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Critical and Collaborative Making with augmented technical tools

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Abstract: Our research practices a critical approach to collaborative design making and speculates how present technologies shift future possibilities where interactions and exchanges are limited to those mediated by technological devices. Through a series of investigations, a collaborative, critical making process is prioritized over the final artifacts. The investigations consider and address the social and technological implications of how remote collaborative-making, mediated by augmented technical tools, might (1) foster new ways of thinking and making through play and experimentation (2) affect social interactions and empower people to become producers (3) affect relationships between collaborators and the technologies in use through transparent processes. This paper shares the outcomes of our investigations, based on participant data collected through qualitative and quantitative measures.

Keywords: collaboration; critical making; socio-technical systems; drawing robots

1. Introduction

The relationship between technology, collaboration, and ways of making continue to evolve as new digital tools (and systems of tools) enable transformative and unique working methodologies that drive and shape the discipline of design. Our research examines the socio-technical systems that influence and shape interactions between people and technologies through the use of present technologies that challenge people to make collaboratively in remote scenarios in unfamiliar ways. The act of making collaboratively fosters critical thought and inspires new ways of thinking and making. The present technologies are the digital tools (and systems of tools) that include multiple drawing robots as augmented technical tools in remote collaborative making processes.

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Our research practices a critical approach to collaborative design making and speculates how present technologies shift future possibilities where interactions and exchanges are limited to those mediated by technological devices. Further, the research investigates how the use of present technologies support remote collaborative making that takes place off the screen and occurs in a physical environment. Through a series of investigations, a collaborative, critical making process is prioritized over the final artifacts. The investigations consider and address the social and technological implications of how remote collaborative-making, mediated by augmented technical tools, might (1) foster new ways of thinking and making through play and experimentation (2) affect social interactions and empower people to become producers (3) affect relationships between collaborators and the technologies in use through transparent processes. This paper shares the outcomes of our investigations, based on participant data collected through qualitative and quantitative measures.

2. Literature Review

A socio-technical system can be defined as a system of working, often realized as a complex phenomenon, that recognizes and responds to the interactions between people and technology in a working environment. Our research examines what socio-technical systems are in order to address how our work relates to this phenomenon. We examine the social interactions that occur through the use of, and restriction of, certain technologies for communicating and working. This system affects how participants work and make together in certain collaborative experiences. Matt Ratto (2011) emphasizes that the act of critical making should “signal a deep research commitment to the co-constructed nature of our socio-technical world” (p. 206).

We examine socio-technical systems through a critical making process. Critical making, as defined by Ratto is a process in which the “material and conceptual work is interwoven” (2011, p. 205). He explains that critical *thinking* and *making* are often thought of as different. Critical *thinking* is often conceptual and articulated through writing while *making* is understood purely as “goal-based material work” (p. 205). He suggests that ‘critical making’ creates insightful understandings of processes, not necessarily objects, artifacts, or services, and shares these making experiences to research and understand socio-technical phenomenon for others. In our research, ‘critical making’ is the method for framing and planning the design processes and procedures that initiate and foster critical thinking among participants. Through the use of materials and processes in the investigations, an emphasis is placed on working with one’s hands to think and learn. Rosanne Sommerson (2013) defines critical making as “process-oriented and scholarship-oriented.” She argues that critical making emphasizes “the shared acts of making rather than the evocative object” (p. 19). With an emphasis on making, it is important to note that critical making is not *critical* if the conceptual is not interwoven into the process. John Dunnigan in his article, “Thingking” explains, “critical making requires critical thinking and social consciousness along with embodied knowledge if it is to be distinguished from making in general [...] In critical making,

the very process itself opens up new possibilities for deep, expansive thinking and the serious inquiry that stimulates discovery” (2013, p. 98).

Critical making is not an act of production, which is often considered the execution of a preconceived concept. In production, the thinking happens before the making. Ellen Lupton (2011) writes, “production is rooted in the material world. It values things over ideas, making over imagining, practice over theory” (p. 12). In our research, we consider the thinking and making simultaneously. We are not producers, but rather empower others to be producers through a critical making process. We consider participants to be producers of their own experiences and that they engage and explore ideas with materials and processes. By providing open-ended prompts for participants, we observe how they can be creative and critical simultaneously.

