having with strap alignment and the tension clips, SpecialistS1, Makapo's orientation and mobility specialist, suggested using Velcro straps. She explained how the textural variations helped with fastening and alignment. – *Session 6, Field Notes*

Drawing on her background in orientation and mobility work, SpecialistS1 introduced a different perspective to the design process. Rather than focus on design or engineering requirements, SpecialistS1 considered the experience of negotiating objects without sight. As the lead for the kids program at Makapo, SpecialistS1 was not initially involved with the CoOP project. The project's public orientation, however, led to days where design sessions and kids paddling activities overlapped. SpecialistS1's insight introduced a critical design requirement to the process that the team incorporated into future iterations, reflecting the type of positive results championed by co-design practitioners [49]. Textured thumb screws, a tactile power switch, and the suction cup mount we describe in the previous section, were all changes that reflected SpecialistS1's insight. Assistive technology researchers looking to engage in co-design may need to consider intentionally including this type of expertise on their design teams, and the development of supports for the larger non-research community to cooperatively create such solutions is an important area of future inquiry.

The benefits of disabled-abled co-design go well beyond the improvement we witnessed to the technology itself. Drawing from the expertise that surrounded the project—including both blind and sighted co-designers—established a community wide interest in the project. As the director of Makapo explained:

> People are excited. They keep hearing about what you are building and want to learn more. I think this has the side effect, you know, of drawing more people over when we are testing. – *DirectorLV1*

Notably, in the above quote, the "they" to whom the director is referring are not the people directly participating but a broad range of people who are involved with the Newport Aquatic Center, or who are local to the area but not involved, and so on. In this way, the co-design exercise organically grew wider than the direct participants, broadening awareness about the potential of the technology and the activities of blind paddlers. Novelty of the project likely led to a part of the curiosity and engagement, however, the months following the development of CoOP indicate that awareness extends beyond initial curiosity, allowing further engagement.

Every Fall, the Newport Aquatic Center sponsors an open water race for human-powered vehicles that is designed to promote water sports and bring the various paddling communities together.

Makapo typically participates in the OC6 category with a sighted steerperson. For this particular race, Makapo received permission to allow PaddlerB1 and CoachS1 to enter the race using CoOP. When the race was set to start, the race director focused everyone's attention on PaddlerB1:

> Waiting for the official race kick-off, I am on the support boat alongside DirectorLV1, PaddlerB1's dad, and the film crew. SupportS2 is driving the boat and CoachS1 is steering CoOP. We are surrounded by approximately sixty race participants as the race director prepares to start the race. Using a megaphone, he informs everyone that PaddlerB1 will be the first blind paddler to compete in an OC1. PaddlerB1 receives a round of cheers from the other paddlers. – *Race Day, Field Notes*

The director's announcement served to make sure the race participants understood why PaddlerB1 would be followed by a support boat, but it also brought attention to the significance of PaddlerB1's participation. After the race, while we were cleaning the OC1 on the wash deck, we were greeted by numerous participants interested in learning about the CoOP system. These events directly reflect the public co-design nature of the project. Our visible presence at the Newport Aquatic Center, and involvement with the community, brought merit and meaning to the project that would likely be absent if the team simply showed up with CoOP on race day.

In the months that followed the race, we observed two changes that reflected an increasing awareness and engagement of this community through better accommodations for Makapo's blind paddlers. When we returned to the Newport Aquatic Center for the first time after the race, we found that Makapo's OC6 canoes were no longer stacked in a hard to reach area of the beach. From our field notes:

> At the Newport Aquatic Center today, noticed that the Makapo OC6's are no longer crammed between the other paddling crew canoes on the beach. They are now located on the outer edge of the area with a lot more spacing around them. – *Field Notes*

The change was significant. The coordinated actions of launching and stowing the OC6 that we described in the previous section were a constant challenge for Makapo paddlers when the canoes were stored in the original location. The proximity to other boats, support stands, ropes, and debris, added unnecessary obstacles for the sighted team members to attend to when maneuvering the canoe. The additional space provided by the new location removed the need to navigate these obstacles. Similarly, in a meeting a few weeks later ResearcherS1 learned that a staff member at the Newport Aquatic Center expressed interest in continuing to make the wash deck and beach area more accessible, from our field notes:

> Met with Makapo today to discuss the installation of portable walkways on the beach designed to support wheelchair access. DirectorLV1 mentioned that the Newport Aquatic Center has expressed interest in supporting some type of installation to make traversal easier for blind paddlers. – *Field Notes*

While we are unable to broadly claim that the public co-design orientation of our work influenced staff members at the Newport Aquatic Center, our observations align with positive changes in attitude associated with mixed-ability exposure [8]. In an interview conducted with DirectorLV1, we explored his thoughts about the changes:

> I think it [public co-design] has had an impact, more so with the staff at Newport Aquatic Center than with the general public—they need to see more, but for the staff, they are more aware of what we are doing here and we are starting to see that effect more and more. – *DirectorLV1*

Fig. 3. The design evolution of the CoOP system in order of iteration from left to right.

Our public co-design advertised much more than just the feedback into the design process—it brought attention to and made more people outside of the direct community consider some of the issues that individuals with disabilities struggle with on a day-to-day basis.

Although physical constraints of canoes had forced the project to be conducted in a public space, it had the unintended and positive effects of promoting engagement, shaping the project in ways likely different from how the original partnership between the research team and the community organization would have, and spreading information about the project to a disparate audience. Researchers doing community engaged work should leverage this by thoughtfully incorporating public space projects as an intentional part of their process, even without the forced constraint.

