How Teens Can Build Remote Social Connection through an Emotionally Supportive Robot Swarm

by

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Abstract

Social connection plays an important role in early adolescent development, yet teenagers are increasingly turning to remote communication technologies like social media in order to fulfill their social needs. Unfortunately, these technologies are often missing several important elements of in-person interaction, such as nonverbal emotional cues and affective social touch. To address these shortcomings, this thesis explores the interaction design for ESSbots, one implementation of a proposed new kind of social medium that focuses on the shareable, expressive behaviours of an "emotionally supportive swarm" of small mobile robots.

We grounded our initial design framework in the cognitive science theories of participatory sensemaking, embodied, embedded, enactive cognition, and actor network theory, and explored how the swarm robot properties of tangible embodiment, multiplicity and coordination, and animacy, agency, identification, and roleplay support remote group communication and connection through a series of iterative participatory design workshops. Based on participant feedback, we developed an interaction prototype and interface to support accessible swarm robot behaviour authoring and remote sharing between friends via atomic behaviours, i.e., basic actions that can be combined and modified to create complex, expressive behaviours with one or several robots.

Our workshop findings revealed that teenagers wanted to use the swarm to communicate in creative and playful ways, share expressive emotions, and reflect their own personalities through the robots as proxies. They viewed the embodied aspect of ESSbots as a unique and important element of remote communication, and felt that mediated touch in particular would help them feel closer to their friends. We also found that our design was generalizable to both a new and returning group

of participants. It was consistently easy to use and engaging, although participants felt the clarity of remote communication works best with friend groups who already know each other well.

Finally, we highlight important design recommendations for ESSbots. Most notably, participants wanted a high level of autonomy over their own robots, including mechanisms to support consent when others use the swarm, as well as a mix of possible control methods including visual scripting, pre-made buttons, and direct manipulation to support expressive affect sharing and playful interaction.

Lay Summary

We explored the design of a new kind of remote social technology though interactive workshops with a returning group of teenagers, in which we aimed to support emotional communication and connection between friends in a tangible way via groups (swarms) of small mobile robots. Through a co-design process, we developed an interactive prototype, investigated how teen participants felt about the overall interaction concept, and generated design recommendations.

We found that teenagers wanted to use the robots to show their personality, share expressive emotions, play games, and feel closer to distant friends. Additionally, both a new group of participants as well as the group who helped design our prototype found it easy to use, however, they felt the clarity of communicating via robots works best for people who already know each other. Further design recommendations included the need to support autonomy through different robot control methods or mechanisms to show consent.

Preface

The work presented in this thesis was conducted as part of the Emotionally Supportive Swarm Robot project, led by Professor Karon E. MacLean in the Sensory Perception and Interaction Laboratory (SPIN) at the University of British Columbia, Vancouver, Canada. All research studies associated with this project were approved by the University of British Colubmia's Research Ethics Board (certificate number: H22-01554).

This project was a highly collaborative effort between several researchers and students at UBC, including myself (Computer Science), fellow graduate student Vasileia Karasavva (Psychology), undergraduate students Erin Chong (Cognitive Systems), Patrick Lee (Computer Science), and Felicia Yin (Cognitive Systems), SPIN lab manager Haley Foladare (Computer Science), Professor Amori Mikami (Psychology), Associate Professor Rebecca Todd (Psychology), and Professor Karon E. MacLean (Computer Science). Additionally, we collaborated with researchers outside of UBC, including graduate students Chen Ji and Ella Dagan (Computational Media, University of California, Santa Cruz), Professor Katherine Isbister (Computational Media, University of California, Santa Cruz), and Assistant Professor Lawrence Kim (Computing Science, Simon Fraser University, Vancouver).

None of the text of this thesis was taken from previously published articles. Chapter 1 is entirely my own work, and Chapter 2 was primarily written by myself, with compositional support from Dr. Maclean and Dr. Kim.

Chapter 3 includes content from an in-progress paper, led by Dr. MacLean and incorporating considerable input from all faculty collaborators, particularly regarding the theoretical framing of this work. In particular, the section on cognitive science grounding theory in Chapter 3 was conceptualized and written by Dr.

Todd, and the section on adolescent friendship groups by Dr. Mikami and Vasileia Karasavva. Table 3.1 was also co-created with Dr. MacLean, particularly the section which links the important properties of ESSbots to our theoretical concepts. All other sections in this chapter were written by me, and the exploratory workshops and data analysis discussed in Chapter 3 were also led by myself. The initial activity plan and workshop protocol was created with support from Dr. Isbister, Ella Dagan, and Dr. Kim. Vasileia Karasavva was the main workshop facilitator, assisted by myself, Felicia Yin, and Haley Foladare to run all workshop activities. Felicia Yin and Haley Foladare assisted me with data processing, and qualitative data analysis was conducted by myself, Vasileia Karasavva, and Haley Foladare.