Critical making draws on Seymour Papert’s learning theory of constructionism¹, which advocates student-centered, discovery learning where students construct models for learning through materials and processes. In Papert’s seminal book, *Mindstorms* (1980, 1993), he describes learning as an “intellectual activity that does not progress by going step-by-step from one clearly stated and well-confirmed truth to the next. On the contrary, the constant need for course corrections, which he calls ‘debugging’ is the essence of intellectual activity” (1993, p. xiii). In this statement, Papert surmises his central theme which is that the acquisition of knowledge requires learners to think through making and to ‘figure things out’, which is directly in opposition with learning models that emphasize the memorization of abstract theories. He believes that thinking and making (and the human connection and enjoyment of those actions) are interrelated and discusses how the use of computers can be used as “objects-to-think-with” (p. 23). In our research, we consider how augmented technical tools and design processes can be “objects-to-think-with,” as Papert dictates, to explore concepts and materials simultaneously and to learn and understand socio-technical systems of working in design. In our investigations, each robot is the augmented technical tool designed for participants to explore collaborative making across different scenarios.

The objects that we “think with and through” are simple drawing robots constructed from open and available present technologies. We refer to these robots and the digital systems in which they function as our augmented technical tools. David Rose (2015), defines ‘enchanted objects’ as augmented technical tools that are “enhanced through the use of emerging technologies—sensors, actuators, wireless connection, and embedded processing—so that it becomes extraordinary” (p. 47). He describes them as ordinary objects that ‘come alive’ to “become more useful, delightful, informative, connected, and more engaging than it was in the first place” (p. 47). Rose discusses how enchanted objects are the future of computational tools as they are much more likely to connect with people in an emotional way (beyond the dry and detached future of digital screens). He describes them

1 Constructionism is connected with experiential learning and builds on Jean Piaget’s theory of constructivism.

as objects enhanced by technology with a “humanistic approach to computing that is not about fanciful, ephemeral wishes, but rather persistent, essential human ones” (p. 8). Rose makes this connection with enchanted objects, but designers have been recognizing and articulating this emotional connectivity with designed objects long before computational tools were as ubiquitous as they are today. Don Norman writes in *Emotional Design* (2004) that “technology should bring more to our lives than the improved performance of tasks: it should add richness and enjoyment” (p. 101). He argues that “beauty, fun, and pleasure all work together to produce enjoyment, a state of positive affect [...] positive emotions trigger many benefits essential to people’s curiosity and ability to learn” (p. 103). Norman values function and usability but writes extensively about the designer’s roles and responsibilities to merge the fun and pleasurable with the practical. Designed objects should connect emotionally with people and attempt or contribute to improving people’s experiences in the process. We use our augmented technical tools to facilitate fun, delight, and play. Rose further connects enchanted objects with ways in which people express themselves creatively. He discusses how tools and technologies can enable the exploration of creative-making and self-expression. He says, “we often look to technology to enhance our skills and enable us to express ourselves” (p. 146). In our research, we attempt to foster and support people’s innate desire to create with augmented technical tools, and to challenge participants to work in unfamiliar ways.

3. Research Methodology

Our research responds to these ideas through three unique investigations that were designed and implemented to test how people respond to activities conducted with and through augmented technical tools. Each investigation utilizes a digital system made up of drawing robots constructed with present technologies and a collaborative working environment. The ways in which these augmented tools are controlled vary from investigation to investigation and the people involved range from being passive users to active participants.

Our primary research questions are:

- In what ways can augmented technical tools & design processes foster play and experimentation through new forms, meeting the fundamental human desire to create?
- In what ways can augmented technical tools & design processes affect social interactions and empower people to become producers within a collaborative online context?
- How can augmented technical tools & design processes support new ways of making, thinking, and learning about technology for the collaborators?