4.2 DIY within the context of community

A common challenge when designing for individuals with disabilities is gaining access to the community for running user studies [24]. Our partners were cautious about allowing their community to become subjects of an experiment that may give undue hope or stress without resulting in something that they could use in the foreseeable future. By emphasizing a do-it-yourself (DIY) approach, we were able to clearly demonstrate the steps for reproduction and giving our partners a sense of reciprocity. As we note in our field notes:

> Today we conducted the first water test. I joined DirectorLV1 and SupportS2 on the support boat while PaddlerLV1 paddled in the OC1. Afterwards, as we inspected the system on the wash deck, DirectorLV1 was pulling in anyone who walked by to share the news, emphasizing how inexpensive it was to build. – *Session 4, Field Notes*

The initial test process showed our partners that the relationship would not be a one-sided where they were limited to answering our research questions. Parting ways is an inevitable outcome for nearly all community research projects [20], so communicating our intentions early on was an important step in the co-design process. Our transparency about our working progress—articulating precisely how we produced the prototype, including cost, tools, and part suppliers—gave Makapo confidence that they would be able to use and continue the project independent of our involvement.

The paddling community—as far as it is represented at the Newport Aquatic Center—exhibits attributes reflective of DIY practices, which have been shown to support assistive technology work [18, 21]. Canoes are personalized, modified, customized, and reappropriated to satisfy paddler interests. We frequently observed DIY behavior throughout our time with Makapo. When we asked about canoe personalization, DirectorLV1 explained:

> Our canoes have a personality, they are considered part of the family. The modifications people make, the stickers, custom colors...it comes from a long history of use. The outrigger canoe has deep history with the pacific island culture, and I think those historical practices just emerge when people get into the sport. – *DirectorLV1*

Bringing a DIY approach to assistive technology design into a community that engages in similar practices influenced how CoOP was perceived. Attaching an obviously handmade device onto a canoe, was not seen as out of the ordinary with the context of established community practice. On the wash deck, every outrigger canoe looks different, even when they are the exact same model from the same manufacturer. Although the most common forms of personalization can be observed through color and semi-permanent attachments, the canoes also undergo permanent physical modification, as with the following example from our field notes:

> The canoe we will be evaluating CoOP on looks pretty beat up. It's not painted, has areas where the buoyancy material is exposed, and has random beer can stickers on its hull. – *Session 1, Field Notes*

Although the canoe was fully functional, it was far from "normal" in its visual appearance compared to the backdrop of outrigger canoes, rowing sculls, and kayaks that surrounded it. Despite its looks, the canoe is an employee favorite. The hull has been cut apart and reshaped a number of times to fulfill performance curiosities of paddlers, eliciting a desire for creative expression and identity that echo sentiments common to crafting communities [7]. The primary canoe we used for testing went through a similar journey:

> Makapo acquired a new canoe to use for CoOP evaluation. The canoe had fallen off of a car on the highway and received so much damage that the owner decided to replace it rather than repair it. The canoe repair team at Newport Aquatic Center rebuilt the fiberglass hull and repainted it. – *Session 2, Field Notes*

In both cases, the repairability of the particular style of canoes we were using made them conducive to modification. What we found interesting, however, was not the fact that the canoes could be modified, but rather how the modification reflected back on the behavior and attitudes of the broader community. For paddlers, DIY is an expected, normal part of canoe ownership. Nobody noticed when we started strapping large chunks of plastic to the back of the canoe. Throughout the prototype design process the only critique we received came from a non-paddler:

> PaddlerB1 brought a large group of family members out for our evaluation today. One relative provided some critique on my bolt size choices for the mounting legs, noting that they were probably overkill for the application. I later learned that he was a retired aviation engineer. – *Session 5, Field Notes*

These kinds of comments hint at the contrast between a DIY stance and one more aligned with professional production. For the DIY community, successful operation of the artifact takes precedence over decisions such as bolt size. Rather than constant scrutiny over design decisions, those around us during prototype development accepted the status of the system at each new session and only tried to assist when we were met with a challenge.

Making structural changes to canoes is one of numerous ways that the paddling community engages in DIY behavior, and one that from our observation appears to be reserved for a subset of paddlers with a particular skill set. For others, DIY manifests itself in non-permanent modifications and customization. At the end of Session 7, DirectorLV1 and PaddlerS1 were discussing their plans to have custom decals created for their canoes. They talked about options for ordering, colors, designs, and meaning behind their choices. Other paddlers maintained a variety of attachments used for carrying artifacts such as phones, fitness trackers, water bottles, and cameras. Although many of these attachments were commercial products, they imbued each canoe with a distinct appearance.

While the personalizations we observed are certainly not unique to the paddling community, they demonstrate the heterogeneity of paddling culture. The perception of an assistive technology attached to a canoe is that of typical paddler behavior rather than a beacon for disability. This allows Makapo paddlers to maintain control over the visibility of their disabilities. In one example from early on in our field work we observed that PaddlerLV1 wore a bright orange shirt with the Makapo logo on the front and the words "Blind Paddler" on the back in large black block letters. After we had spent more time working with Makapo we noticed that the PaddlerLV1 had stopped wearing the shirt. When asked about the purpose of the shirt, the DirectorLV1 noted:

> We had those shirts made up for a race a few years ago. There are no requirements that it be worn, we just thought it would be helpful for other race participants. It's also a good way to let them know what we can do! – *DirectorLV1*

Rather than a requirement, the shirt is representative of how Makapo perceives itself within the broader paddling community. They didn't need to inform other paddlers of their disability, but did so when they were proud to declare their participation in an outrigger canoeing event. As others have demonstrated, control over disclosure is a desirable feature for assistive technology [44, 52].

