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Facilitating critical reflection in online distributed maker workshops: Case studies

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A B S T R A C T

The global pandemic has brought numerous challenges for designers, researchers, and practitioners whose work involves children and new technologies. While many of us have found creative ways to address the obstacles of facilitating activities with children remotely, inciting critical reflection through making, which is already difficult in in-person settings, has become an even greater challenge in online distributed settings. This paper reports on the lessons learned from two two-week online afterschool maker workshops where participants in remote locations engaged in critical reflections on ethical implications of biowearable technologies through designing a biowearable device that benefits their own lives. The results showed preliminary evidence that participants were able to produce a prototype and engaged in critical reflection on the ethical issues of biowearables. We also found that while online environments offer limited social cues and flexibility, access to multiple communication channels enabled just-in-time and situated facilitation for critical reflection.

1. Introduction

The global pandemic forced everyone to shift their practices into online distributed environments. This was particularly challenging for those of us who work with young children and with innovative technologies that require constant interaction and troubleshooting. Our team is interested in the potential of maker activities, e.g., hands-on, constructive activities with digital or physical artifacts, which Ratto (2011) calls "critical making", in fostering critical reflection about the ethical implications of biowearables on well-being of children and youth (Antle & Kitson, 2021).

In the past decade, we have become increasingly aware of the educational potential of a maker pedagogy (Bevan, Gutwill, Petrich, & Wilkinson, 2015; Clapp, Ross, Ryan, & Tishman, 2016; Sheridan et al., 2014; Valente & Blikstein, 2019). Maker pedagogy is guided by constructionism that posits learning happens most effectively when learners are engaged in the construction process of a shareable artifact that bears personal importance to them (Harel & Papert, 1991). This shareable artifact manifests learners' understandings and misunderstandings about concepts, their ideas, and discoveries, as well as their interests and motivational orientations. These artifacts broaden opportunities for critique and elaboration by knowledgeable or like-minded others (Halverson & Sheridan, 2014; Kafai, 2006) enabling critical reflection and understanding of various ideas and concepts relevant to the artifact/project. One of the most commonly observed strengths of the approach is its power to spark the interests and engagement of learners (Vossoughi & Bevan, 2015). Other studies have shown a variety of competencies that can be cultivated through maker learning such as agency (Clapp et al., 2016), problem-solving skills (Gutwill, Hido, & Sindorf, 2015), Science, Technologies, Engineering, and Mathematics (STEM) practices (Sheridan et al., 2014), and persistence (Blikstein, 2013). Critical making could be a compelling approach to inviting children who are increasingly engaged with technology to reflect on the relationships between technological design decisions and negative or positive impacts on their well-being.

The outbreak of the COVID-19 pandemic has placed educators who employ maker approaches in an extremely challenging position. Most maker activities involve physical interactions with materials, tools, and other learners, which was considered to be unsafe under most countries' health guidelines back then. We too were left with no choice but to transform our workshops with youth into online workshops where participants were distributed across remote locations where they live. Facilitating maker learning in online or blended learning environments adds

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another layer of unique challenges to the already discussed difficulties of inciting critical reflection during maker activities. For instance, since most people do not have tools and materials like makerspaces, educators must find an alternative way to provide learners access to such resources that are necessary for maker activities, either by shipping them to their homes or limiting the tools/materials to the things that they can find at home. In online environments, social cues are drastically limited even with video conferencing, so educators must be responsive to the impacts that a lack of social cues may have on the way learners participate in activities. Layered onto these challenges, there may be technical issues with communication systems that enable participation in online/blended learning environments that may disturb the flow of activities at any time (e.g., the internet connection is lost). As remote learning continues to be a viable alternative option for education, there is an urgent need to advance our understanding of how to best overcome these difficulties.

In this paper, we share insights from two iterations of the workshop, particularly focusing on strategies to support critical reflection in online maker workshops. For each iteration, we first examine whether our workshop met the goals to support children to reflect critically during the making. This provides evidence of the validity of the workshop as a good exemplar to use to study how to support critical reflection specifically in online distributed environments. We then report on specific elements of workshop design that supported or limited critical making during the workshop. The research questions that guided this study were: RQ1: Can an online distributed critical making workshop enable participants to critically reflect on ethical and/or social issues in biowearables? And RQ2: What are the unique forms of interactions that enable or limit critical making in an online distributed critical making workshop? Our findings from a study of two two-week online distributed critical making workshops contribute to the nascent but growing body of knowledge of how to facilitate critical making, in particular in online distributed settings.

2. Related work

2.1. Making as a critical learning approach

Few researchers have explored how the process of making may contribute to critical reflection and engagement with social issues. Ratto (2011) explored how physical material forms of engagement with technology can deepen critical reflection and conceptual understandings of the role of technology in social life. For example, one of his projects invited media arts and design professionals to discuss the social impact of closed networked Web 2.0 applications. Schwartz (2016) also examined the role of the physical making process with materials in generating ideas and promoting embodied cognition based on his experience teaching students in an architecture program. While the enthusiasm toward maker pedagogy continues to grow, little is understood about how making may contribute to a critical understanding of the ideas and concepts behind the artifacts being made (Bevan, 2017; Halverson & Sheridan, 2014). While these existing studies focus on adult students or designers, there is a potential in adapting the critical making approach for older children as a way to introduce design ethics for biowearables. Some researchers criticize that many maker activities offered to school-age children create opportunities to produce artifacts through mindless trial and error, without helping them understand the deeper concepts behind artifacts (Valente & Blikstein, 2019). Often referenced as "keychain syndrome" (Blikstein, 2013), children tend to focus on creating relatively simple products and refuse to move on to more complex, insightful activities, since technologies in makerspaces enable them to create artifacts with high production value with relatively little effort. Critical reflection through making provides tangible and embodied means to examine otherwise abstract ethical implications of biowearables. Involvement of learners in critical reflection through designing and developing technologies has also been increasingly recognized as a form of empowerment, as such process can cultivate learner capacity to participate in the development of ethical technologies in the future, instead of merely being a user (Iversen, Smith, & Dindler, 2018; Kafai, 2016)

The challenges faced by educators to utilize maker pedagogy for critical learning come from several unique characteristics of the making process itself. First, maker learning takes place as an exploratory and learner-centered activity (Sheridan et al., 2014), which inevitably makes each learner work on their tasks in a distributed manner, at a variety of speeds, and in a variety of orders. Thus, facilitating critical inquiry and reflection at the timing that works best for each learner requires logistical considerations. Second, the maker approach can yield a wide range of learning outcomes across skills, mindsets, and social practices (Bevan et al., 2015) that are not inherently visible and capturable to educators, especially when there are a number of learners for an educator. Educators need to actively encourage learners to articulate their thinking processes and try to understand them in order to effectively facilitate their development. Finding a way to document learners' thinking processes is also crucial to make sure knowledge building can occur throughout activities. Thus, there is still a knowledge gap about how to effectively facilitate critical inquiry and learning during maker activities.

