Facilitating Online Distributed Critical Making: Lessons Learned

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The global pandemic has brought numerous challenges for educators who take a maker-centered approach, whose instruction involves direct engagement with materials through collaborative and exploratory social interactions. Many educators have found creative ways to address the obstacles of being remote. However, inciting critical reflection through making, already difficult during in-person settings, has become an even greater challenge in remote settings. This paper reports on the lessons learned from a two-week online afterschool maker workshop where participants worked on a maker project being in remote locations, while engaged in critical reflections on ethical implications of biowearable devices. 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 facilitation for critical reflection.

CCS CONCEPTS • Applied computing~Education~Interactive learning environments • Applied computing~Education~Distance learning

Additional Keywords and Phrases: Maker-centered learning, critical making, critical reflection, online learning, online workshop, design thinking, design ethics, teaching ethics, biowearables, quantification of self, youth.

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1 INTRODUCTION

As maker education is being introduced into more and more learning environments around the world, we are increasingly becoming aware of the educational potential of a maker-centered learning approach [6,10,26,27]. One of the most commonly observed strengths of the approach is its power to spark interests and engagement of learners [28]. Other studies have shown a variety of competencies that can be cultivated through maker-centered learning such as agency [10], problem solving skills [14], STEM practices [26] and persistence [7]. However, a relatively limited number of studies have explored how maker-centered learning contributes to

deeper learning of important ideas and concepts involved in the learning process [27]. As the field further extends into broader educational environments, there is an urgent need to understand how exactly a maker-centered approach contributes to knowledge construction, and how to best support the process.

Our team is interested in maker activities' potential to foster critical reflection about ethical implications of emerging technologies during maker processes in online distributed settings. While all maker activities have the potential to support critical learning, in this paper we use the term "critical making" to describe maker activities that intentionally aim to inspire critical reflection and inquiry about ethical aspects of technologies. Our study explores how critical making can be supported in an online distributed setting, and examines challenges and opportunities related to the online format in inspiring critical reflection through making.

2 RELATED RESEARCH

2.1 Making as a critical learning approach

Maker-centered learning is guided by constructionism that posits learning happens most effectively when learners are engaged in the construction process of a sharable artifact that bears personal importance to them [17]. This sharable 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 [16,19] enabling critical reflection and understanding of various ideas and concepts relevant to the artifact/project.

Few researchers have explored how the process of making may contribute to critical reflection and engagement with social issues. Ratto [23] 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 [25] also examined the role of physical making process with materials in generating ideas and promoting embodied cognition based on his experience teaching students in the architecture program. While the enthusiasm towards maker-centered learning continues to grow, little is understood about how making may contribute to critical understanding of the ideas and concepts behind the artifacts being made [5,16]. Some researchers criticize that many maker activities create opportunities for learners to produce artifacts through mindless trial and error, without helping them understand the concepts behind artifacts [27]. Often referenced as "keychain syndrome" [7], 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.

The challenges faced by educators to utilize maker-centered learning for critical learning comes from several unique characteristics of the making processes itself. First, maker-centered learning takes place as exploratory and learner-centered activities [26], which inevitably make 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, maker-centered learning can yield a wide range of learning outcomes across skills, mindsets, and social practices [6] 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

This paper focuses on critical making and its facilitation, specifically in online, distributed settings. 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 is now considered to be unsafe under most country's health guidelines. While remarkable efforts have been made by educators to continue offering learning opportunities, few of them have been documented. One example is Jayathirtha et al. [18] who studied an e-textile unit for sixth graders that included development of a physical artifact, circuit drawings, and coding that was transformed to 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. [20] 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, interactions) and advocated for the need to use improvisation to anticipate and respond to disruptions as they emerged.

Our study was also impacted by the COVID-19 pandemic and rather than cancel we chose to move to an online environment. Facilitating maker-centered learning in online or blended learning environments adds another layer of unique challenges to the already discussed difficulties of inciting critical reflection during maker activities. For instance, most people do not have tools and materials like makerspaces. So, 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 videoconferencing, 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 technological issues with communication systems that enable participation in online/blended learning environments may disturb the flow of activities at any time (e.g., internet is lost).

In this paper, we first examine whether our workshop met the goals to support children to reflect critically during 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. The research questions (RQs) 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 study of a two week online distributed critical maker workshop hosted as an afterschool program contribute to the nascent but growing body of knowledge of how to facilitate critical making, in particular in online distributed settings.

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 [30]. 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.

3.1 Context and participants in the study

Five children aged from 12 to 14 (F=4, M=1) participated in the study from a room in their residences in Atlantic Canada. All children worked independently without direct assistant from their parents. All of them had coding experience prior to the workshop but some were new to micro:bit, a small programmable computer device that is widely used for educational purposes around the world.