4.3 Physicality and Interdependence as Design Requirements

Another theme drawn from our data is the impact of physicality on the paddling experience. We frequently modified our design goals for CoOP as we observed the existing practices of Makapo's paddlers. We observed ways in which Makapo's blind and low vision paddlers appropriated naturally occurring phenomena from the environment to support the loss of auditory cues in the OC6. The first author observed the value of auditory cues while joining Makapo for their weekly kids program:

> Today I joined the Makapo team and the [kids paddling program] in the triple hull canoe. I sat in the front behind PaddlerB3 and PaddlerB2. PaddlerS1 was the steerperson and called out [paddle commands]. She teased PaddlerB3 and PaddlerB2 whenever they started to paddle out of sync. So PaddlerB3 started audibly calling his strokes. PaddlerB2, listening to the calls, could then sync his water entry point with PaddlerB3. – *Session 5, Field Notes*

The steerperson is the sixth person in an OC6 who is responsible for steering and calling out pace. For Makapo paddlers who are visually impaired, the sounds of paddles entering and leaving the water combined with calls from the steerperson provide feedback on their individual pace. The absence of these auditory cues makes gauging pace more challenging. When asked if the audible calls to synchronize paddles was typical behavior, PaddlerB3 and PaddlerB2 explained that they usually don't have to, but were having a hard time differentiating paddle sounds in the triple hull with so many people (twenty kids and adults). While synchronization is not necessary in an OC1, blind and low vision paddlers appropriate audible sounds in other ways. According to CoachS1, sighted paddlers will use the wake created by the canoe, movement of objects in a stationary position (*e.g.,* fishing boats, buoys, and landmarks), and GPS based fitness devices to measure pace. For Makapo's visually impaired paddlers, these visual indicators are either entirely absent or too difficult to see to be worth using. At Session 7, we were evaluating CoOP with PaddlerB1 for the day. PaddlerLV1, who was also at Newport Aquatic Center that day, decided to join us using a PaddlerS1's OC1. When we returned he described how it was harder to manage pace without the "sucking sounds." Curious about what he meant, we probed further:

> When I'm paddling hard in [their usual OC1 model], I can hear suction sounds from the drainage holes in the canoe. So I use that sound to know how fast I am going. But in [a different OC1 model], there are no sounds. – *PaddlerLV1*

In the absence of the visual indicators from landmarks and audible feedback in the form of noise from paddles moving through the water available in an OC6, PaddlerLV1 learned to rely on the unique sounds generated by a component of the canoe designed to drain water from the foot area. Such a phenomenon is not uncommon for people with visual impairments who frequently rely on background noise for contextual cues about their environment [27]. However, acknowledging the value of ambient sounds, taking steps to identify them, and integrating them into the design process for assistive technology presents an opportunity to enrich the usefulness of the devices we create. Learning about the reappropriation of the use of drainage holes inspired us to reflect on our design decisions for CoOP differently. We do so in the following case. One constant side effect of using a digital servo motor to turn the canoe rudder is the constant high pitched hum the motor generates when it is engaged. As testing progressed, the hum was frequent enough that the research team grew concerned over potential damage to the motor. During post-session discussions about the issue, PaddlerLV2 and PaddlerB2 explained their interpretation of the hum:

> It's kind of funny, cause when you turn you want to make sure you are paddling on the correct side of the canoe, so when you turn on the motor or whatever, I can hear it squeal, and prepare for a turn. – *PaddlerLV2*
>
> Yeah, I know when I hear the motor noise start that the boat is going to turn. – *PaddlerB2*

Recognizing the value of the audible noise CoOP emitted, we embraced the servo noise as a feature rather than an undesirable artifact. In the final version of CoOP, we integrated a relay between the battery and the servo motor, allowing the guide to turn the motor on and off as needed, while isolating the servo noise to moments of steering activity. In subsequent tests, our participants noted that a direction change was easier to anticipate when the hum only occurred as the guide was preparing to steer. These observations on the physical experiences of paddling were not limited to auditory cues. The introduction of CoOP to the canoe transferred steering responsibility from the paddler to the guide, leaving the pedals unnecessary except during a CoOP failure. Yet as paddlers spent time in the canoe, they discovered that they could use the movement of the pedals as feedback for directional changes. Through these two sequences we learned that without verbal communication paddlers learned how to interpret secondary effects of CoOP to anticipate course changes and direction.

The physicality of CoOP extends to more than just allowing users to understand and anticipate its state. As all paddlers have Newport Aquatic Center membership in common, the typical social interactions one might expect from similar organizations, occur throughout the day as paddlers come and go. The Newport Aquatic Center operates with a consistent ebb and flow: paddlers arrive, pull their canoes from storage, prepare them for use, carry them to the waterfront, paddle, and reverse the process before departing. The prep and stow routines practiced by Newport Aquatic Center members are an essential part of the paddling experience, serving as a rally point for social engagement. Our observations of established customs and practices at the Newport Aquatic Center demonstrated how important it was for CoOP to fit into this paddling culture. For example, the prep-paddle-stow process is a fundamental aspect of the paddling experience, one that all paddlers practice, regardless of ability. As we observed in our field notes:

> Today PaddlerLV1 helped PaddlerB1 take down the OC1 and clean it. PaddlerLV1 took the lead carrying the bow up to the rinse area while PaddlerB1 followed with the stern. I have seen PaddlerLV1 carry the canoe by himself before, so the split duty was not about weight, but rather including PaddlerB1 in the process. – *Session 6, Field notes*