Chapter 4 presents our approach to the main workshop series, led by myself. Workshop activities and protocols were developed by myself, Vasileia Karasavva, Haley Foladare, and Erin Chong, with minimal support from Chen Ji. *W1 (Conceptualizing ESSbots)* and *W2 (Customization & Control)* were facilitated by Vasileia Karasavva, myself, and Erin Chong. *W3 (Social Dynamics)* was additionally facilitated by Haley Foladare, and *W4 (Communication)* and *W5 (Design Generalizability)* by Vasileia Karasavva, myself, and Patrick Lee. Haley Foladare was also responsible for our workshop recruitment, and helped to prepare materials for workshop activities throughout the workshop series. Data analysis for each workshop was conducted primarily by myself, Vasileia Karasavva, Erin Chong, and Haley Foladare, as well as Patrick Lee for the final two workshops as well as the final overall data analysis and synthesis of results.

Chapter 5 describes our conceptual model for ESSbots and our interaction prototype. The conceptual model was developed in close collaboration with Dr. MacLean, and a more detailed version of the model developed by MacLean will appear in our current in-progress paper. The interaction prototypes described in this chapter were co-developed by myself and Patrick Lee.

Finally, the remaining chapters were all written entirely by me. Haley Foladare helped summarize our iterative workshop series activities for inclusion in Appendix A, and the remaining two appendices were created by myself. Along with my supervisor, I take primary responsibility for all other analysis and written material in this thesis, including research questions, discussion, and synthesis of results.

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Glossary

ANT Actor Network Theory, a cognitive science theory in which agency is considered to be distributed by both human and non-human actors within networks

ESS Emotionally Supportive Swarm, composed of individual ESSbots, or emotionally supportive swarm robots

EEEC Embodied, embedded, and enactive cognition, a cognitive science theory in which cognition is treated as embodied action, emerging from the coupling of the body with the environment and other bodies

PSM Participatory Sensemaking, a cognitive science theory in which cognition is considered to be a kind of embodied action applied to social cognition

TMA **T**angible Embodiment; **M**ultiplicity and Coordination; and **A**nimacy, Agency, Identification, and Roleplay: shorthand for the main important properties of swarm robots that could facilitate meaningful remote group communication and connection

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First, thank-you to my supervisor, Dr. Karon MacLean, for always providing great feedback, ideas, and support as I worked on this thesis project and my degree overall. I would also like to thank Dr. Robert Xiao for his insights into how to make this work better as my second reader.

Thank-you to all the faculty who have been involved in the ESSbots project: Dr. Amori Mikami and Dr. Rebecca Todd, for providing invaluable insight into the psychological and cognitive science grounding theory for this thesis; Dr. Katherine Isbister, for guiding me on how to organize and run participatory design workshops; and Dr. Lawrence Kim, for providing us with several of his own swarm robots and for his patience as I figured out how to use them.

Thank-you to fellow graduate student Vasileia Karasavva, for coming up with some great ideas on how to make our workshops better and for always being such a wonderful person to work alongside of. I'd also like to thank graduate student Chen Ji for her feedback on our workshop and data analysis plan, and our lab manager Haley Foladare for her extensive support on recruitment, workshop planning, and data analysis throughout the ESSbots project.

Additionally, I'd like to thank all the undergraduate students who helped me run workshops, prepare materials, and analyze data for the ESSbots project: Erin Chong, for her valuable support and suggestions throughout the design workshop series; Patrick Lee, for his work developing our prototypes and additional help with the workshops towards the end of the project; and Felicia Yin, for her early support and assistance running our initial exploratory workshops.

Further, thank-you to all the students I've worked alongside of in the SPIN lab, who have always been so supportive not only in terms of my research, but also as my friends. I'd like to especially thank Devyani McLaren for brainstorming ideas about atomic behaviours with me, and Preeti Vyas for her home-cooked food when I was feeling particularly stressed and busy.

Finally, I'd like to acknowledge the funding support I received from the Natural Sciences and Engineering Research Council of Canada (NSERC), and everyone else at MUX and UBC who have supported me during the course of my degree.

Dedication

To my friends: online, and in-person.