2.2. Online distributed maker activity

While remarkable efforts have been made by educators to continue offering learning opportunities, few of them have been documented. One example is Jayathirtha, Fields, Kafai, and Chipps (2020) who studied an e-textile unit for sixth graders that included the development of a physical artifact, circuit drawings, and coding that was transformed into an online course during the pandemic. The study reported that asynchronous online interaction made physical making difficult to share and as a result, the unit was focused on circuit drawings and coding. The lack of physical interaction also impacted the depth of inquiry the teachers could enable learners to engage in. Lee et al. (2020) conducted ten consecutive intergenerational participatory design sessions with children (aged 7–11) and researchers, using video chat for online synchronous sessions. They proposed a framework of components that must be considered in online sessions (incl. logistics, people and settings, and interactions) and advocated for the need to use improvisation to anticipate and respond to disruptions as they emerged.

3. Methods

This study employed a case study method to gain an in-depth understanding of the experiences of learners as a phenomenon in the context (Yin, 2011). By examining multiple different sources of evidence and closely observing interactions and relationships between sources of evidence, case studies enable researchers to garner a broad yet deep understanding of a particular problem or situation. We examined a subset of data collected for a larger study, whose full description of the methodology can be found in Antle et al. (2022).

3.1. Contexts

This study explored two online maker workshops focused on ethical issues and biowearable technologies. After the first workshop, the researchers iterated the activities based on the lessons learned from the workshop and then conducted the second workshop. A total of 11 children aged 12–14 participated in the study from their homes in their residences in East or Atlantic Canada: five for the first workshop (Girl = 4, Boy = 1) and six for the second workshop (Girl = 3, Boy = 3). All except two (one participant from each workshop missed one session) participated in all sessions. Most participants worked independently without direct assistance from their parents. One participant in the second workshop was assisted by a parent at first as he missed the first session. One participant from the first workshop and four participants from the second workshop had no coding experience prior to the workshop. Few of them from the first workshop had experience using micro:bit, a small programmable computer device that is widely used for educational purposes around the world.

Each workshop was run by a team of six researchers and one staff member of a partner community organization that specialized in maker education. Researchers included: two facilitators, who alternated in leading the synchronous sessions, along with two technical supports, who led technical breakout sessions, and two data collectors. We ensured that only one or two facilitators would directly interact with the participants at a time, while the rest remained muted and invisible. From Day 2 of the first workshop, the team members communicated using a backchannel chat platform not visible to the participants.

Our main communication platform used with participants was a videoconferencing tool developed by our community partner using an open-source conferencing platform, BigBlueButton. The platform has a member list on the left, public and private chats, a shared note, and a main window that can simultaneously display multiple webcam feeds and presentation slides or a screen of participants. It also has a breakout room function.

We developed a biowearable prototyping kit that allowed participants to design variations of a breath-controlled biowearable that provides feedback through LED lights and a tangible pinwheel. For more details on the design of the biowearable-tangible prototyping kit, see Antle et al. (2021). The kit used a micro:bit for both input and output. Using a block-based coding interface called MakeCode, participants could configure how inputs from the breath sensor were processed and mapped to provide light and tangible feedback. We shipped this kit, including a breathing sensor, a pinwheel, and a LED monitor, to all participants via mail.

We also developed and shipped a set of 12 Bio-Tech Ethics Cards designed to support reflection on ethical issues related to child development and biowearables based on and extended from an ethical framework developed in Antle and Kitson (2021). Building on prior work that identified the benefits of using cards in introducing key ideas during the design process, we used the cards as a tool to introduce critical reflection skills to youth (Dao-Kroeker, Kitson, Antle, Murai, & Adibi, 2021). The complete card deck can be found in Dao-Kroeker, Kitson, Antle, Murai, and Adibi (2019). Our cards describe in plain language six ethical issues–ways that biowearables could negatively impact child development (e.g., identity formation, sources of authority children turn to). Each issue comprises two cards: one providing definitions and examples of the issue (e.g., Authority: the sources of information that tell you about yourself) and one providing a set of reflective questions participants can use while prototyping their ideas (e.g., What can the breathing data tell me about what I experience inside of me and what I feel?). For more details on the design of the ethics cards used in this study see Dao-Kroeker et al. (2021). Fig. 1 shows these workshop materials.

Participants documented their ideas and reflections in their personal Design Journal (DJ) throughout the workshops, using Google Slides. Facilitators added reflection and documentation templates into each participant's slide deck prior to the workshop to guide their reflection processes.

3.2. Workshop design

Each of the two online maker workshops was hosted across two weeks, the total meeting time being 10 h. The first workshop was hosted in six 90-minute sessions on weekdays and one 60-minute session on one Saturday (Fig. 2).

We hosted four office hour opportunities in between the synchronous sessions on the weekdays as well as one on Saturday and encouraged them to work on their own time. However, most participants did not have time to work outside the synchronous sessions due to the tight scheduling of this workshop. After each session, a facilitator sent out an email including all the relevant information and encouraged them to ask questions if necessary. Due to the ethics protocol, we were only able to communicate with the participants through their parents' email addresses. A few participants reached out using email. Each day after the workshop, participants were encouraged to document their ideas and reflections in their DJ. With the scheduling constraints, only a few participants managed to document their ideas in DJ.

The second workshop was held as four-day, two-weekend sessions, allowing us to work with participants for a longer period of time per day (Fig. 3). The first and second sessions were 120-minutes long, the third session was four hours and 30 min with a lunch break, and the last session was 90 min.