Each of the investigations consider and address the social and technological implications of how remote collaborative-making, mediated by augmented technical tools, might (1) foster new ways of thinking and making through play and experimentation (2) affect social

interactions and empower people to become producers (3) affect relationships between collaborators and the technologies in use through transparent processes.

The first investigation demonstrates how collaboration and social interactions may take place through one system of augmented technical tools in one physical location. It sought to (1) foster play and experimentation among many participants and (2) empower people to become producers within a collaborative context by inviting people into an open collaborative making process via their smart-phone devices.

The second investigation demonstrates how two participants collaborated from two remote locations to (1) experiment through and with new forms that were unfamiliar to the participants in order to (2) support new ways of making, thinking, and learning about technology for the collaborators. This also sought to (3) empower the participant to become producers within a collaborative online context by planning and implementing a series of designed drawings with the robots.

The third investigation demonstrates how teams of participants worked collaboratively to build and construct their own technical tools for making activities. Through the process of building and working with the drawing robots and digital system, participants were able to (1) learn about the technologies in use and how it can foster collaboration, (2) manipulate and develop the technologies to engage more deeply with the material and concepts to foster new ways of thinking and making and (3) empower further making, with a deeper understanding of project capabilities and future possibilities.

To capture findings from these interventions, we collected data through qualitative and quantitative research methods including observation, surveys, personal testimonials, digital data, and making activities. Each investigation articulates which research methods and data collection techniques were utilized for measuring, collecting and concluding on the outcomes. Qualitative and quantitative data was analyzed across all three of the investigations resulting in conclusive themes and insights such as unexpected patterns of use, considerations for other possible augmented tools, and how the experiences created the conditions for thinking more about artistic making and collaboration.

4. Investigation #1: An Exhibition Experience with Open Participation

The first investigation demonstrates how collaboration and social interactions may take place through one system of augmented technical tools in one physical location. It sought to (1) foster play and experimentation among many participants and (2) empower people to become producers within a collaborative context by inviting people into an open collaborative making process via their smart-phone devices. Based on these goals, an exhibition experience was designed in a museum space as a participatory installation that utilized a single robot with a drawing surface. Participants of this investigation included visitors to The Eli and Edythe Broad Art Museum, a contemporary art museum at Michigan State University in East Lansing, Michigan. These visitors could easily interact with the robot

to draw contributing to a shared, collaborative outcome, which was a series of physical drawings. Individuals with access to a smart phone with texting capabilities were able to participate by sending directional commands to the robot (Figure 1).

Figure 1 Once a directional text message is sent, the message was delivered to the Twilio cloud. Twilio was the communication platform used to manage the text messages. The text command was communicated to a computer off site, which connected to the Electron on the robot, prompting the robot to respond.

Visitors were invited to engage with the installation through simple, instructional signage. The research population sample included visitors of this public museum who visited the exhibition over the course of two months and who had access to a smart phone with texting capabilities (Figure 2).

Figure 2 Museum visitors were prompted to control/draw with the robot via vinyl text adhered to the floor beside the drawing frame. Any device that sends a text could be used from any location.

The goal of this investigation was to set up a digital system in which open participation was possible to foster play and experimentation (meeting the fundamental human desire to create). This investigation allowed anyone to draw with the robot and contributed to a shared (collaborative) outcome. The museum as a setting for this investigation offered the optimal space in which to test an installation with multiple users (Figure 3). The single robot functioned within a drawing space which consisted of a simple rectangular 8' x 5' frame that was constructed out of wood and painted white. At each end of the frame a dowel rod held the paper and functioned as a feed for the paper, enabling a weekly "roll up" of the paper. The height of the frame was about 5 inches tall.

Figure 3 Installation view at the Eli and Edythe Broad Art Museum at Michigan State University, 2018. Photo: Eat Pomegranate Photography

This exhibition experience was focused on initiating play among the participants, as visitors experimented with the tools and technology to become producers and makers. To design this participatory installation, a collaborative drawing surface was created that could change over time as the outcomes developed and expanded through participant interaction with the tools. Over the duration, drawings were 'completed' after a dictated amount of time and new paper was rolled out. The finished drawings recorded the activities of the space and drawing parameters such as color marker designations documented the dates and times participants interacted with the tools.