Blind and low vision paddler participation in the same community practices encouraged us to consider CoOP not just as as an artifact for the Makapo organization, but as a tool to extend and enrich the social engagement of Makapo paddlers. These kinds of shared activities increase awareness and inclusion for people with disabilities in society more generally, and particularly can improve social and emotional intelligence for children without noted disabilities as much as for those with [37]. Sharing canoe carrying was just one of several procedural activities where we observed Makapo paddler participation. PaddlerLV1 and PaddlerB1 frequently teamed up during our sessions as they were the primary paddlers helping us evaluate functionality of CoOP. During other sessions PaddlerLV1, CoachS1, and SpecialistS1 guided PaddlerB1 through the process of attaching the outrigger to the canoe. The role that canoe maintenance played for paddlers shaped how we thought about design for CoOP. Attaching, cleaning, and removing CoOP from the canoe should parallel other aspects of the canoe preparation cycle such that the Makapo paddlers could take ownership of the process. Having established that a portion of CoOP would be shared with sighted paddlers in our preliminary sessions (see Section 3.3), we wanted to ensure that all other aspects of the system were accessible to Makapo paddlers. Working through these issues *in situ* served as a critical step towards identifying design decisions to consider both independence and interdependence as design goals for CoOP.

Assistive technology enables people with disabilities to perform tasks that would otherwise be difficult or impossible to complete. Ingrained in this definition is the idea that assistive technologies should allow the people who use them to live with greater independence. In our preliminary sessions with Makapo we probed the extents to which the system we built needed to support independent navigation. Drawing from our knowledge of recent research in blind navigation, we discussed the use of sensors for obstacle avoidance, haptic feedback mechanisms, and computer vision. Although Makapo expressed interest in exploring autonomous technologies, they emphasized the importance of simply getting their paddlers on the water in OC1's, as DirectorLV1 described:

> We reached out to a local [robotics club] for help a few years ago that said it would cost us a few thousand dollars. The thing is, for us, we really just need a way to get our paddlers in a canoe by themselves. Training in an OC1 is the best way to improve your performance in an OC6. Since it's going to be a training situation, there will be a sighted coach with them anyway, so we really don't need anything fancy. – *DirectorLV1, Session 1, Field Notes*

For Makapo, the desire for an entirely independent experience was secondary to the need to build a competitive outrigger paddling team. Team driven cooperation is an intrinsic quality of outrigger paddling, regardless of the individual abilities of team members. What is interesting here is how that team driven culture influenced Makapo's perception of assistive technology. As much as they might benefit from a fully autonomous solution, they realized a practical approach was the best way to accomplish their goal. Knowing that a sighted coach would be present for OC1 practices meant that some responsibility could be transferred from the paddler to the coach, thereby limiting the amount of technology required to support the paddler, and effectively leading us towards building a shared assistive technology.

As part of the team-based culture, the practice of sharing manifested itself in numerous ways. As we described in Section 3, the Newport Aquatic Center is home to a wide variety of aquatic activities. Over the course of the eight months we were at Newport Aquatic Center we observed row and outrigger paddling crews of various sizes working alongside each other to setup, carry, clean, and break down their canoes. A practice reflected with Makapo as well, from our field notes:

> CoachS2 was the first out of the canoe, followed by PaddlerS2. PaddlerS2 held the canoe while CoachS2 retrieved a wheeled carriage used to roll the canoe up the beach. CoachS2 aligned the carriage and instructed the remaining four paddlers to step out of the canoe. CoachS2 and PaddlerS2 verbally guided the blind paddlers into positions around the canoe. The blind paddlers used differing tactile cues of the canoe to navigate towards the requested positions. In concert, they lifted the canoe onto the carriage and pushed up the beach to its storage location. – *Session 11, Field Notes*

When Makapo's OC6 group practices, they verbally coordinate positions around the hull of the canoe, push the canoe down to the water at the start of practice, and bring up to the beach after practice. In both situations, blind and sighted paddlers work together, sharing responsibility for the care and operation of the equipment. From this perspective, designing an assistive technology that shares control between sighted and visually impaired paddlers fits naturally within the context of the paddling experience at Makapo. As PaddlerB3, explained:

> It's not much different than what we do in the OC6, it's somebody else's job to steer, I just focus on my stroke. – *PaddlerB3*

Here, PaddlerB3 is describing an experience similar to all paddlers, regardless of ability, participating in a coordinated team-based activity. The role of steering is singular, assigned to a team member with a particular skill set. For PaddlerB3, that an assistive technology fills that role in an OC1 is irrelevant, the experience remains the same. His primary goal is to perform his assigned role as effectively as possible for himself and for his team. DirectorLV1 expressed a similar sentiment, stating that opportunities for contribution are rare:

> When I paddle in a six-person outrigger canoe, it's one of the few times as a blind person where I know my sighted teammates are relying on me, and that doesn't happen very often, so it's really empowering." – *DirectorLV1*

For DirectorLV1, the contribution that he makes to the success of his team is an empowering activity. He has found empowerment through contribution, rather than by executing his own independence. We are not asserting that independence is not a worthy goal for assistive technology, but that assistive technology can help achieve empowerment in unexpected ways.

5 DISCUSSION

Our results highlight the ways that public co-design with mixed-ability groups can support the development of assistive technology, like CoOP. In particular, the publicity and the physicality of the public design work contributed to improved awareness of blind athletes, as well as the eventual inclusion of people with a variety of abilities in activities surrounding design and use of the resultant technology (*i.e.,* CoOP). People began to understand what we were doing, why it was potentially relevant to them, the abilities of the blind paddlers sharing space with sighted paddlers, and that they could contribute to our work with Makapo.