For the second workshop, we incorporated most of the activities assigned as homework in the meeting time because the first workshop revealed that participants had very limited time outside the workshop. We hosted office hours during the week between the two weekends and asked participants in advance to sign up. Four out of six participants could connect with one of the facilitators to check-in and catch up. We also introduced ethical issues to students earlier than the first workshop by making it clearer from Day 1 that participants were critical designers of biowearables and thus needed to be aware of the unintended consequences of the product that they designed. We drastically re-designed the DJ based on the feedback we received in the first workshop to better assist participants to document their design process. We also took time multiple times during the workshop for participants to reflect and keep notes of their ideas and prototypes in the DJ, instead of leaving them as homework. Finally, we reflected on several vocabularies that were confusing or misleading during the first workshop and tried not to use them with participants during the second workshop.

3.3. Data collection and analysis

Data collected during the workshops included detailed observation notes focusing on behaviors and interactions related to critical reflection taken by a dedicated observer and other team members when they were not interacting with the participants; chat histories; video recordings of breakouts and the main synchronous sessions; and documentation of ideas and reflections kept by participants in the DJs. Observational notes were informed by sensitizing concepts related to critical reflection including reasoning or explanations by participants. These notes included the mention of potential social or personal negative impacts of biowearables, based on Antle and Kitson (2021), such as concerns over biowearables taking away the autonomy of a user or forcing a user to do unauthentic behavior to address RQ1. We also took notes on critical reflection actions illustrated in

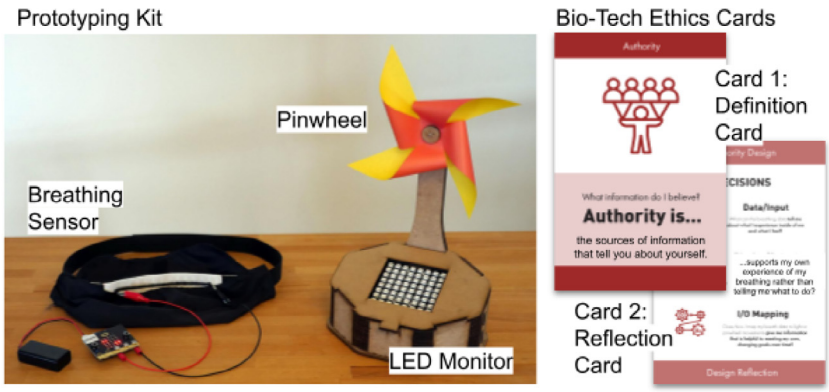

Fig. 1. Workshop materials.

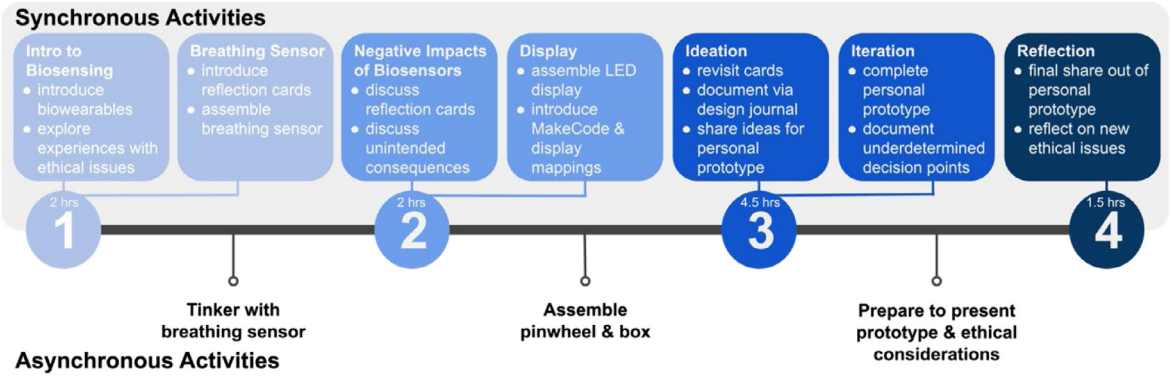

Fig. 2. Schedule of the first workshop.

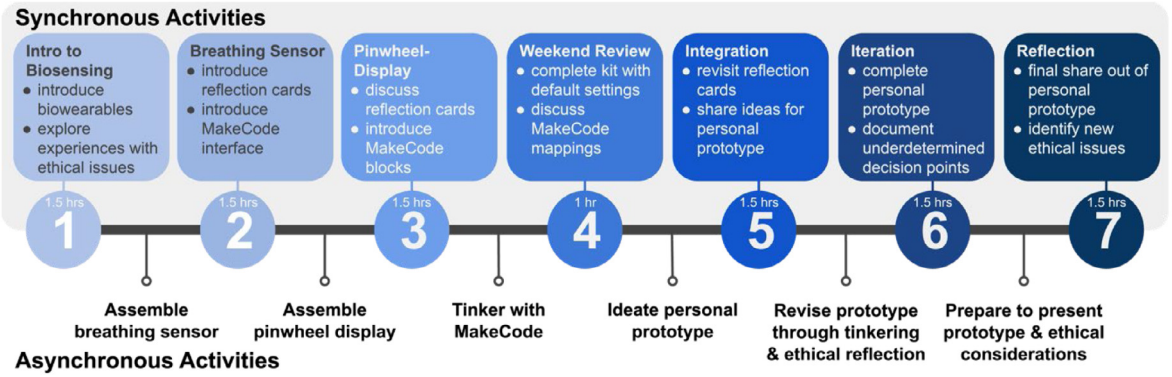

Fig. 3. Schedule of the second workshop.

Fisher (2003) such as articulation of one's own values or biases. We noted when discussion and reflection arose (e.g., in response to facilitator prompts, during activities with ethics cards, during design and prototyping activities, or during group discussions). Notetakers also looked for aspects of the workshop that did or did not work as intended in the online environment to address RQ2.

During data analysis, three researchers (the two facilitators and main observer) first individually familiarized themselves with the observational, video, and chat data. They then conducted a deductive/inductive thematic analysis of the team's observational notes, supplemented by video and chat records. The three researchers discussed the main evidence that addressed RQ1 to ensure validity and then focused on the themes related to online facilitation to address RQ2, which are summarized in the discussion. Through the analysis, we aimed to understand how online facilitation in conjunction with other workshop elements enabled individual participants to engage in critical reflection being in online distributed environments and identify design implications for online critical making workshops. In the following section, we provide five case descriptions that highlight episodes of critical making and/or missed opportunities for such drawn from each workshop and then describe how we iterated the activities for the second workshop and share insights from the implementation of it. Finally, we will summarize the overall insights from both of the workshops.