Chapter 1

Introduction

Friendship and social connection are essential parts of the human experience, and serve several important roles in our daily lives: we seek out others to share in positive moments, to support us in times of need, or simply to have fun together. The specific ways that we stay connected can take several forms as well. People may see each other in person during shared common activities, like work or school, or may arrange to meet up with their friends outside of these passive daily interactions, such as by seeing a movie or eating a meal together. People can also stay connected to others online rather than in person. These online forms of communication may be personal and direct, like a shared group chat, video calls, or private multiplayer games. Alternatively, they can be more open and performative, such as public social media pages like Instagram or TikTok, where individuals may not only connect with friends they know in person, but maintain unique parasocial relationships with followers they do not directly interact with at all.

Both in-person and online communication are important means of social connection; however, each has unique advantages and disadvantages. In-person communication supports fully robust, shared experiences: people experience things in the same synchronous environment, and can react and respond to the same stimuli together. They can easily communicate subtle non-verbal cues to one another through things such as facial expressions, body language, and physical proxemics to the other people they are interacting with. In-person interactions also facilitate social touch, which can help people to communicate emotions [13] and reduce stress [70]. However, in-person communication is ultimately limited to people who are in the same physical location, and may be restricted or unavailable due to factors outside of an individual's control, like the COVID-19 lockdown period or simply when one person moves away from their co-located social group.

Online communication, on the other hand, is accessible and widely available even when people are in distant locations or otherwise aren't able to see each other in person. It allows individuals to tailor their own experiences by curating the content they see on social media pages, taking more time to respond to direct messages, or even creating their own online persona to explore aspects of their identity they may not be ready to explore in person. People can also use richer forms of online communication to communicate in groups and convey limited non-verbal social cues. For example, people can convey tone through voice and facial expression over synchronous calls, which can facilitate dyads or group communication; however, proxemics, social touch, and body language remain hard to convey over video calls alone. Online communication is also often more conveniently asynchronous than in-person communication—people are able to communicate with each other without the restriction of needing to be in the same place at the same time, since most messages or social media posts can be read and responded to at any point after they are originally posted.

While online connection can indeed benefit individuals, especially when they facilitate support-seeking that may not be possible within local social circles, online social networks have also been negatively associated with overall subjective well-being [90]. The often filtered and performative nature of "broadcast-style" social media in particular can invite negative comparisons between people, and potentially lower individuals' self esteem. In general, online interactions lack many of the benefits of in-person interaction, like affective social touch and non-verbal social cues, and without careful design considerations, even richer forms of online communication, like video calls, can feel draining or lack a sense of genuine connection to communication partners [80].

Thus, we aimed to address some of the current limitations of remote communication technologies for friend groups by considering how we could design a new kind of group remote communication technology that supports the positive aspects of both in-person and online communication, and limits some of the negative aspects common to many social media platforms. We hypothesized that swarm robots—small, mobile robots that coordinate together to perform functional tasks [57], serve as tangible user interfaces [50], or provide haptic feedback [45]—could naturally support more authentic remote group interactions through mediated proxemics, embodiment, and affective touch, and serve as a new kind of physical social medium, akin to a embodied group chat, through which groups of friends could communicate and connect with one another. In particular, swarm robots can naturally support group interactions, as they are composed of several individual robots that could be used as proxies to represent individual people within a friend group.

To that end, we further identified three important properties of swarm robots that we believed were important not only to swarmbot-supported remote communication, but could serve as an important set of properties to improve other forms of online communication technology as well: **T**angible Embodiment; **M**ultiplicity and Coordination; and **A**nimacy, Agency, Identification, and Roleplay (TMA). First, online communication that is tangibly embodied could allow users to feel closer and more connected over a distance, engage in mediated affective social touch, and convey non-verbal cues to one another, similar to the way people engage with each other in-person. Second, remote communication technology that supports multiplicity and coordination and naturally represents several individuals can allow groups of people to connect with one another at the same time, and when combined with the property of tangible embodiment, can allow them to engage in a kind of mediated proxemics with one another where individual group members take up physical or virtual space in relation to each other. Finally, animacy, agency, identification, and roleplay frames the technology itself as a potentially animate and independent part of the interaction—the affordances of the communication platform could not only support individuals to engage in role play and directly represent themselves through the technology, but also find the technology itself engaging beyond what they themselves directly contribute to it.