4.1 Data Collection Methods + Analysis Process

The research instruments for analysis of the successes and short-comings of the installation employed public observation during the two-month exhibition period, the physical artifact created as a result of robot drawing by the visitors, and the digital data collected through the text messages sent. The digital data revealed an unexpected pattern of use by the participants, people texted the robot outside of the typical museum hours and beyond the physical space of the museum. Prior to the installation of the exhibition, process documentation of the planning phases (prototyping and testing) were recorded to capture

insights on the development of the augmented tools and the objectives specific to working in a public space.

4.2 Results

Due to this investigation taking place in a public space, there were limitations in setting up our technical tools with open networking capabilities. Previous uses of a Raspberry Pi would not be feasible in the museum based on the need to connect the Raspberry Pi to an open WIFI network in order for it to be remotely controlled. Additionally, the space was assigned by the museum as this installation was part of a larger group exhibition and requesting the optimal space was not an option. The final space assigned by the museum did not allow for any wall or electrical outlet opportunities and was situated in the middle of the room occupying roughly a 9' x 9' space on the floor. Finally, the duration of the exhibition was a two-month period of time (every day of the week except Mondays), determining a system that could sustain use for this long period of time was necessary.

Specific objectives and considerations arose throughout the planning process in response to the multiple challenges brought on by the public museum as a setting. Three distinct challenges in the museum prompted the working objectives and working considerations; *networking limitations*, *space assignment*, and *exhibition duration*.

Networking limitations: The digital system in which all the technology (but the robot) needed to be invisible to the viewer. The need for transparent technology in this investigation enabled the ease of use of the tools for the visitors/participants.

Space assignment: The drawing surface would require spatial boundaries for the robot in order for it to not be physically disturbed and to protect the museum floor surface. The tool needed to account for these boundaries via motion sensors on the robot.

Exhibition duration: This investigation needed to consider tools that offered minimal maintenance for the museum staff and functioned in an open network in a public space for a long period.

In order to solve for the networking limitations, the exploration of the technical capabilities of the robot led to the use of an Electron Board from Particle, a hardware company and software company that produces a platform for Internet of Things products. The Electron Board is a 3G cellular-connected electronic board with a SIM card and is programmed via the Particle cloud programming platform. (Figure 4). This enabled the robot to have its own phone number and be controlled via a cellular network, eliminating the need for a WIFI connected network. The device needed to be charged nightly and during the day it was powered by a cell battery.

Figure 4 Drawing robot on the drawing surface and the robot with components labeled.

Decisions for how the robot could be controlled informed the technical capabilities of the robot, thus informing the design of the drawing surface and space. Controlling mechanisms for the robot were explored and considered given that the WIFI network would not be an option for various WIFI connected controllers. What tools were readily available was then considered leading to the decision to explore and augment smart phones with texting capabilities as the controlling mechanism. This is a device in which we could assume that all or at least most visitors would have access to during their museum visit. In addition to the facility and technical parameters that directed design decisions of the robot, we also considered how these tools would be “objects-to-think-with” for museum goers.

Observations during the use of the robot evoked a sense of delight; visitors were intrigued by the robot and often stayed longer than expected to test their drawing capabilities. As Papert argued, the robots allowed museum goers to explore concepts and materials simultaneously by participating with this particular socio-technical system. The feedback from notetaking and photo-documentation suggest that the digital system in the exhibition/ installation format fostered play and experimentation among participants, meeting the fundamental human desire to create. Visitors were eager to create with the robots and the ways in which some tried to push the limitations indicated a strong desire to explore the tools given to them. An unexpected outcome was that several visitors attempted to control their drawing outcome by making a pattern or writing a word. It is possible that the collaborative nature of the installation was lost on some of the participants. Perhaps the process-driven, abstracted drawing wasn’t enough for some visitors and prompted their desire to create a familiar literal form. Nevertheless, this does suggest that participants wanted to play and experiment with the tools, and that the technologies in use empowered participants to be active makers and producers, regardless of whether they wanted to interact and collaborate with one another or if they preferred to interact only with the tools and space of the exhibition.