4. Results: Cases of online distributed critical making

We present five cases, three from the first workshop and two from the second workshop, followed by our interpretation of the

cases, which we then integrate and relate to prior work in the discussion.

Critical Reflection through Chat Interaction (Jamie: Workshop 1, Age 13, Girl)

Jamie stood out even before the start of the workshop as someone who seemed to have well-developed thinking about biowearables. In the pre-workshop survey, her responses were very concrete, and she provided reasons for different impacts biowearables might have based on her own experiences. Jamie mentioned that she had participated in a workshop in which she developed a step tracker using a micro:bit. Jamie was less outspoken than most participants, not often responding to questions that the facilitators asked and most of the time responding in the chat instead of using her microphone. But when Jamie did voice an opinion, there was her commitment to thinking through each prompt and question. Jamie was also independent and proactive at solving problems she faced. When she discovered that the battery pack for the micro:bit was not working, for example, she stood up and came back with another battery pack and got it working.

[J1][1] From Day 1, Jamie spoke about the negative health effect of stopping breathing when sleeping or when something important was happening as one of the ways that breathing can impact our health and well-being, which became the theme of her final project. When a facilitator showed an example and asked whether the feedback from the light display and/or pinwheel about her breathing could impact her over time (Day 3), she mentioned "I feel like I would not like this because I would be angry at the fact that I would breathe manually and I don't always want to know". This brought a new perspective to the discussion that the constant presence of biowearables can become a disruptive factor, negatively impacting authenticity. A facilitator who was monitoring the chat asked, "I wonder how you could avoid this?" Jamie responded, "I feel like the simple answer is, don't [use it] but you could also [program] it so it has modes like one that tracks and one that shows", articulating one idea that she should be able to turn off the feedback when she liked. This idea was incorporated into her final prototype; being able to turn the display on/off as wanted while continuing to track breathing.

[J2] On Day 5, as the prototypes were being finalized, there was a short share, where each participant explained how her project worked. After Jamie's initial share, a facilitator followed up to elaborate on her thoughts behind the prototype (some side conversation was omitted from this blockquote for clarity):

"Jamie: I am just trying to make it light up when you stop breathing. [J]ust s[o] that its[2] not on all the time

Facilitator: Only when you stop breathing. What if this happens when you are asleep? Will the light wake you?

Jamie: hopefully, you have to k[n]ow if you have some condition like sleep apnea

Facilitator: maybe the noise/wind from [pinwheel] could wake you!!

Jamie: yes there will also be a noise so you should be woken up

Facilitator: That makes sense. So you would use it ongoing ... do you think it could help you sleep better or the waking you up might be annoying (like you mention)?

Jamie: I feel like you could use it for a few nights to see if you have if so how often etc. and then do something ab[o]ut it, you can't realize whats happening when your sleeping

This back-and-forth conversation between Jamie and the facilitator seemed to have helped to articulate her critical reflection about the impacts of use that she had never shared with us before at the time of the workshop. Jamie's case provides an example of a participant who was largely able to develop critical perspectives on biowearables throughout the workshop. While Jamie was not verbally active, she used the chat to articulate and develop ideas over time.

Contextually Embedded Critical Reflection (Emma: Workshop 1, Age 12, Girl)

Emma was one of the participants who were actively participating from the beginning of the workshop. Right away she was comfortable using her microphone as well as the chat, responding to facilitators and other participants casually but promptly; and she was vocal when something did not work during her making process.

[E1] On Day 4 the goals were to go through the MakeCode interface and to begin to develop personal project ideas. Emma showed up saying that she had to leave in 30 min because she had basketball practice. She paired up with a facilitator and decided to go over the coding interface, which was what the rest of the group was going to do later that day. The facilitator shared her screen and explained each MakeCode block by pointing to each section with the mouse cursor and highlighting it. Emma expressed her interest in changing the pattern of the LED display, but by then she had to leave for her basketball practice. Her mother appeared in the room and encouraged her to bring the kit and the computer with her in the car so she could continue participating while driving to basketball. Unexpectedly, the workshop was taken to the road! Since Emma was no longer able to see the shared screen anymore without the stable internet in the car, the facilitator verbally walked her through each step and used the chat. As a way to help Emma think about what the code could do, the facilitator related breathing to basketball by asking, "What kind of breathing would help with basketball?". Emma responded that heavy breathing would help because you want to relax. The facilitator then demonstrated heavy breathing by breathing in and out heavily. Then the facilitator directed Emma to think about how the current configuration of her prototype's light display might be useful to her or not. Emma responded yes. The facilitator further asked why she thought breathing deeply would be helpful for basketball and Emma responded that it would bring more oxygen into her system and help her catch a breath.

[E2] While the facilitator continued to assist Emma to relate code decisions to designing a breath-based prototype for basketball, another researcher who was monitoring their interactions noticed that Emma seemed a little confused and suggested in the backchannel: "[Emma] looks a bit lost. Maybe explain one simple part and get her to do a little task (change a value) and see if she can get it to work – like change a colour or?" The facilitator then asked Emma if the current color would be helpful for basketball, what color would look better and why. Emma responded that blue or purple might be better because they were more relaxing colors for her.

[E3] On Day 5, Emma continued to work on her prototype with the same facilitator. Emma noted that her pinwheel was not working. The facilitator tried to help by asking various questions but it was unclear if it was a hardware or software issue. In the last share out of that day, while Emma said that she could not get her pinwheel working, however, she was able to share her idea very clearly, "I do a lot of sports so I want to do something that relaxes me afterward... Lighting would be a nice calm color, and it wouldn't be too bright, so it would be really dim. It would be small and it would play calming music almost". When asked why she wanted it to be dim, Emma responded, "because if you have really bright light then … it just stands out, so bright and

[1] We number key segments from each case with the initial of the pseudonym for the participant in square brackets prior to the segment.

[2] The quotes directly written by participants in the chat are included as-is without corrections unless they are not readable.

more intense", describing her thinking around the consequences of different light options. While this episode showed how troubleshooting took much of their time, the process to troubleshoot was not entirely unrelated to Emma's reflections on the impacts of using the prototype. By Day 7, Emma managed to articulate her full idea clearly. She did not, however, show her kit at the share out explaining, "[i]t was kind of acting up on Wednesday and I haven't really fiddled with it since, because I don't want to mess things up", which may imply her fatigue from troubleshooting and/or not wanting to cause further problems.