While existing remote communication technology may support one or two of these properties, no system has robustly incorporated all three to explicitly support a sense of genuine connection among *groups* of remote friends. Thus, in this thesis we implemented TMA in the form of ESSbots, or *"emotionally supportive* *swarm robots"*, which we hypothesized could improve remote group interactions by explicitly adding some of the elements of in-person interaction back into remote communication technology. We further hypothesized that these unique affordances of swarm robots would help friends to communicate in a more genuine, expressive, and emotional way, and that the elements of mediated social touch and embodiment in particular would help them feel closer to one another.

1.1 Participatory Design with Teens and Swarm Robots as a TMA Technology

Given that early adolescent friendship plays an important role in development [14, 31], and that teenagers are increasingly turning to social media to connect with their friends [76], we were particularly interested in how we could design a new kind of physical social media to better support teenagers as they connect with their friends online. We were especially interested in how TMA-based swarm robots could support the *group* aspect of remote online interaction, since most existing research on social robots or mediated social touch focuses on dyadic interactions [34].

In past work, swarm robots have typically been used locally to perform standard tasks such as collective manipulation, self-assembly, and distributed sensing [54, 69, 91]. However, more recent work has explored how swarm robots can directly interact with users via tangible user interfaces [43, 46, 50, 81] or by providing haptic feedback [45, 71, 82, 83, 95]. One of the main features of a swarm robot system is scalablity, which is typically considered to be the ability to add more robots to the same local system. However, we consider a slightly different aspect of scalability to support remote group interactions, in which sets of connected robots could be accessed simultaneously by multiple users, thus bringing the benefits of a local swarm into a distributed network.

We also felt that the TMA affordances of swarm robots in particular could naturally support group interactions: members of the group could access their friends' embodiment through multiple swarm robots, which could interact with them physically (i.e., tangibly) as a form of mediated social touch; multiple robots could work in coordination to reflect expressive meaning or could represent individuals within the group; and the robots themselves could appear animate and life-like, potentially further supporting individuals to feel embodied and actively engaged through them. Additionally, the robots could have perceived agency as well, where they may seem to have their own agenda or purpose beyond how individual people enacted their own will through them. This potential for various levels of perceived agency could support interesting interactions, where group identity could be mediated through the robots themselves and influenced by them, or where individuals could engage with each other through the robots as direct proxies or avatars that have little of their own separate agency.

Thus, we decided to take advantage of these unique affordances of swarm robots in our interaction design, hypothesizing that teens would be able to use individual robots or the entire swarm to convey expressive, embodied messages to one another, enact mediated proxemics to their friends via the robots, and ideally feel closer to one another due to the physical presence of swarm robots in their own space. We proposed an initial interaction framework where each person in a friend group would have access to a set of swarm robots, which would be synchronously connected to one another and support primarily synchronous interactions between a small group of friends, similar to a kind of physical group chat or a physical form of multiplayer game avatars. We call this implementation of swarm robots for social connection a Emotionally Supportive Swarm (ESS), composed of individual *ESSbots*.

We wanted to ensure that we designed something that teenagers would actually find enjoyable and fun to use, and therefore decided to take a participatory design approach to get ongoing feedback from users as we worked on our interaction design. In particular, we decided to approach our co-design with teenagers as a series of participatory design workshops, where a returning group of participants would act as a "teen advisory board" to discuss different aspects of what ESSbots should be, interact with ongoing prototypes through an iterative design process, and help us to understand how teens actually wanted to use swarm robots to communicate and connect with one another.

In order to provide our teen advisory board with a grounded framework to focus their design ideas, we also considered relevant theories from cognitive science, such as Embodied, embedded, and enactive cognition (EEEC) and Participatory Sensemaking (PSM) [17] that we felt strongly related to the kind of interactions that teens would engage in with ESSbots. By approaching our design from both a theoretically grounded standpoint as well as an iterative, flexible, and participant focused process, we hoped to gain a robust set of design guidelines that could support future iterations of ESSbots as well as create a system that could be used to investigate remote group social connection in the future.

1.2 Larger Design Space

Though our iterative design process, we arrived at a particular design and design context for what ESSbots could be. However, it was also evident that there was a much larger design space for TMA technology that could be explored in future work. We describe several dimensions of this design space below to futher contextualize the potential for ESSbots and TMA technology, although we note that there may be other dimensions not mentioned here that are uncovered in future work.