After the completion of the exhibition experience, the physical drawing resulted in 36 ft of paper that was drawn upon over the span of 58 days. Each week the color of the marker was changed, revealing a pattern of use from week to week. The physical drawings became

collaborative recordings or data visualizations of the activity and interactions of every participant with the robot over the course of the exhibition. Additionally, the data cumulated from Twilio revealed a timestamp of the texts as well as the phone numbers and the messages sent for every command sent to the robot. Frequency of the texts indicated that in the first weekend alone over 2000 text messages were sent to the robot and over time the texts were being sent at all hours of the night despite the museum being closed and visitors not being present at the installation. Another unexpected outcome was the sheer number of participants engaged with this collaboration and the reach beyond the exhibition space to include others via word of mouth and social media sharing of the project. Finally, we learned from the data, that commands other than “Left”, “Right”, “Forward”, and “Back” were tried (although failed) such as “Dance”. This indicated that participants understood how to think and make through the use of the robot by making assumptions about other commands the robot may recognize. Papert discusses a similar type of interaction between student and computer as an indication that participants are considering more in-depth concepts about the tools through their use. This further implies that the participants were seeking more opportunities to be delighted by the experience as visitors found alternative ways to interact with the installation.

4.3 Conclusions

The goal of this investigation was to set up a digital system in which open participation was possible to foster play and experimentation. This investigation allowed anyone to draw with the robot and contributed to a shared (collaborative) outcome. It was focused on initiating play among many participants, as visitors experimented with the tools and technology to become producers and makers. It surpassed our expectations of how many people participated during their visit to the museum and remotely, after their experience with the installation. The reach also expanded to people who had not visited the installation yet participated remotely. Future iterations of this investigation could consider alternative outcomes such as exploring other artifacts from participant interactions with the experience, incorporating more directions enabling better control of the tool, and facilitating a system that enables participation in both a digital and physical environment to better support collaboration.

5. Investigation #2: A Remote Experience with two Participants

The second investigation demonstrates how two participants collaborated from two remote locations to (1) experiment through and with new forms that were unfamiliar to the participants in order to (2) support new ways of making, thinking, and learning about technology for the collaborators. This also sought to (3) empower the participant to become producers within a collaborative online context by planning and implementing a series of designed drawings with the robots. The investigation involved two participants who often collaborate and reside in different parts of the United States. Each participant was given a robot with an online interface and making tools, together both participants experimented

with prompts for making collaboratively through four working sessions across the span of one month (Figure 5).

Figure 5 When directional commands were made via the online control panel by the participants, the commands were sent to the Particle cloud which then relayed the directions to the robot.

The main goal of this remote experience between two participants was to invite other like-minded design collaborators into a remote collaborative making process that was unfamiliar to them to see if they might engage with the tools and/or a design process in unexpected ways through experimentation and play. With very little direction for how to interact with the robots and digital systems provided, this investigation attempted to test for unforeseen outcomes, challenges, and considerations that had not yet been revealed to us².

Additionally, this investigation sought to find ways in which augmented technical tools and design processes affect social interactions and empower people to become producers within a collaborative online context. By providing the tools and digital system for working, the participants could experiment through new forms and potentially provide insight to consider for future iterations.

Each participant was sent a robot kit and was given an HTML control panel link for the robot that resided with the other collaborator. The kits each included a drawing robot, a set of markers, a roll of paper, and an instruction sheet (Figure 6). How and when the participants decided to draw with the robots was determined by them over the course of one month. Additionally, how they chose to use additional technical tools was up to them, i.e. live video chat platforms and use of cameras for live streaming. Participants were encouraged

2 For more on authors' previously published research, see: Normoyle, C., & Tegtmeier, R. (2017). Speculating the Possibilities for Remote Collaborative Design Research: The Experimentations of a Drawing Robot, *The Design Journal*, 20(1), S4038-S4051, DOI: 10.1080/14606925.2017.1352906

to experiment and test alternative solutions to making. Some example prompts included considering alternative drawing surfaces and spaces, media and mark-making tools, and/or processes and methods.