A series of seven online synchronous workshop sessions were hosted across two weeks: six 90-minute sessions on weekdays and one 120-minute session on one Saturday (Figure 1). All participants except one (who missed one session) participated in all sessions. The study was run by a team of six researchers and one staff member of a community partner organization who specialized in maker workshops[1]. Researchers included: two facilitators, who alternated in leading the synchronous sessions, along with two technical support people, who lead technical breakout sessions, and a coach from the community partner, who supported participants using chat and breakout rooms, 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, 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 and a shared note, and the main window that can simultaneously display multiple webcam feeds and presentation slides or a screen of participants. It also has a breakout room function.

The participants were told that the goals of the workshop were to design and prototype a biowearable device using a breathing sensor for themselves and to reflect on ethical implications of biowearable technologies. 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 [4]. The kit used a micro:bit for 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. All participants received the kit via mail.

We also developed and shipped a set of 12 *Biotech 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 [3]. 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 Biotech Ethics Cards used in this study see [11].

The summary of the schedule of each day is described in Figure 1. We hosted four office hour opportunities in between the synchronous sessions 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

[1] https://www.brilliantlabs.ca/

workshop. After each session, a facilitator sent out an email including all the relevant 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 address. A few participants reached out using this email channel.

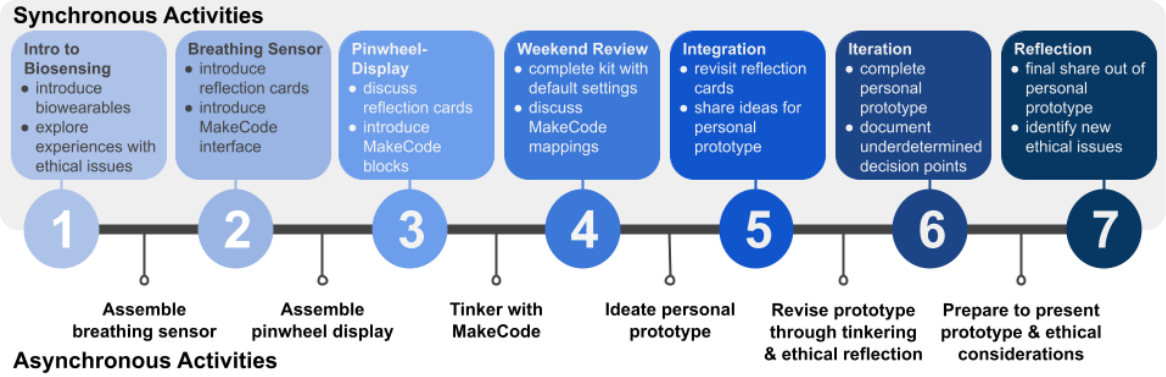

Figure 1: Schedule of the workshop.

3.2 Data collection and analysis

During the workshop data collected 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 survey data administered before, during and after the workshop. Observational notes were informed by sensitizing to concepts related to critical reflection including for reasoning or explanations by participants that included mention of potential social or personal negative impacts of biowearables based on Antle [3] and Fisher [13] to address RQ1. We noted when discussion and reflection arose (e.g. in response to facilitator prompts, during activities with Biotech cards, during design and prototyping activities, or during group discussions). Note takers also looked for aspects of the workshop that did or did not work as intended to the online environment to address RQ2. Survey questions administered during and after the workshop were designed to look for evidence of changes participants' thinking about potential biowearable impacts (RQ1). For example, we asked*, What kind of positive impacts do you think biowearables might have on your life? and List any ways that you think that everyday use of biowearables might impact the formation of your identity*. We also asked about what they liked, learned, disliked, had difficulty with and wanted to explore more (RQ2).

During data analysis, three researchers (the two facilitators and main observer) first individually familiarized themselves with the observational, video, chat and survey 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 themes they found for each question and reconciled themes, which are summarized in the discussion. Through the analysis, we aimed to understand how participants engaged in critical reflection and identify design implications for the subsequent online critical making workshops. First, we provide three case descriptions that highlight episodes of critical making and/or missed opportunities for such.

4 RESULTS: CASES OF ONLINE DISTRIBUTED CRITICAL MAKING

We present three cases, followed by our interpretation of the cases, which we then integrate and relate to prior work in the discussion. We number key segments from each case with the initial of the pseudonym for the participant in square brackets prior to the segment (e.g., first segment for the “Jamie” case is designated [J1]).