In this discussion, we reflect on what contributed to the success of this project and present three strategies for conducting public co-design to build assistive technology.

5.1 Embrace Mixed-Fidelity Prototypes

Our practice of placing early iterations of CoOP in view of the public served to generate community interest. Many of our sessions displayed incomplete or semi-functional prototypes that were optimized to evaluate specific features. As is common with traditional rapid prototyping design iterations, we were focused on evaluating early and often before committing to high quality output, which provided the knock-on effect of giving both blind and sighted paddlers—involved with Makapo and not—the ability to critique and respond to the designs.

In our first evaluation session, we were unprepared for the level of interest we received from the public, leaving us with concerns about how our own early prototypes reflected our abilities as designers and researchers. As researchers stepping into a new community, we worried that presenting non-functioning, incomplete work would undermine community confidence. However, an analysis of our preliminary session revealed how public input contributed to our design process. We thus felt more comfortable adopting this strategy of showcasing our rapid prototyping approaches to the public to guide our design and engineering decisions in future sessions.

The mixed-fidelity nature of the prototypes helped to manage expectations, passively—but explicitly—inviting commentary on components that were being tested (*e.g.,* does this make sense at all vs can it last hours). In traditional user-centered design practices, the researcher typically embraces a leadership role within the project [49], but our use of mixed-fidelity prototypes empowered community partners to share ownership and opinions of various aspects of the project.

5.2 Support Public Input

While mixed-fidelity prototypes serve to invite critique, public input in the design process can supply crucial design considerations for and raise community awareness of the disability community. Technology is frequently described as a force for inclusion, enabling people with disabilities to participate in activities that might otherwise be unavailable to them. Similarly, a significant effort has been put forth to formulate methodological approaches that include people with disability in the design process [30, 31, 33, 51, 57]. What we saw in this work, however, is another potential future, one in which people with disabilities and others with different abilities can participate together, not only in the design and use of assistive technologies but also in broader contexts (*e.g.,* in sports or recreation).

As Bennett et al. argued, an interdependent perspective "considers everyone and everything in an interaction to be mutually reliant" [10]. Design with a mixed-ability group in a public space can serve to affirm to the broader community that people with disabilities are not simply "recipients", as Bennett et al. point out, but designers, facilitators, and participants in the co-design process. We identified mixed-ability challenges *in situ* rather than through a structured evaluation, enabling us to refocus our design requirements after each session. The introduction of a tactile switch to CoOP, inspired by a conversation about the tactile qualities of Velcro (see Section 4.1), exemplifies the ways that mixed-ability co-design can support assistive technology design. As a sighted research team designing for a blind and low vision community, providing our end users with prototypes early and often directly shaped our decisions.

Although our process grew organically from the conditions in which we conducted our work, our inclusive design practice, *ad hoc* iterative process, and public dialogue align closely with Teal and French's Designed Engagement [54]. Similar to their "pop-up" engagement approach, many of our design insights were drawn spontaneously from the public, rather than through formal recruitment methods employed by traditional participatory design methods. However, our work diverges from Designed Engagement in two distinct ways that inform assistive technology design practice. First, our design team included members from the community that our work was designed to serve, integrating the co-design principles articulated by Sanders and Stappers into our public engagement. Second, our work remained situated within a single location for an extended period of time, establishing a consistent presence for the community to both actively and passively observe. Collectively, these practices contributed to the increased public attentiveness to inclusivity and community interest we described in Section 4.1.2.

5.3 Facilitate Rapport and Trust Through Reciprocity

Rapport and trust can be crucial for obtaining and maintaining access to a community or research site. While values-centric participatory design approaches like co-design can build rapport and trust between researcher and community partners through methods like reciprocity [15, 29], explicit actions to drive trust are less mature, and far from solved. In this section, we describe two approaches that were pivotal for our relationship with our community partner—although we acknowledge that they may not work for all community partners and contexts.

First, an ongoing issue with participatory design stems from concerns from community partners that researchers are just "mining" the community for data [29]. DirectorLV1's depiction of Makapo's preliminary efforts in Section 4.3 expressed their caution towards researchers pursuing designs that align closer to research than community goals. Although we were also initially imagining a different research path, we were able to build rapport by shifting our research trajectory to align with Makapo's immediate need for a training tool that could be used without researcher supervision. However, mere verbal agreements did not assuage DirectorLV1's fears of misaligned goals. It was not until the first short-lived test on the water that we were viewed as taking Makapo's goals seriously. After which, DirectorLV1 began investing more of their resources and enthusiasm into this project. Using mixed-fidelity rapid prototyping—although not robust—served to demonstrate to Makapo that we aligned with their goals.

Second, to maintain our rapport with Makapo, we wanted to ensure that they didn't feel like we were developing something that would be unusable after our partnership ended. Managing the transition from research to application of technological systems can pose challenges for co-design projects. As Hayes explained, it is not enough to simply leave an intervention behind, researchers must ensure that partner organizations have the resources to utilize and maintain deployments [19]. As we describe in our results, our DIY approach to design and co-design practice, assured that CoOP could be maintained by our community partners at the end of the project. For example, we disassembled the prototypes, described each component, and shared cost estimates and acquisition sources. This process helped demystify CoOP, which instilled Makapo with the confidence that they would be able to reproduce CoOP independent of researcher involvement.

6 FUTURE WORK

This work glimpses at a promising future for the development of new design approaches that are even more inclusive and context-appropriate, that promote interdependence, and that produce high-quality designs to empower athletes from a wide range of abilities.