Throughout the workshop, Emma received a lot of individual support, both for troubleshooting her device and for supporting her inquiry to develop. However, her case represented a unique example of a project deeply contextualized in her life and, as a result, inspired critical reflection.

Critical Reflection Hindered by Frustration (Amelia: Workshop 1, Age 14, Girl)

Amelia had a connectivity issue on Day 1, which made it difficult for her to fully engage in the workshop from the beginning. She was able to resolve the issue on Day 2.

[A1] Participants were asked to assemble part of the kit at home between Day 1 and Day 2, but Amelia could not find a time to do it. We decided to use breakout rooms to provide personalized support for participants in different stages of development. Amelia joined a room with one of our team's tech supports and another participant, who was having a problem with the kit. Even though she started from scratch that day, Amelia managed to get her kit working almost immediately in the breakout session. The tech support person reminded her that she could go back to the main room, where the rest of the workshop was going, but she elected to stay in the breakout room trying to help the other participant together with the tech support person.

[A2] On Day 3, Amelia did not show up for the workshop. She was able to participate in Day 4 to work on her prototype with tech support for a full hour. During this time, she discovered coding blocks on MakeCode that allowed her to play sounds and became curious, mentioning that she wanted to further explore the idea. On Day 5 and 6, a facilitator prepared a sample project that incorporated sound blocks to assist Amelia to get started adding sound to her prototype. By this time of the workshop, she clearly described that she wanted to track how deep she was breathing because she thinks shallow breathing is not good for her health. However, it was difficult for the facilitator to know if she was following along and got it working, or having trouble following.

[A3] Day 7 started with a final share-out of their prototype and ideas. Amelia was prompted to share her work as the second presenter. The facilitator asked probing questions to assist her in describing the details of her idea–for example, how do you imagine your pinwheel to work?–trying to focus her attention on the idea instead of the prototype, which she said was not working. However, as Amelia continued to talk about her work, several team members who were watching the session began to notice that she was increasingly getting upset and in the backchannel the team let the facilitator know that it might not be appropriate to continue any longer. The facilitator paused her presentation and another facilitator invited her into a breakout room to have a private conversation with her. From the one-on-one conversation, we learned that she was stressed out from not being able to make time to work on the kit while juggling many other things that she was tasked to do outside the workshop. Earlier in the workshop, she described that she had no time between school and the workshop even if she rushed back from school. The facilitator and Amelia decided to revisit the kit and walk through what was going on with the kit together and resolve some of the issues Amelia was encountering. At the end of the day, she decided to join the rest of the group in the main video window and participated again in ethical reflections.

Amelia's case highlighted the challenges of facilitating maker activities from remote locations and potential consequences such as a lack of support by facilitators.

Challenge of Articulating Critical Reflection (Vida: Workshop 2, Age 13, Girl)

Vida joined the workshop without much experience in coding and biowearables. While she was a relatively quiet participant in the workshop, she fully participated in all the sessions even though her kit did not arrive in time for the first weekend of the workshop due to shipment trouble (she took notes during the workshop and caught up using the office hours).

[V1] At first, whenever a facilitator asked about her understanding of biowearable technologies, her response tended to be minimal. For example, on Day 2, when a facilitator asked the group what unintended consequences biowearables can cause, her initial response was "technology is limited". Being asked to elaborate, she gave an example of a watch that only tracks steps and emphasized that function of technology can be limited, which was a fair account of technologies but implied that she had not yet constructed a full understanding of what "unintended consequences" meant.

[V2] However after this discussion, the group had a small group discussion on one of the issues featured in ethics cards, Autonomy. During this time, she started to show the development of her understanding of the ethical issues and elaborated on the example that she talked about the day before: "If you took your limited steps that you do each day, but your watch says, 'no, you need to take more,' it's telling you what to do. It's making a choice for you". In response to the facilitator asking how it makes her feel, she answered, "Like you can't be independent. You have to depend on the watch", accurately connecting her experience to the issue of Autonomy.

[V3] During the ideation process on Day 3, Vida shared that she plays sports and wants her biowearable to keep her breathing slower so that she can maintain her stamina and play longer. She continued to work on the idea and presented her prototype at the final presentation on Day 4 which notifies her when she is stressed out and breathing very rapidly. She shared her rationale behind her design decisions for this notification using the LED panel, explaining that she chose colors and movements to prevent it from being distracting to users. When the facilitators tried to encourage her to articulate how she incorporated consideration for unintended consequences, she was not able to explicitly identify any unintended consequences that she had considered, despite the scaffolding provided by the facilitators:

Facilitator 1: What could be the potential impact of someone using your tool for a long time?

Vida: If they don't have the device with them, then muscle memory. Like if they do it repeatedly they can remember and repeat the exercises so eventually their breathing will slow down and they can relax".

Facilitator 1: Is there anything you wanted to try to address a bit more with Authority or you struggled or couldn't do with the kit?

Vida: Not really.

Facilitator 2: [Vida] - Authority is about a device telling you what to do vs feeling yourself what you need to do ... how does your design address this?

Vida: You have two options: you can do the exercises or watch the colors.

Facilitator 2: Remind me what the exercises are?

Vida: Take a deep breath and hold it. Deep breaths. Holding your breath a little bit. Some stretches or close your eyes and focus on one thing and block out everything else around you".

Facilitator 2: How would your design communicate the exercise to people?

Vida: Arm stretches maybe or rubbing your head a little bit. I do soccer.

While Vida was starting to show her understanding of the ethical issues when we introduced the concept with ethics cards, she was not able to articulate a connection between those issues and her ideas and prototype. Her case reminded us that each child has a different level of ability and experience with working with abstract thought.

Deepening Critical Reflection by Prototyping (Kiana: Workshop 2, Age 13, Girl)

Kiana also began this workshop with limited knowledge of biowearables, having never worked with electronic kits or components nor had she done coding before. However, her limited experience with technology did not stop her from actively engaging in the workshop and articulating her critical reflections on the potential impacts on herself and others.