1. Scale of group:

ESSbots could be used with a few close friends or a large network of relative strangers, similar to how social media platforms are used today. While we consider ESSbots to be a kind of physical social *medium* applicable to small groups of existing friends, we can also consider how ESSbots could be expanded into a kind of social *media*, and thus contextualize the definition of social media as it could apply to ESSbots. According to the Merriam Webster dictionary, social media is: "forms of electronic communication (such as websites for social networking and microblogging) through which users create online communities to share information, ideas, personal messages, and other content (such as videos)" [56]. Missing from this definition is a sense of scale: implicitly, we typically think of social media as enabling connections between large networks of users, possibly even people who were initially strangers, who can in turn form sub-communities with one another (e.g., Facebook friends or TikTok followers).

Swarm mediated emotional communication could also apply to either large networks of connections (e.g., individuals create and share behaviours that can be viewed by anyone with a set of swarm robots, potentially more authentically than traditional social media given that movement-based messages by nature cannot convey complex context necessary for inauthentic, performative status updates), or small networks of close friends who interact with the robots together (like a private group chat or private multiplayer game, where individual robots could act as physical avatars or game pieces).

2. Form of interaction:

How individuals interact with fellow ESSbot group members could exist on a spectrum, where at one end users could receive static broadcasts from one individual, or at the other could engage continuously with many other people using their swarm. For example, ESSbots could be used to strictly send movement-based messages to connected remote others who must wait until the message is fully sent before responding or broadcasting their own message to the group. Alternatively, many individuals could contribute to an ongoing behaviour state, where the swarm represents their collective will, or even more directly control individual robots at the same time to play games or have fun together.

3. Synchronicity:

We note that remote communication technology in general can support both synchronous and asynchronous interaction. There are several benefits to both: in the case of synchronous interaction, people may feel a better sense of co-presence and can engage with one another in real time; asynchronous interaction, on the other hand, supports more flexible interactions and connection where people can engage with each other whenever they wish. ESSbots could be used in either way, where individuals could have the opportunity to "open" ESSbots messages from their friends at any time, or have each remote swarm synchronize with their connected friends' swarms in real time to create behaviours or play games together.

4. Co-located to remote:

While we are primarily interested in how technology with the properties of TMA can support feelings of connection and closeness among a remote group, we also note that ESSbots could still be used in co-located settings as well. For example, a group of friends could all meet in person to customize their robots as part of a group "unboxing" experience, upon which they could then use them remotely to more clearly identify individual representations of their friends in the overall swarm. People could also continue to use the robots as a co-located group by coming up with behaviours and programming them together, or engaging in local play with the robots (e.g., racing them around the room). People could also use them entirely remotely, potentially learning from others online via open-source customizable ESSbot programs or examples that other users have posted, or by utilizing other remote connection technology to learn how to use them with remote friends (e.g., over a Zoom call).

5. Rehearsed interaction vs. improvisational:

How individuals interact with the robots and, in particular, share behaviours that they created with their friends could also feel pre-made and rehearsed or improvisational. For example, it would be possible to design ESSbots so that connected swarms are always closely synchronized, so that any experimentation with the robots by one person locally would automatically happen on all sets of swarm robots as well—that is, other people would see ongoing behaviour creation at all times. On the other hand, users could have a mechanism to interact with only their own local set of robots, so that they could experiment with them in order to create and share finalized behaviours with their friends.

6. Sensory sophistication:

The extent to which individual robots or the swarm as a whole can sense external information about the environment or users is also highly variable. For example, the robots could operate at a minimum level of sensory capacity, where they would only be equipped with enough sensors to detect important factors for swarm control, such as relative position to other robots and position in local space. They could also include additional sensors to support interactivity, like posture angle or touch detection with human skin, so that picking up or touching the robots could be detected and potentially reacted to by the system. Finally, they could potentially utilize sensors to detect complex states, such as the affective state of individual users, which could then in turn be shared with others via swarm robot behaviours meant to emulate the same affect.

7. Scale of embodied elements:

The size of the swarm itself is also an important dimension. It could pertain to the total number of robots, or the relative size of individual robots themselves, though it is likely linked—it would be cumbersome to have hundreds of large robots, and a few tiny robots may feel insufficient. How groups use the robots may depend on their size or number as well. For example, a group of friends could have as many robots as friends in their group (e.g., 3–5), where each robot could easily represent an individual person and could be used as embodied avatars or programmed directly. On the other hand, a different group could have the same number of robots per swarm (3–5), but could consist of many more individual users—in this case, individual robots may need to "take turns" representing different individuals in the group, or the swarm as a whole might take input and react based on the larger group feedback (e.g., individuals influence an overall group behaviour rather than enact their will through specific robots). Alternatively, access to hundreds of tiny robots may better support system-mediated interactions compared to things like direct programming, as individually tailoring content for hundreds of robots would not be an easy task.