The success of CoOP raises questions on how shared assistive technology might enable the visually impaired community more broadly. Functionally, CoOP requires the support of multiple people (*e.g.,* guide boat driver and steerperson), a known source of friction for blind athletes [46]. The cultural and social aspects of paddling that we observed at the Newport Aquatic Center highlighted how frequently paddlers exercised alongside each other in one-person boats, a practice that could potentially be leveraged by CoOP. We see an opportunity to reimagine CoOP to focus on the experience of paddling together—rather than supporting one blind paddler.

Although our work is highly contextualized to the practices of the outrigger paddling community, we believe that our experiences transfer to other community-oriented activities where support for individuals with disability is lacking. Adoption of our design considerations presents one path forward for identifying and creating the types of novel, single-purpose assistive technologies to support the disability community.

7 CONCLUSION

In this work, we presented the results of a multi-month public co-design project with sighted and visually impaired outrigger canoe paddlers. Through the co-design and development of a shared control steering system called CoOP, we empowered blind paddlers to paddle alone in one-person canoes. We identified three major themes that can inform how designers and researchers think about assistive technology design. First, public-facing co-design with sighted and visually impaired communities brings awareness of the disabled experience to the surrounding community. Second, leveraging existing economies and DIY practices can support the creation of functional novel assistive technologies. Third, the physicality and interdependence of real-world activity presents challenges and opportunities for multi-modal assistive technology design.

This interdependent approach would never have been achieved without the insights of a mixed-ability, public-facing, co-design team. Taken together, these results remind us that not only must we consider assistive technologies in light of context and abilities of primary users, but that interdependent users—made explicitly here but implicit in so many other assistive technologies—have important perspectives as well. In some ways, assistive technologies have often considered the allies and the co-users. We found in our public-facing interactions, however, that other participants—the bystanders, the curious, the nearby—became essential parts of the design process and ultimate product development and testing as well. By bringing design out of the shadows—and in our case quite literally into the bright sunshine of an ocean dock—assistive technology researchers and designers can bring mixed-ability recreation into the light as well.

ACKNOWLEDGMENTS

This work was supported in part by grant 90DPGE0003-01 from the National Institute on Disability, Independent Living and Rehabilitation Research, and Robert and Barbara Kleist. We would like to thank the Newport Aquatic Center for access to their facility, Makapo for their dedication and support, and the outrigger paddlers who welcomed us into their community. We would also like to thank Wendy Yang for her reviews of drafts, the STAR Group at UCI, and the anonymous reviewers for their insightful feedback on this paper.

REFERENCES

[1] Chadia Abras, Diane Maloney-Krichmar, Jenny Preece, et al. 2004. User-centered design. *Bainbridge, W. Encyclopedia of Human-Computer Interaction. Thousand Oaks: Sage Publications* 37, 4 (2004), 445–456.

[2] Majed Al Zayer, Sam Tregillus, Jiwan Bhandari, Dave Feil-Seifer, and Eelke Folmer. 2016. Exploring the use of a drone to guide blind runners. In *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, 263–264.

[3] C Andrews. 2014. Accessible participatory design: engaging and including visually impaired participants. In *Inclusive Designing*. Springer, 201–210.

[4] Liv Berit Augestad and Lin Jiang. 2015. Physical activity, physical fitness, and body composition among children and young adults with visual impairments: A systematic review. *British Journal of Visual Impairment* 33, 3 (2015), 167–182.

[5] Mauro Avila Soto, Markus Funk, Matthias Hoppe, Robin Boldt, Katrin Wolf, and Niels Henze. 2017. Dronenavigator: Using leashed and free-floating quadcopters to navigate visually impaired travelers. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, 300–304.

[6] Shiri Azenkot, Catherine Feng, and Maya Cakmak. 2016. Enabling building service robots to guide blind people a participatory design approach. In *2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 3–10.

[7] Shaowen Bardzell, Daniela K. Rosner, and Jeffrey Bardzell. 2012. Crafting Quality in Design: Integrity, Creativity, and Public Sensibility. In *Proceedings of the Designing Interactive Systems Conference (DIS '12)*. ACM, New York, NY, USA, 11–20. https://doi.org/10.1145/2317956.2317959

[8] Jason J. Barr and Kristi Bracchitta. 2015. Attitudes toward individuals with disabilities: The effects of contact with different disability types. *Current Psychology* 34, 2 (2015), 223–238.

[9] No Barriers. 2014. *No Barriers Grand Canyon Expedition*. http://kayakingblind.nobarriersnetwork.org/

[10] Cynthia L. Bennett, Erin Brady, and Stacy M. Branham. 2018. Interdependence As a Frame for Assistive Technology Research and Design. In *Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '18)*. ACM, New York, NY, USA, 161–173. https://doi.org/10.1145/3234695.3236348

[11] Jeffrey P Bigham, Chandrika Jayant, Hanjie Ji, Greg Little, Andrew Miller, Robert C Miller, Robin Miller, Aubrey Tatarowicz, Brandyn White, Samual White, et al. 2010. VizWiz: nearly real-time answers to visual questions. In *Proceedings of the 23nd annual ACM symposium on User interface software and technology*. ACM, 333–342.

[12] Mark T. Carew, Masi Noor, and Jan Burns. 2019. The impact of exposure to media coverage of the 2012 Paralympic Games on mixed physical ability interactions. *Journal of Community & Applied Social Psychology* 29, 2 (2019), 104–120. https://doi.org/10.1002/casp.2387

[13] International Blind Sports Federation. 2019. *Sports - IBSA*. http://www.ibsasport.org/sports/

[14] Kate Ferrara, Jan Burns, and Hayley Mills. 2015. Public attitudes toward people with intellectual disabilities after viewing Olympic or Paralympic performance. *Adapted Physical Activity Quarterly* 32, 1 (2015), 19–33.