[K1] At first, Kiana considered mainly the positive health effects biowearables could afford to help users toward their goals. For example, on Day 1, when the facilitator asked the group what they thought technology could do to support people's well-being, Kiana shared that "I find that tracking your steps can help with making goals", which is an answer primarily focused on the functionality of the technology rather than the long-term impact. However, after some workshop activities and discussion around unintended consequences of biowearable technology on Day 2, Kiana began to see a potential dark side. Being asked what they thought might be the unintended consequences of biowearables, she answered, "Technologies can be used in the wrong uses, such as tracking steps. What I mean by that is people can pretend, like swinging your arms it will count one step. People will sit down and just swing their arms and it will count as more steps, which is sort of a cheat". By the end of Day 2, Kiana read through the ethics cards and began to consider the ethical issue of Authenticity as important to her own life and not wanting a biowearable to take control of her attention.

[K2] On Day 3, Kiana began to zero in on her project idea to use a biowearable to help her maintain a state of calm focus and over time reduce angry outbursts. After documenting the idea in DJ, Kiana was able to articulate her goal and how that would relate to her design choices with some facilitator prompting:

Facilitator: What was your issue and how are you addressing that with your design?

Kiana: For one thing, it is hard to breathe and match the depth, so the target depth. So that way I'm looking at the breathing sensor and trying to match it. I picked authenticity. I think this is going to help with, as it says, to be true to yourself in each moment. I think this is going to help you think about your surroundings and focus in on yourself and not about troubles worrying you or thoughts".

Facilitator: Kiana, remember you saying the issue was when you're experiencing anxiety or anger. is that right?

Kiana: The way I was describing is how to really take care of it, focusing on the sound of the pinwheel and the colors of the display along with breathing can help with those feelings.

In this conversation, Kiana rationalized her choice to only focus on the pinwheel sound and simple display would help one focus on oneself, utilizing the ethical issue that she has chosen. By the last day of the workshop, Kiana was able to share her code and working biowearable prototype with rationale drawn from the ethics cards. She explained that she was bothered by the first prototype as it was too distracting, and inspired by the concept of Authenticity, she noticed that those distracting sounds can disturb the user from being in the present moment.

Kiana spent a lot of time carefully thinking through her prototype's design while considering the ethical implications of her chosen ethics card, Authenticity. She was able to take direction from the facilitators and incorporate their feedback related to ethical considerations into her final biowearable prototype. Her case also shows that she was able to learn the language of ethical concepts and incorporate that into her vocabulary through the process of assembling the biowearable kit. Although not initially knowing about biowearables, technology, or programming, Kiana was able to learn the basics that enabled her to critically reflect on ethical ideas during the workshop.

5. Discussion

In this study, we investigated two two-week online distributed maker workshops where participants in remote locations engaged in critical reflections on the ethical implications of biowearable technologies through designing a biowearable device that benefits their own lives. We first examined whether the workshop achieved the primary goal to support children to critically reflect while making, and then explored specific elements of workshop design that supported or limited critical making during the workshop.

The five cases presented above illustrated different ways participants engaged in critical reflection during the two online distributed biowearable workshops. These cases from both workshops provided some evidence that the workshop participants were engaged in critical reflection about the ethical implications of biowearables during the workshop, and thus are a suitable situation in which to explore how online facilitation may enable critical making. In the first workshop, many critical reflections occurred during conversations between facilitators and participants, where participants were prompted to elaborate on their ideas and prototypes as illustrated in the Jamie and Emma case segments [J1, J2, E1]. The chat space seemed particularly helpful for Jamie, who often did not turn on the microphone. We also saw evidence that Emma was able to deepen her critical reflection through one-on-one dialogue with a facilitator in the breakout room, as she was going to basketball practice [E1]. On the other hand, Amelia did not seek help from the facilitators and this limited her ability to fully participate in the workshop [A1, A2], and as a result, there was limited evidence of her critical reflection. In the second workshop, while facilitation still played a crucial role to help participants elaborate on their reflections [K2], we were also able to see them reflect on their prototype using the language from the ethics cards [V2, K1]. By being introduced to the concept of critical making from Day 1, most participants seemed to consider the potential negative impact of biowearables as they prototyped their ideas [K1], yet in varying degrees of depth in their reflections. While Vida's case highlighted the challenge of learning the issues and immediately applying those ideas in practice while designing [V3], both workshops showed that it is possible to engage participants in critical reflection in online distributed environments.

Our cases enabled us to highlight several key characteristics of our online environment that resulted in interactions that led to either challenges and/or opportunities for supporting critical making in online workshops:

Lack of visibility of the making progress

Learning from peers is one of the fundamental components of maker learning experiences (Sheridan et al., 2014). In co-located, in-person maker activities, learners engage with a community of people, share their ideas, get feedback on the artifacts they are making, get inspired by what other people are doing, and get help not just from instructors but also from other participants. In our online environment, none of that spontaneously happened. The

limited social cues available through video conferencing and chat communication channels made it difficult for facilitators to determine when a participant was not in sync with the activities of the whole group. This led to various challenges in both workshops.

One of the ways this issue of limited visibility was manifested was the gap in progress between participants. While it is common for learners to be at different stages of progress in project-based, student-centered maker learning contexts, in an online setting, the progress gap placed unnecessary pressure on learners who may be struggling by themselves in their homes. Amelia's case from the first workshop reminded us that we may have underestimated the pressure and frustration that she was experiencing by seeing other participants moving forward while she was struggling to catch up in and out of sessions [A3]. Without her explicitly asking for support, and without being co-located with her to view her progress directly, the cues we received from her through online means were insufficient to make us aware of her lack of progress and resulting frustrations.

The limited social cues available through online channels also lead to the need for extended troubleshooting time on some occasions. Without an option to provide participants with a working replacement kit, we had no choice but to troubleshoot using the materials that they had at hand. For example, Emma and a facilitator worked together for a long time to solve the problem of a malfunctioning pinwheel, which could have been easy to resolve had they been in the same room. The facilitator tried multiple strategies to acquire enough information from Emma to understand what was needed to progress [E3]. Some of those efforts led to progress and her engagement in some critical reflection while they were troubleshooting, but this took up a lot of time outside of the main session. If they were in the same room, facilitators would have access to a variety of non-verbal evidence of learning to understand the state of each participant, such as physical movements in the space (Strawhacker & Bers, 2018), the interaction between materials and participants (Keune & Peppler, 2019), and the artifact itself (Kajamaa & Kumpulainen, 2020). However, in an environment where participants do not share a physical space and cannot "show and tell" what they are doing, facilitators need to rely more on what participants say and write to understand what trouble they are encountering. This is consistent with Jayathirtha et al. (2020) that reported the difficulty of supporting physical making in remote settings.