8. Portability:

The portability of the swarm itself could also differ, where robots could be confined to horizontal surfaces like tables, or in theory could extend to tiny swarm drones that could fly or fit into a user's pocket and be transportable. In the first case, people would be constrained to using the robots in specific locations, whereas in the second case, they could take their set of robots representing their friends with them wherever they go. However, there are several technical requirements that would be needed in order to support portable swarms, such as robust sensing systems that could work in many different environments, and thus the highly portable aspect of this dimension is largely theoretical.

We could also consider the level of software portability for the system: a highly portable version of the software could adapt to different hardware models of swarm robots from different manufacturers, or at least support running the same swarm robot hardware from different operating systems or devices, like mobile phones and laptops. Notably, how swarm behaviours are enacted by different hardware models may differ without deliberate management by the backend system, since, for example, different swarm robots may have different motors or speed capabilities, or even different features, like lights or sound. Even the interface itself or behaviour authoring access may need to adapt to different control devices. For example, it would be difficult to create complex programs directly on a small smartphone screen compared to a laptop screen or computer monitor, but easy to select buttons or draw path-following trajectories.

9. Other forms of TMA technology:

Finally, we note that the hardware design for technology that supports the properties of TMA need not be swarm robots at all, although they are a natural platform that strongly possess all three properties compared to other possibilities. Thus, here we can consider how an ESS is distinct from ESS*bots*. For example, we could consider a shape display [52] or display with tactile pixels [38], which supports tactility and potentially limited embodiment via the adaptable and formable display itself; each tactile pixel is one of many connected multiples; and the display itself could operate with some perceived agency, although whether it could be considered animate or whether users could engage in role-play through it is debatable. However, a shape display could be more practical than a set of swarm robots, especially in order to create a more portable version of ESS technology, since each tactile pixel would remain connected to the same surface at all times.

Current focus:

Therefore, given such a large potential design space, we first focused on a small section of this space to explore what TMA technology could look like in practice, including how teens would want to use it, and, restricting our use-case to a set of approximately 3–6 connected tabletop swarm robots, how we should approach the interaction design for such a system. Rather than focus on how a larger community of ESSbot users might use the technology to engage with each other, in this work we focus explicitly on a single pre-existing friend group as a contained sub-community and how they would use sets of swarm robots to stay connected with each other in an embodied, authentic way. We also focus on many-to-many interaction, where several users could potentially engage with the swarm at the same time, and primarily focus on synchronous interactions to explicitly investigate how remote friends could use the robots in an ongoing, dynamic way with one another. We consider a design scenario of remote interaction which could be rehearsed or improvisational, implemented through an existing set of swarm robots with moderate sensory sophistication and limited portability.

In summary, we address the following from each dimension:

1. Small groups
2. Primarily continuous interaction (many-to-many)
3. High synchronicity
4. Remote
5. Rehearsed and improvisational interaction
6. Moderate sensory sophistication
7. Small scale (3–6 robots)
8. Low portability
9. Existing swarm robot platform

We further note that while all possible dimensions of this design space are important and potentially useful to investigate what ESSbots interaction could be, in this work we focus specifically on the elements outlined above, as we believe these elements support much of the relevant core functionality of a technology to support TMA interaction and can help guide future design work on ESS systems in the future.

1.3 Objectives

We aimed to explore the idea of ESSbots with teens that was explicitly grounded in theory, yet also directly included teens in the design process in an engaging and iterative way. We wanted to determine how such a system, which was focused around the TMA properties of embodiment and tangibility, multiplicity and coordination, and animacy, agency, identification, and roleplay, should be constructed in order to maximize its accessibility to non-expert users. That is, we wanted our system to give teens robust access to swarm behaviour creation and control, so that they would be able to use the technology however they wanted in order to communicate and connect with their friends.

Further, we hoped to uncover what aspects of this technology teens found compelling, and what kinds of interactions and swarm behaviours in particular teens would use to share expressive meaning with one another. We were also curious how elements of our grounding theory, such as PSM, played into these interactions—would teens indeed treat the robots as an additional actor in their overall interaction with each other in order to build up meaning together, or would they interact with the swarm in new, unexpected ways?

Finally, we wanted to develop a interactive prototype based on participant feedback from the workshop series, and evaluate both its usability and overall generalizability with a new group of participants who did not influence the design. We were curious to see how people less familiar with ESSbots would interact with the prototype and communicate with one another, and whether our design process indeed resonated with participants and helped us to construct the interaction design for ESSbots in a robust, meaninful way.