Figure 6 Drawing Robot kit of components, the Drawing Robot online interface/control panel

5.1 Data Collection Methods + Analysis Process

The research instruments chosen for this investigation included a pre and post survey. The pre-survey sought to gain insight prior to the participants beginning their workshop sessions and asked about their previous remote collaborative experiences and what technical tools mediated these collaborations. The post survey asked the participants to reflect on their collaborative experience. Additionally, the participants kept a process journal via a Google document file which outlined the goals and conclusions for each working session. Photographs and video captured in process documentation as well. The journals were analyzed for themes and insights into how the participant's approached the experience. The findings from the surveys led us to question what other tools and processes have not yet been considered, relevant for future research.

5.2 Results

Developing the kits for the participants required technical considerations for the drawing robots and the digital system. Several challenges needed to be solved prior to engaging the participants involving the robots and the control mechanisms. It was necessary to provide robots, directions, and a control panel that was easy to use and understand. This investigation required the development of robot kits that contained directions for use, robots that could connect easily to a network, and battery mechanisms for charging the robots efficiently.

The kits included robots that were informed by the robot used in the first investigation. A robot, that operated via a cellular network rather than a WIFI network, would eliminate any possible connecting issues within a closed WIFI network. These robots however, were

controlled by the use of an online interface rather than texting. Drawing with the robots through an HTML interface was best for this configuration since the collaborators also utilized web video chat platform (Google Hangouts) while working remotely (Figure 7). The control panel included buttons for moving the robot forward, backward, left, and right. There were two options for each direction, a continuous movement and a shorter movement.

Figure 7 Screen captures of participants collaboratively working via Google Hangouts.

Once the kits were in the hands of the participants, the rest of the working process was up to them. The augmented tools provided a way for them to test a systematic approach that pushed the limitations and affordances of how the robots were controlled and how they functioned. Together they determined a system by which they controlled the robots, using mapping as the common idea. One of the participants used a series of bike routes connecting time as it relates to distance. These moments of time were translated to the buttons controlling the robots. The other participant used their daily route via a geographic map. This way of working supports a facet of ‘critical making’ as defined by Sommerson—the way the tools were used was prioritized over the objects and the outcomes.

After testing this system numerous times via their collaborative working session, it became evident that using a systematic approach might not work as well as a more organic approach due to the limited control and abilities of the robots (Figure 8). A few factors that prohibited the systematic approach was due to the limited capabilities of the robots. The robots don’t move in a straight line nor make turns at a 90-degree angle. This limited any accurate representation in the physical drawing outcomes. Also, the stationery mark making tool limited the natural ability to pick it up and reposition easily. In realizing the challenges with a systematic approach, the participants imagined a future scenario in which the robots are controlled via a behavioral process. For example, having the robots move in response to participants’ actions or behaviors in the physical environment. This discovery and future experiments would not have been realized without the robots contributing to the systematic process, a factor Norman and Rose state as important for designed objects to connect on an emotional-level with people and support their curiosity and ability to learn.

Figure 8 The participants experimented with controlling the robot using bike route times.

5.3 Conclusions

This investigation sought to find ways in which augmented technical tools and design processes affected social interactions and empowered people to become producers within a collaborative online context. It invited other like-minded design collaborators into a remote collaborative making process that was unfamiliar to them to see how they might work with the tools. The results brought forth insight into our participants (across all investigations) and the expectations that come with using digital tools when one has previous expertise in making digitally and collaboratively. In this case, the participants, who are experts in design making, were more interested in the outcomes of the artifact than the experimental process of working with the tools. This caused a conflict between prioritizing a process-oriented approach versus an artifact-oriented approach.

Additionally, the working process became the most collaborative part of the experience between the participants, experimenting with the robots as a tool was less collaborative than they expected it to be. The experience did empower them to think in alternative ways about the possibilities as well as the limitations of collaborating in the digital space. Based on post-survey responses, this investigation led to further inquiries about remote collaborative making such as what other possible augmented tools, aside from the robots, should/could be considered. Additionally, it was considered how creative remote collaborative making activities might expand on existing systems i.e. commercial/industry settings, academic/research, educational, healthcare, manufacturing, etc., which could facilitate visual thinking artifacts created in the digital space.