However, our study identified a couple of concrete strategies to overcome the difficulty of remote environments. For instance, it highlighted the importance of having multiple check-in points where participants can share their progress and sync up with the rest of the group. This would help avoid allowing the gap of progress to grow too large to close. In the second workshop, we had several rounds of small-group work time on the projects and checked in between the work time on what they have been working on and what they are trying to work on next. This approach seemed to work well for participants to reflect on their progress and revisit their goals during the process before the final presentation, as depicted in the interaction between Kiana and her facilitator [K2].

It is also crucial to establish a process-oriented mindset among the participants at the beginning of the workshop to mitigate the pressure of catching up with others in the workshop. For example, facilitators can discuss the norms of the workshop such as that learning from mistakes and unfinished work in the process is more important than the product, and that the goal of the workshop is to construct ideas through prototyping. Understanding such norms can guide participants while working remotely by themselves, mitigating negative affective experiences. Taking documentation of progress also signifies the norm that the process of thinking and idea development is important, not just the final product. While we were not able to help participants take much documentation in DJ in the first workshop, in the second workshop we incorporated documentation as part of the meeting time and all participants were able to keep notes of their progress multiple times throughout the workshop. Documentation worked as a way to help participants articulate their idea and frequently participants referenced what they wrote in the DJ as they interacted with the facilitators during the workshop [K2].

Lack of open-ended exploration

One of the core principles of maker learning is that learners gain perspectives and skills through iterative processes (Bevan et al., 2015). When learners create shareable artifacts, their ideas and thinking become available for critique and elaboration (Halverson & Sheridan, 2014; Kafai, 2006). For learners to be able to engage in this process, the fluency of skills to accurately articulate their ideas through the artifact becomes a critical requirement (Cavallo, 2000; Eisenberg, 2013; Halverson, 2012). With in-person makerspaces, learners often acquire this fluency through physically tinkering with tools and materials. And tinkering can also benefit from scaffolding such as immediate feedback and acknowledgment that inspires further iteration and tinkering (Resnick & Rosenbaum, 2013). In an online environment, however, it was difficult to support these processes for participants.

With very little information about what participants were doing in our workshops, providing timely scaffolding to each participant to help their tinkering process was a challenge. In addition, at times, when a facilitator verbally encouraged participants to share what they were doing it sometimes disturbed their engagement with their prototyping process because they had to stop and type in the chat or turn on microphones to respond.

To support fluency in an online environment, students may need more support than in co-located environments to move iteratively back and forth between engaging with in-depth exploration and stepping back to share, reflect, and discuss their findings. This type of cognitive growth during online making requires attention to the facilitation of what Ackermann (2011) calls "diving in and stepping out". One approach that we found productive was to structure making activities into small steps, for example, as follows, in order: (a) clearly communicate what needs to be done by the end of the activity, (b) model what needs to be done using online tools, (c) enable students to try out tools, (d) provide pre-set time for independent work, (e) provide pre-set time to share reflections on issues (e.g., what worked, did not work), (f) return to independent work, and (g) return to the group to reflect critically on issues and outcomes. The tension between structure and open-endedness is not a new issue in constructionist learning (Halverson & Sheridan, 2014), however, our experience from both workshops underscored the importance of designing open-ended exploration within a step-by-step structure with time limits and clear goals for each step in an online environment.

Continuity between activities and critical thinking

We re-designed the schedule for the second workshop to create a longer work time each day. This simply seemed to have created more time for the participants to understand the kit and try it out on their own and supported a few participants, such as Kiana, to develop their ideas and thinking based on their interaction with the kit [K2]. The continuous time for participants to work on activities seems to also have contributed to continuity in their thinking. Compared to the first workshop where participants needed to stop and start from where they left off every 90-minute session, the participants in the second workshop were able to continue building their ideas and thinking over a long period without interruption. This is counterintuitive given that

there has been increased recognition that longer sessions should be avoided in online synchronous programs to prevent participants' exhaustion and loss of focus (Smith & Schreder, 2020). Our experience may imply that a longer continuous synchronous session can create a meaningful learning experience as long as there is a variety of activities involved, such as physical hands-on activities and writing a design journal, rather than passively looking at the screen and listening to a speaker. In our workshop, it seemed that ethics cards helped participants pick up the thinking from the previous session by returning to the questions they worked on during the previous session [K1, K2]. We also noted that students used the ethics cards during independent work to guide their thinking and sharing [K2]. Resources such as our cards, which can be used flexibly to scaffold reflection during both diving in and stepping out, provide continuity of thought throughout the making activity. All participants had a physical copy of the ethics cards and many participants used them while they were engaged in a conversation about their prototypes. Having the physical copy of the ethics cards seemed to have been beneficial for participants providing ease to reference and remember the issues and expressions to talk about those issues. Future studies should consider tools and activities that help to maintain such continuity between the activities.

Personalized facilitation through multiple communication channels

This study highlighted how facilitators used the chat communication channel to have side-track conversations with one or more participants. While existing studies often report difficulty of synchronous communication with participants in online maker activities (Jayathirtha et al., 2020; Lee et al., 2020), these additional online communication channels enabled personalized interaction (e.g., encouragement for elaboration) without disrupting the main activity being conducted in the video conferencing window. For example, in [J2] from the first workshop, after Jamie shared her idea to the group, there was limited time left but a second facilitator used the chat to encourage Jamie to elaborate, and together they quickly developed Jamie's idea without disrupting the group. A similar interaction was also observed in the second workshop. Vida often left a short and minimal response in the chat and the facilitator was able to ask an elaboration question which she often answered verbally [V1]. When she was struggling to describe the rationale behind her design, two facilitators took turns asking questions to encourage her to think about the issue from different angles using both chat and voice [V3]. The interactions between facilitators and participants also highlight the benefit of having multiple facilitators who can flexibly monitor different communication channels and engage with students in real-time using channels as relevant to support the development of individual critical thinking [such as E2]. Co-teaching is commonly done during in-person maker learning activities, but an online environment where facilitators can communicate in back channels allows even greater flexibility and possibilities for real-time improvisation, as mentioned in Antle et al. (2022). By allowing multiple team members with different expertise to collaboratively work together to do this work more efficiently using backchannels we were able to provide appropriate assistance without overwhelming learners, as observed in [E1, V3]. This backchannel was also used to help synchronize participants and facilitators spread across multiple breakout rooms. For example, it was used to check in on troubleshooting progress in individual rooms to bring everyone back together to proceed with the next activity. One limitation of using multiple channels of communication simultaneously is that this could distract or disrupt some learners. In addition, while it occasionally occurred, we did not notice a lot of peer-to-peer interaction. It is possible that having multiple facilitators engaging across channels may have taken away opportunities for participants to engage with and learn from each other. Thus, it is crucial to coach facilitators to identify beneficial times to jump in to support individuals versus leaving the group to work together.