4.1 Jamie

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, their[2] responses were very concrete, and they provided reasons about different impacts biowearables might have based on their own experiences. Jamie mentioned that they had participated in a workshop in which they 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 their microphone. But when Jamie did voice an opinion, there was their commitment to thinking through each prompt and question. Jamie was also independent and proactive at solving problems they faced. When they discovered that the battery pack for the micro:bit was not working, for example, they stood up and came back with another battery pack and got it working.

[J1] 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 their final project. When a facilitator showed an example and asked whether the feedback from the light display and/or pinwheel about their breathing could impact them over time (Day 3), they 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," bringing 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 they should be able to turn off the feedback when they liked. This idea was incorporated into their final project; 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 their project worked. After Jamie’s initial share, a facilitator followed up to elaborate on their thoughts behind the prototype (some side conversation was omitted from this block quote for clarity):

> “Jamie: I am just trying to make it light up when you stop breathing. [J]ust s[o] that its 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)?

[2] In this case description, they/their/them is used as a gender-neutral pronoun.

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 articulate their critical reflection about impacts of use that they had never shared with us in full picture at the time.

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, they used the chat to articulate and develop ideas over time. Jamie described that one thing they learned was that "[t]here are a LOT of moral issues with biowearables," indicating their engagement with ethical ideas during the workshop.

4.2 Emma

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 in 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 minutes because she had a 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 since there was no 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, and what color would look better and why. Emma responded that blue or purple might be better, because they were more relaxing colors for her. Next, they worked on the pinwheel motor code and the facilitator walked Emma through how it worked again. The facilitator tried to encourage Emma to decide what to do but she still seemed not to be able to picture what she could do to help her breathe better. The facilitator gave examples of three ways that Emma could use the kit to regulate her breathing: monitoring how she is breathing, practicing breathing in a better way, or making you feel nice just to look at it. Emma seemed to have understood these examples.

[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 afterwards ... 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 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 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.

During the workshop Emma received a lot of individual support, both for troubleshooting her device and for supporting her inquiry to develop. This case provides examples of some of the ways online facilitation worked well and did not work, which we expand on in the discussion below.

4.3 Amelia

Amelia faced challenges from Day 1. Her audio was constantly breaking up and we could not fully understand what she was saying. We were able to communicate with her through the chat, but it was quite likely that the audio from us was also breaking up on her side as well. At the end of the first day, we found that she was using a tablet device to connect to video conferencing software, which was not recommended. On Day 2, Amelia joined using a desktop computer and the issue with the connectivity was resolved.

[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 a personalized support for participants in different stages of development. Amelia joined a room with one of our team’s tech support and another participant, who was having a problem with the kit. Despite the fact that 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 a 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 was not good for 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 details of her idea.

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 ended 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 has no time between school and the workshop even if she rushed back from school. The facilitator and Amelia decided to revisit the kit and walked through what was going on with the kit together and resolved 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 felt comfortable participating 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.

5 DISCUSSION

5.1 Can an online distributed critical making workshop enable participants to critically reflect on issues in biowearables?

Our cases provide some evidence that the workshop participants were increasingly engaged in critical reflection about ethical implications of biowearables during the workshop. At earlier stages of the workshop, participants often responded with silence when they were asked about possible impacts of biowearables. However, by the end of the workshop, all but one participant was able to explain their prototype detailing the potential impacts their design could have on them, and solutions to mitigate negative ethical and social impacts.

As illustrated in the Jamie and Emma case segments [J1, J2, E1], many critical reflections occurred during conversations between facilitators and participants, where participants were prompted to elaborate on their ideas and prototypes. 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 struggled to get 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.

5.2 What are the unique forms of interactions that enable or limit critical reflection during the process of making in an online distributed critical making workshop?

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.

5.2.1 Lack of visibility of the making progress

Learning from peers is one of the fundamental components of maker learning experiences [26]. In co-located, in-person maker activities, learners engage with a community of people, sharing their ideas, getting feedback on the artifacts they are making, being inspired by what other people are doing, and getting 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 whole group. This led to various challenges in our workshop including using time to troubleshoot rather than support critical reflection.

One of the ways this issue of limited visibility was manifested was the growing gap of progress between participants. It is common for learners to be at different stages of progress in project-based, student-centered maker learning contexts. However, in an online setting, the progress gap placed unnecessary pressure on learners who may be struggling by themselves in their homes. Amelia's case 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 [A1, A2]. 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 in a number of instances. For example, Emma and a facilitator worked together for a long time to solve the problem of 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, the facilitator also could have provided Emma a working replacement kit, but being in an online setting, they had no choice but to troubleshoot using the materials that they had at hand.