[15] Judith Gregory. 2003. Scandinavian approaches to participatory design. *International Journal of Engineering Education* 19, 1 (2003), 62–74.
[16] Susan J Grosse. 2009. Aquatics for individuals with disabilities: research implications. *International Journal of Aquatic Research and Education* 3, 4 (2009), 4.
[17] Justin A Haegele. 2015. Promoting Leisure-Time Physical Activity for Students with Visual Impairments Using Generalization Tactics. *Journal of Visual Impairment & Blindness* 109, 4 (2015), 322–326.
[18] Foad Hamidi, Melanie Baljko, Toni Kunic, and Ray Feraday. 2014. Do-It-Yourself (DIY) assistive technology: a communication board case study. In *International Conference on Computers for Handicapped Persons*. Springer, 287–294.
[19] Gillian R. Hayes. 2011. The Relationship of Action Research to Human-computer Interaction. *ACM Trans. Comput.-Hum. Interact.* 18, 3, Article 15 (Aug. 2011), 20 pages. https://doi.org/10.1145/1993060.1993065
[20] Gillian R Hayes. 2014. Knowing by doing: action research as an approach to HCI. In *Ways of Knowing in HCI*. Springer, 49–68.
[21] Amy Hurst and Jasmine Tobias. 2011. Empowering individuals with do-it-yourself assistive technology. In *The proceedings of the 13th international ACM SIGACCESS conference on Computers and accessibility*. ACM, 11–18.
[22] GoPro Inc. 2019. *GoPro Suction Cup Camera Mount*. https://shop.gopro.com/mounts/suction-cup/AUCMT-302.html
[23] Glenda M Jessup, Elaine Cornell, and Anita C Bundy. 2010. The treasure in leisure activities: Fostering resilience in young people who are blind. *Journal of Visual Impairment & Blindness* 104, 7 (2010), 419.
[24] Shaun K Kane, Amy Hurst, Erin Buehler, Patrick Carrington, and Michele A Williams. 2014. Collaboratively designing assistive technology. *interactions* 21, 2 (2014), 78–81.
[25] Jessica M Keith, Loisa Bennetto, and Ronald D Rogge. 2015. The relationship between contact and attitudes: Reducing prejudice toward individuals with intellectual and developmental disabilities. *Research in developmental disabilities* 47 (2015), 14–26.
[26] Karen D Könings, Tina Seidel, and Jeroen JG van Merriënboer. 2014. Participatory design of learning environments: integrating perspectives of students, teachers, and designers. *Instructional Science* 42, 1 (2014), 1–9.
[27] Athanasios Koutsoklenis and Konstantinos Papadopoulos. 2011. Auditory cues used for wayfinding in urban environments by individuals with visual impairments. *Journal of Visual Impairment & Blindness* 105, 10 (2011), 703–714.
[28] Gerard Lacey and Shane MacNamara. 2000. Context-aware shared control of a robot mobility aid for the elderly blind. *The International Journal of Robotics Research* 19, 11 (2000), 1054–1065.
[29] Christopher A. Le Dantec and Sarah Fox. 2015. Strangers at the Gate: Gaining Access, Building Rapport, and Co-Constructing Community-Based Research. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing (CSCW '15)*. ACM, New York, NY, USA, 1348–1358. https://doi.org/10.1145/2675133.2675147
[30] Jennifer Mankoff, Gillian R Hayes, and Devva Kasnitz. 2010. Disability studies as a source of critical inquiry for the field of assistive technology. In *Proceedings of the 12th international ACM SIGACCESS conference on Computers and accessibility*. ACM, 3–10.
[31] Janis Lena Meissner, John Vines, Janice McLaughlin, Thomas Nappey, Jekaterina Maksimova, and Peter Wright. 2017. Do-It-Yourself Empowerment As Experienced by Novice Makers with Disabilities. In *Proceedings of the 2017 Conference on Designing Interactive Systems (DIS '17)*. ACM, New York, NY, USA, 1053–1065. https://doi.org/10.1145/3064663.3064674
[32] Microsoft. 2018. *Soundscape Kayaking Scavenger Hunt*. https://www.microsoft.com/en-us/research/video/soundscape-kayaking-scavenger-hunt/
[33] Cecily Morrison, Edward Cutrell, Anupama Dhareshwar, Kevin Doherty, Anja Thieme, and Alex Taylor. 2017. Imagining Artificial Intelligence Applications with People with Visual Disabilities Using Tactile Ideation. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '17)*. ACM, New York, NY, USA, 81–90. https://doi.org/10.1145/3132525.3132530
[34] Annika Muehlbradt, Varsha Koushik, and Shaun K Kane. 2017. Goby: A Wearable Swimming Aid for Blind Athletes. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, 377–378.
[35] Michael J Muller. 2003. Participatory design: the third space in HCI. *Human-computer interaction: Development process* 4235, 2003 (2003), 165–185.
[36] David H Nguyen, Gabriela Marcu, Gillian R Hayes, Khai N Truong, James Scott, Marc Langheinrich, and Christof Roduner. 2009. Encountering SenseCam: personal recording technologies in everyday life. In *Proceedings of the 11th international conference on Ubiquitous computing*. ACM, 165–174.
[37] Elinor Ochs, Tamar Kremer-Sadlik, Olga Solomon, and Karen Gainer Sirota. 2001. Inclusion as social practice: Views of children with autism. *Social Development* 10, 3 (2001), 399–419.
[38] Americans With Disabilities Act of 1990. 1990. Pub. L. No. 101-336, 104 Stat. 328.
[39] United States Association of Blind Athletes. 2019. *Home - United States Association of Blind Athletes*. https://www.usaba.org/
[40] Mike Oliver. 2013. The social model of disability: Thirty years on. *Disability & society* 28, 7 (2013), 1024–1026.