Ideation and reflection situated in the student's environment

While online synchronous maker workshops are often conducted in an environment where participants are seated in one place where they have access to a stable network connection and computer devices to ensure full, undisrupted participation (Lee et al., 2020), Emma's case showed the potential of the flexibility inherent in remote environments to support situated learning (Antle & Kitson, 2021). Emma's project was inspired by an activity she was deeply associated with, basketball, which emerged as she was remotely participating in the workshop from the car on the way to her basketball practice. The facilitator was able to make a direct connection between her prototype idea and her passion for basketball because the conversation took place on the way to basketball practice. When maker learning happens remotely, it can be flexibly and dynamically situated in locations where participants' daily lives take place. This kind of situated learning would not have happened in a classroom workshop. In our workshop, we shipped learning materials to participants' homes. However, another opportunity for situated learning arises when participants can integrate materials and resources that they already have at home into their learning processes, as advocated for in many remote maker learning projects (Antle et al., 2021). Future work should consider opportunities to leverage the situatedness of participants' everyday lives so that critical reflections arise from and are embedded into their lived experiences. While Emma's case was a happy accident, further consideration on how to take advantage of the situatedness of learning in remote, online environments is warranted.

6. Conclusion

This study presented five case studies from two online critical making workshops that we conducted to investigate how to foster critical reflection on ethical implications of biowearable technologies in online distributed environments. The cases provide some evidence that most participants were able to develop and articulate critical reflection during the online workshop. One contribution of our study that is in alignment with others' work on online maker workshops (Jayathirtha et al., 2020; Lee et al., 2020) was the challenges due to reduced visibility of progress during making and the lack of communication cues that would be present in a co-located environment. However, contrary to concerns that critical making, like other forms of physical making, may be difficult to conduct remotely, our study revealed some ways in which the unique characteristics of online environments can be utilized to support critical learning in online maker activities. For instance, our study demonstrated how multiple communication channels were used to enable a personalized facilitation space that supported different communication forms of reflective thinking. We also found that multiple communication channels can enable multiple facilitators who have different expertise co-facilitate learning experiences for learners, which can allow learners receive personalized, just-in-time scaffolding for critical reflection. In addition, while maker learning which is grounded in constructionism, which often emphasizes the importance of student-centered exploration of learners (Harel & Papert, 1991), our study showed that online distributed settings require more structure for open-ended exploration may be needed. Another contribution that is somewhat contradictory to the existing norm to make online sessions shorter than face-to-face would have been (Lee et al., 2020), was that a long and continuous synchronous session could be valuable to support reflection resulting from making, as long as there are a variety of activities and breaks

to prevent exhaustion from being on screen. We pointed out that physical manipulatives such as our ethics cards can help participants maintain their thinking across separate sessions. Future work can explore participants' perspectives on what facilitation may be valuable to them, as this study was primarily focused on facilitators' perspectives.

Based on this preliminary work, we propose six recommendations from this study for researchers and practitioners who conduct critical making activities in online distributed settings: (1) Create a greater number of check-in points with the participants than there would be for an in-person workshop. Our study showed that, in remote settings where visibility and social cues are limited, participants may not be able to receive the timely support that they need. (2) Foster a process-oriented mindset. In online environments, there can be various obstacles that may prevent participants from achieving the same goal as their peers. Creating an opportunity where they can reflect and celebrate the process rather than the final product would help participants focus on their experience rather than what they end up achieving, particularly when the goal of the activity is to inspire critical reflection. (3) Cultivate vocabularies to express technical issues. Our study highlighted how the difficulty of understanding the trouble caused emotional distress and also lead to a loss of time for critical reflection. Having an expansive language to explain their troubles can help learners and facilitators focus on making and thinking. (4) Create a structure for an unstructured exploration. Our study showed creating small chunks of set time with a relatively specific prompt for exploration can help facilitators ensure all participants engage in the opportunity of tinkering, regardless of their progress. (5) Prepare physical material (like our Bio-Tech Ethics Cards) that participants in remote locations can use during and between the online sessions to keep concepts that are to be reflected in the foreground for each remotely located participant. While we used the physical ethics cards in both workshops, we were able to see increased focus and elaboration on the ethics of biowearables in the second workshop where we introduced and utilized the cards more consistently throughout the workshop. This experience implies supplemental material to help participants continue their ideas and critical thoughts beyond a single session for them to cultivate reflective thinking. (6) Embrace the situated nature of the remote learning environments in learners' living spaces. While we tend to worry about connectivity and full access to online resources when we design online events, allowing participants to connect the workshop to the activities and environments that they care about can open up various opportunities for critical reflection. While not all learners are equipped with tools and environment that allow them to participate in the workshop from inside a car, researchers and practitioners can design activities to allow participants their connect learning experiences on the screen to the objects in their homes, places in their neighborhood, or activities that they regularly do. This study contributes to a growing body of work on how to design and facilitate effective online critical maker workshops that support reflection during the process of making in remote environments.

Selection and participation

Children were recruited through the email listserv of the partner community organization that specializes in maker education. The recruitment email described that this was a workshop and a research study exploring how to introduce ethical issues of biowearables to young people. Anyone interested in the workshop was able to apply to participate and the researchers selected participants to maximize diversity in gender, age, and school they belong to. Consent was obtained using our institutional consent mechanism, which was approved by the authors' Institution Ethics Committee. We sent an email to each parent of the participants before the workshop containing a link to web-based consent forms to be filled by both a parent and a child.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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