With limited visibility of progress, it is extremely important to have multiple check-in points where participants can share their progress and sync up with the rest of the group. This would help avoid the gap of progress to grow before it becomes too large to close. It is also crucial to establish a process-oriented mindset among the participants at the beginning of the workshop. For example, facilitators can discuss 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.

5.2.2 Lack of open-ended exploration

One of the core principles of maker learning is that learners gain perspectives and skills through iterative processes [6]. When learners create shareable artifacts, their ideas and thinking become available for critique and elaboration [16,19]. 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 [9,12,15]. In in-person makerspaces, learners often acquire this fluency through tinkering with tools and materials physically. And tinkering can also benefit from scaffolding such as immediate feedback and acknowledgement that inspires further iteration and tinkering [24]. In an online environment, however, it was difficult to support these processes for participants.

With very little information of what participants were doing, providing timely scaffolding to each participant to help their tinkering process was a challenge. As we observed in Amelia's case, the limited feedback from participants on what they were doing and how they were feeling made it challenging for us to facilitate their iterative process. 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. In the future work, researchers may want to investigate

how facilitators can better support fluency within the technical bounds of the online communication tools to iteratively tinker and share without disrupting participants during their process.

In order 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 in in-depth exploration and stepping back to share, reflect, and discuss their findings. This type of cognitive growing during online making requires attention to facilitation of what Ackerman [1] calls “diving in and stepping out.” One approach that we found productive was to structure making activities into small steps, for example, as follow, 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 (e) return to group to reflect critically on issues and outcomes. Tension between structure and open-endedness is not a new issue in constructionist learning [8], however, our experience underscored the importance of designing open-ended exploration within a step-by-step structure with time limits and clear goals for each step. We also noted that students used the Bio-Tech Ethics Cards during independent work to guide their thinking, and that we also used the cards to guide sharing sessions. Resources such as our cards, which can be used flexibility to scaffolding reflection during both diving in and stepping out, provide continuity throughout the making activity.

5.2.3 Personalized facilitation through multiple communication channels

This study highlighted how facilitators used the chat communication channel to have a side-track conversations with one or more participants. This enabled personalized interaction (e.g., encouragement for elaboration) without disrupting the main activity being conducted in the video conferencing window. For example, in [J2] after Jamie shared their 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. This interaction also highlights 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. Co-teaching is commonly done during in-person maker learning activities, but an online environment allows even greater flexibility and possibilities for real time improvisation, as mentioned in [20].

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 leave the group to work together.

5.2.4 Ideation and reflection situated in student's environment

Another unique positive characteristic that we identified through Emma’s case was the flexibility inherent in remote environments to support situated learning [2]. 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 as the conversation took place on the way to basketball. 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 they already have at home into their learning processes as advocated for in many remote maker learning projects [21]. 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.

5.2.5 Co-facilitation of reflection through back-channel communication

Scaffolding critical reflections requires close observation of learners' interests and frustrations, and facilitators providing directions for them by prompting questions or highlighting important ideas [22]. Online environments allow multiple team members with different expertise to collaboratively work together to do this work more efficiently, by using backchannel communication without overwhelming learners. There were multiple occasions during the workshop where there was much discussion going on while the main facilitator was verbally talking to the participants. The backchannel communication between the two facilitators who were working with Emma was a good example [E1]. Backchannel conversations between team members often started with a team member who was not actively facilitating at that moment picking up on what a participant had just said or wrote, or how they appeared in the webcam, and then suggested a specific question to ask or information to provide to the facilitator working with that participant. The main facilitator responded in an improvisational manner similar to that described in a co-design study by Lee et al. [20]. In our workshop, such spontaneous communication between team members played a role in supporting students to elaborate on their remarks, perhaps supporting deeper reflection. 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 in order to bring everyone back together to proceed with the next activity.

Our analysis revealed several benefits of online distributed environments that might support critical making: using multiple communication channels with participants, the situatedness of the workshop, and backchannel conversation among facilitators. We need to pay attention to limitations of online learning environments, but educators and researchers should further explore how these unique characteristics can be utilized to support critical learning in online maker activities. In addition, while this study was majorly focused on facilitators' perspectives, future work can explore participants' perspectives on what facilitation may be valuable to them.

6 CONCLUSION

This study reports on three cases from an online critical making workshop that we conducted to investigate how to foster critical reflection on ethical implications of biowearable technologies. Our results provide preliminary evidence that most participants were able to develop and articulate critical reflection during the online workshop. While our study revealed the challenges due to lack of visibility of progress and need for structure for fluent exploration, we also found that various features of online communication environments enabled personalized facilitation, situated learning and effective co-facilitation of reflection. 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.

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