6. Investigation #3: A Workshop Experience with Invited Participants

The third investigation demonstrates how teams of participants worked collaboratively to build and construct their own technical tools for making activities. Through the process of building and working with the drawing robots and digital system, participants were able to

(1) learn about the technologies in use and how it can foster collaboration, (2) manipulate and develop the technologies to engage more deeply with the material and concepts to foster new ways of thinking and making and (3) empower further making, with a deeper understanding of project capabilities and future possibilities.

To investigate these ideas, we planned and implemented a two-day workshop. Participants were invited from the Pitt Pirates Robotics team (<http://pittpiratesrobotics.com/>) of Pitt County, North Carolina to reflect a sample population of people that were directly interested in robotics and technology, in contrast to the previous two investigations, which aligned more directly with art and design interests.

The first day of the workshop was focused on building the augmented technical tools and setting up the digital drawing environment which controlled the drawing robots. The second day was focused on drawing activities, which helped to understand more deeply how the tools functioned, how the analog and digital experiences inter-related, and how the digital system worked as a whole. Through this process, they were encouraged to build beyond the steps provided to construct and contribute their own ideas.

The digital system included a drawing robot with mark-making tools that drew on a physical canvas on the floor in the space. The robots, programmed using a Raspberry Pi, were controlled via a web browser interface. The web browser interface has two drawing modes, a driver mode, which allows you to control movement via navigational buttons and distance increment values and a follow mode, which allows you to control movement via a trace function. You can also enter direct commands via a command line in the driver mode, and both modes include a graphic rendering, which can then be compared with the physical drawings (Figure 9).

Figure 9 The digital system and physical drawing environment

Participants broke up into three teams and built three robots. Each robot was constructed as its own unique digital system, and participants worked adjacent to each other throughout the process. Teams worked with the digital systems independently as well as all together (Figure 10).

Figure 10 Participants logged into their robots via the pi, which had already been flashed with our drawbots software package that is available via github. They used terminal to access their robot via its IP address, which was assigned by our access point/network for the workshop

6.1 Data Collection Methods + Analysis Process

To capture findings from the workshop, research team members conducted observations during the experience through fieldnotes and photo-documentation. The fieldnotes were analyzed for themes and insights relevant to how participants engaged with the technology in use to collaborate and how they considered materials and processes as instruments for learning. A post-survey was also conducted to record details about our population sample as well as to provide quantitative feedback on the workshop experience and possibilities for future investigations. Once analyzed, the feedback indicated that the workshop experience did lead to the participants thinking more about the connections between art and collaboration through technology.

6.2 Results

The kit enabled intuitive development of technical tools and empowered participants to learn complex concepts through design processes, collaborative making, and analog materials. Participants responded well to the written instructions in the kit for building and assembling the robots versus following an instructor-led verbal demonstration/intervention.

The kit allowed participants to work intuitively through procedures and processes, at their own pace, in their own way (Figure 11). Because of this, participants engaged with one another to determine how they wanted to move through the steps to interpret the instructions before seeking answers directly from the instructor. This prompted groups to designate roles and responsibilities amongst themselves. For example, one group designated “readers” versus “finders” versus “builders.”

Figure 11 Students working with the kit to assemble the robots collaboratively.

In observation it was seen that all the groups were comfortable with allowing the process and materials to direct their making. While they followed the instructions, they were thinking critically about the process, thinking ahead, and having foresight into crafting their robot tools. By working collaboratively, their critical thinking through making was made evident through their questions and discussions between each other throughout the process. If they made mistakes in the process, they did not dwell on them and instead, re-examined the instructions and worked with one another to solve the problem. Participants preferred to ask questions after they tried something versus over-thinking the procedures. They worked through trial and error and fell back on the instructions if they needed clarification.