1.4 Research Questions

Through a series of iterative participatory design workshops, we set out to investigate the following research questions, focusing on how ESSbots could support synchronous, authentic interactions between a group of friends through the important properties of TMA:

- **RQ1: How do teens conceptualize an emotionally supportive swarm and what they can do with it?**
  - RQ1.1: How do teens conceptualize the swarm robots and their interactions with them?
  - RQ1.2: What kinds of concepts, emotions, ideas, and more interactive forms of "play" do teens want to share and participate in using the system?
  - RQ1.3: Do teens perspectives about the ESS change as they help design what the system can do?
- **RQ2: What are the elements and properties of a set of swarm robot behaviours that can effectively support affective communication between remote friend groups?**

- **RQ3: How can the ESSbots system support teens to author and share swarm robot behaviours with their remote friends?**
  - RQ3.1: How do teens want to control the robots and/or author new swarm robot behaviours?
  - RQ3.2: How do teens want to share and communicate using ESSbot behaviours with their remote friend groups?
  - RQ3.3: How do these robot control and behaviour authoring preferences translate to system design considerations?
- **RQ4: How did our design and participant reactions to it reflect our grounding theory of participatory sensemaking and the three main ESSbot properties of TMA?**
  - RQ4.1: Does our ESS design reflect the principles of our grounding theory?
  - RQ4.2: How did participants' reactions to our design and the ESSbots concept overall support or contradict our grounding theory?
  - RQ4.3: How can both our grounding theory and participant feedback from our workshop series guide future design recommendations for the ESSbots system?

1.5 Approach

We began by conducting an initial literature review and grounding our ideas in theories from cognitive science, including embodied, embedded, and enactive cognition (EEEC), Participatory Sensemaking (PSM), and Actor Network Theory (ANT). We identified the main relevant affordances of swarm robots, and situated them in the context of existing social media platforms. We then conducted two exploratory workshops to gain initial insight into how teenagers perceived ESSbots conceptually, how they would actually use robots in order to communicate embodied behaviours with one another, and how these ideas related to our grounding theory. Based on the results from our exploratory workshops, we developed a conceptual model for ESSbots as well as a framework for our system structure: atomic behaviours, or simple actions that can be combined and modified to create the expressive behaviours participants came up with in the exploratory workshops.

We then conducted a series of five participatory design workshops with a a largely stable set of seven teenagers over the course of three months, making use of an existing commercial swarm robot platform and focusing on developing the user interface and interaction design for ESSbots. Each workshop primarily explored one aspect of ESSbots: conceptualizing ESSbots, customization and control, social dynamics, and communication (see Table 4.1 for a summary of each workshop). Finally, we conducted an additional workshop with a group of new and returning participants to assess the generalizability of our design. We analyzed our qualitative data from the workshops via semantic data coding, and report quantitative results from a system usability survey for our final prototype as well.

1.6 Contributions

We report three main contributions:

1. The design of a system that novelly introduces the properties of TMA to group social communication in the form of a shared robot swarm, including:
   (a) A functional prototype for ESSbots interactions and an authoring and control interface, which is both engaging and accessible to new users as well as generalizable to teens who did not directly influence its design;
   (b) Supported by a grounded theoretical framework and participatory design workshop feedback.
2. Insights into how teens can *utilize* a EMA-based modality in synchronous remote group social communication, including:
   (a) How they conceptualize TMA and swarm-based communication;
   (b) Their receptivity to this concept;
   (c) How the design of this technology can facilitate usability, engagement, and fun;
   (d) The degree to which our theoretical framework influenced and is reflected in these facilitative design elements.

3. A set of initial design strategies that codify our findings on how, for teenaged social groups with minimal programming experience, we can:
   (a) Facilitate effective group EMA-based affective interaction;
   (b) Give satisfying, creative, and sufficiently customized access to authoring and control of the shared swarm's behaviour.

1.7 Thesis Organization

We begin by discussing related work on remote communication and connection, social robots, and swarm robots in Chapter 2. We then discuss our initial grounding theory and the results from our exploratory workshops in Chapter 3. In Chapter 4, we present our approach to the main participatory design workshop series and report participant demographics, including how participants use existing social media in their daily lives. In Chapter 5, we discuss our conceptual model for ESSbots as it evolved from our grounding theory and exploratory workshop results, and present our final version of the ESSbots interaction prototype, which we evaluated for usability in our last two workshops. We further report our qualitative findings from the workshop series in Chapter 6, organized by the main workshop series concepts of conceptualizing ESSbots, customization and control, social dynamics, communication, and design generalizability. In Chapter 7 we return to our research questions, reflect on the workshop series process, and present final design recommendations. Finally, we report our conclusions, limitations, and possible future work in Chapter 8.