[41] John H Pearn and Richard C Franklin. 2013. Disability and drowning: personal Experiences, Research, and practicalities of adapted aquatics. *International Journal of Aquatic Research and Education* 7, 2 (2013), 7.

[42] Kara Perkins, Luis Columna, Lauren Lieberman, and JoEllen Bailey. 2013. Parents' perceptions of physical activity for their children with visual impairments. *Journal of Visual Impairment & Blindness (Online)* 107, 2 (2013), 131.

[43] Halley Profita, Reem Albaghli, Leah Findlater, Paul Jaeger, and Shaun K Kane. 2016. The AT effect: how disability affects the perceived social acceptability of head-mounted display use. In *proceedings of the 2016 CHI conference on human factors in computing systems*. ACM, 4884–4895.

[44] Halley P. Profita, Abigale Stangl, Laura Matuszewska, Sigrunn Sky, Raja Kushalnagar, and Shaun K. Kane. 2018. "Wear It Loud": How and Why Hearing Aid and Cochlear Implant Users Customize Their Devices. *ACM Trans. Access. Comput.* 11, 3, Article 13 (Sept. 2018), 32 pages. https://doi.org/10.1145/3214382

[45] Kyle Rector, Cynthia L. Bennett, and Julie A. Kientz. 2013. Eyes-free Yoga: An Exergame Using Depth Cameras for Blind & Low Vision Exercise. In *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '13)*. ACM, New York, NY, USA, Article 12, 8 pages. https://doi.org/10.1145/2513383.2513392

[46] Kyle Rector, Lauren Milne, Richard E. Ladner, Batya Friedman, and Julie A. Kientz. 2015. Exploring the Opportunities and Challenges with Exercise Technologies for People Who Are Blind or Low-Vision. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility (ASSETS '15)*. ACM, New York, NY, USA, 203–214. https://doi.org/10.1145/2700648.2809846

[47] Kyle Rector, Roger Vilardaga, Leo Lansky, Kellie Lu, Cynthia L. Bennett, Richard E. Ladner, and Julie A. Kientz. 2017. Design and Real-World Evaluation of Eyes-Free Yoga: An Exergame for Blind and Low-Vision Exercise. *ACM Trans. Access. Comput.* 9, 4, Article 12 (April 2017), 25 pages. https://doi.org/10.1145/3022729

[48] Jacquie Ripat and Roberta Woodgate. 2011. The intersection of culture, disability and assistive technology. *Disability and Rehabilitation: Assistive Technology* 6, 2 (2011), 87–96. https://doi.org/10.3109/17483107.2010.507859 arXiv:https://doi.org/10.3109/17483107.2010.507859 PMID: 20698763.

[49] Elizabeth B.-N. Sanders and Pieter Jan Stappers. 2008. Co-creation and the new landscapes of design. *CoDesign* 4, 1 (2008), 5–18. https://doi.org/10.1080/15710880701875068 arXiv:https://doi.org/10.1080/15710880701875068

[50] Katrina Scior. 2011. Public awareness, attitudes and beliefs regarding intellectual disability: A systematic review. *Research in developmental disabilities* 32, 6 (2011), 2164–2182.

[51] Kristen Shinohara, Cynthia L Bennett, Wanda Pratt, and Jacob O Wobbrock. 2018. Tenets for Social Accessibility: Towards Humanizing Disabled People in Design. *ACM Transactions on Accessible Computing (TACCESS)* 11, 1 (2018), 6.

[52] Kristen Shinohara and Jacob O. Wobbrock. 2011. In the Shadow of Misperception: Assistive Technology Use and Social Interactions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 705–714. https://doi.org/10.1145/1978942.1979044

[53] Boon Siong Tan, Erin Wilson, Robert Campain, Kevin Murfitt, and Nick Hagiliassis. 2019. Understanding Negative Attitudes Toward Disability to Foster Social Inclusion: An Australian Case Study. In *Inclusion, Equity and Access for Individuals with Disabilities: Insights from Educators across World*, Santoshi Halder and Vassilios Argyropoulos (Eds.). Springer Singapore, Singapore, 41–65. https://doi.org/10.1007/978-981-13-5962-0_3

[54] G. Teal and T. French. 2016. Designed Engagement. In *Proceedings of the Design Research Society 50th Anniversery Conference*.

[55] Ahmet Ustunel. 2018. *Paddling from Europe to Asia*. http://www.theblindcaptain.com/

[56] Karel Vredenburg, Ji-Ye Mao, Paul W Smith, and Tom Carey. 2002. A survey of user-centered design practice. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 471–478.

[57] Jacob O Wobbrock, Shaun K Kane, Krzysztof Z Gajos, Susumu Harada, and Jon Froehlich. 2011. Ability-based design: Concept, principles and examples. *ACM Transactions on Accessible Computing (TACCESS)* 3, 3 (2011), 9.

[58] Ester Zychlinski, Menachem Ben-Ezra, and Yaira Hamama Raz. 2016. Changing attitudes about disability: The impact of the 'Accessible Community' program. *Journal of Social Work* 16, 6 (Nov. 2016), 742–757. https://doi.org/10.1177/1468017315589871

Received April 2019; revised June 2019; accepted August 2019