To learn and understand how the tools functioned, participants worked through a series of drawing activities to experiment with the robot's capabilities. One drawing activity prompted participants to compare digital and analog drawings. As a result, teams noticed discrepancies between the digital controls and the physical outcomes and attempted to make modifications to their robots to increase its accuracy. In response, they discussed ideas for refining their tools such as loosening or tightening certain screws to check the integrity of their machinery.

To learn about the technologies in use and how they can foster collaboration, participants worked through a series of prompts to create collaborative drawings. Comparatively, each team worked collaboratively with the tools in slightly different ways (Figure 12). Team 1 was very interested in how their tools functioned to create patterns and repetition in their drawings. They relied heavily on the command line functionality on the driver interface to set

parameters and watched how their robot responded to these commands. They considered collaboration be creating design parameters and then as individuals, created a range of work that followed said parameters. Team 2 was more engaged with collaboration as a process. They responded to each other's work by adding color and linework to the drawing spontaneously, in a more intuitive and organic way. They were more interested in making the robot move versus making the robots move to create a specific drawing. They were less outcome-oriented. Team 3 was very interested in collaboration as a group composition and narrative in their drawing. They thought about an overarching theme, Star Wars and each member drew different parts (pod fighter, Death Star, Millennium Falcon) of a larger composition.

Figure 12 Team 1 exploring pattern and repetition through the command line function and Team 3 exploring narrative by drawing representational compositions.

Further modifications of the tools were implemented by teams during the final drawing activity, which prompted them to hack their robots to customize them for mark-making in one collective collaboration (Figure 13). After some initial movement and drawing exploration, participants competed in a drawing obstacle race where each robot was challenged to reach multiple check points on the paper. One team modified the pen holder by adding multiple marker holders and another team placed different objects on their robot to try and balance weight distribution. In the end all the groups modified their robots in similar ways as inspired by each other.

Figure 13 Each group's modified/hacked robot was placed on one, single sheet of paper for a final drawing activity.

6.3 Conclusions

Through the process of building the robots and then working with them as drawing tools, participants were able to understand the underlying mechanics and programming of the technical tools and therefore engage with and learn the capabilities and future possibilities of the robots in more depth. We were also interested in understanding how the technologies under investigation encouraged and facilitated collaborative making. As this was a primary goal of the investigation, the participants were able to find agency through working with the tools, and thus use the technology for their benefit.

In this investigation, the participants were highly engaged with the technology and system of tools under investigation. They collaborated well to find and solve problems related to the mechanics of the robots and were very interested in experimenting and playing with the modification and hacking of the robots. The participants became producers of the tools, and as Papert taught us, the tools and processes became “objects-to-think-with”. These objects empowered the participants to explore concepts and materials simultaneously and to learn and understand socio-technical design systems. Although these participants did not consider themselves particularly creative, they were incredibly imaginative with the technology and processes introduced. Many of them discussed in the post-survey how their passion for robotics made them think more intently about art and collaboration, an insight not previously discussed in either of the investigations prior. Rose defines ‘enchanted objects’ as the tools and technologies for exploring creative-making and self-expression. In this investigation, we sought to foster and support the participants innate desire to create with augmented technical tools, and to challenge participants to work in unfamiliar ways.

7. Conclusions

By these investigations, we attempt to address the socio-technical systems that emerge when people work collaboratively through and with augmented technical tools in a design making

process. We consider how augmented technical tools and design processes can be “objects-to-think-with,” as Semour Papert dictates, to explore concepts and materials simultaneously. We practice a critical approach to collaborative design making and speculate how present technologies shift future possibilities where interactions and exchanges are limited to those mediated by technological devices. The objects that we “think with and through” are basic drawing robots constructed from open and available present technologies that shift the way we work with one another in collaborative contexts. The conclusions from each investigation yield different insights, yet all intend to (1) foster new ways of thinking and making through play and experimentation (2) affect social interactions and empower people to become producers (3) affect relationships between collaborators and the technologies in use through transparent processes. Through the use of these augmented technical tools and the digital systems introduced in each investigation, we examine how participants engage with and in collaboration differently and to what end.

8. References

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