Chapter 2

Related Work

We discuss relevant work around remote communication and connection, social touch, social robots, and swarm robots to situate ESSbots as a swarm-based social robot system to support mediated social touch and promote increased connection among remote friend groups.

2.1 Remote Communication and Connection

Remote communication technology is an integral part of most people's lives—texting, calling, or engaging with social media sites or online games are activities that many people engage in daily [5, 11]. Teenagers in particular have increasing access to remote communication technology, with a 2018 survey suggesting that up to 95% of American teens have access to a smartphone [3], and many adolescents are turning to social media as a primary communication tool to get their social needs met [76].

Remote social connection can have several benefits, including mitigating loneliness [4], facilitating support-seeking [90], or simply providing convenience and easy access to stay in touch with others. However, these technologies often lack several important benefits of in-person connection, including poor support for non-verbal emotional cues like affective touch [20]. Yet even technologies with high bandwidth can suffer from poor interaction quality [80], leading to issues such as the "Zoom fatigue" many people experienced when relying heavily on videoconferencing software during the COVID-19 pandemic [1, 65]. This potential for poor social connection implies that designing effective remote communication technologies is non-obvious, and should be approached carefully to avoid potential negative impacts on users.

To that end, Stepanova et al. [80] conducted a 2022 review on 50 diverse systems that aimed to foster a genuine feeling of connection among users, and identified nine main strategies: affective self-disclosure, reflection on unity, shared embodied experience, transcendent emotions, embodied metaphors, interpersonal distance, touch, provocations, and play. While some of these strategies are mainly applicable to co-located users, such as interpersonal distance, many can indeed be mediated through remote technology, such as embodied metaphors, touch, and affective self-disclosure.

ESSbots have the potential to encompass several of these properties, even some, like interpersonal distance, that are typically more common in in-person interactions. Users could engage in mediated proxemics with the swarmbots, where individual robots could serve as avatars to represent friends within a group, or mediated social touch, where robots could be used to directly touch communication partners since they are in their own physical space. People could also use the robots as a form of affective self-disclosure by sharing expressive behaviours with the swarm in order to communicate their current emotional state, engage in an embodied experience through the swarm with one another through synchronous interactions with the robots, or simply use the robots to engage in playful interactions with one another.

These possibilities suggest that if designed carefully, ESSbots could indeed help to support a genuine sense of connection among remote communication partners, and we further contextualize our specific design context in related work on social touch, social robots, and swarm robots in particular.

2.2 Social Touch

Affective social touch plays an important role in human development and relationships. It helps people communicate emotions, shape social rewards, and establish secure attachments to others [13]. Several psychological studies have shown that social touch can also help reduce stress and other negative emotions, and even reduce perceived pain [70]. Interpersonal touch has also been shown to affect people's attitudes towards services and increase compliance with requests [24].

There is physiological support for the importance of affective touch as well. There are distinctive receptors in human skin to process affective and discriminative touch respectively [61, 87], and human hairy skin in particular has receptors that respond preferentially to soft stroking touch associated with mammalian affiliation [55]. Additionally, the unmyelinated fibres dedicated to carrying information to the brain from pleasurable touch sensations are fully functional in very early infancy compared to the myelinated fibres dedicated to discriminatory touch [55], further highlighting the importance of affiliative touch in human development.

However, responses to social touch remain contextual. For example, how people interpret the emotions conveyed by touch may be affected by the genders of the interaction pair [33]. People may also react positively or negatively to touch based on a number of other factors, including facial expression, relationship status, or group membership [70]. Social touch can also contextually influence psychological outcomes, such as intimate (but not friendly or professional) touch being associated with increased loneliness and anxiety during the COVID-19 lockdown period [88].

Importantly, affective touch can also be mediated through technology via tactile or kinesthetic haptic feedback [28]. Several devices have been designed to help convey specific types of touches between diads, such as hugs, handholding, pokes, or even kisses [87]. Despite many studies generally lacking rigorous validation or robust theoretical backing [28, 87], there is evidence that people use and react to mediated social touch similarly to in-person touches [87]. For example, mediated touch can affect the quality of shared experiences [84], promote pro-social behaviour [29], and communicate emotions [77], suggesting it is still a valuable aspect of in-person interaction that can be adopted and mediated through technology.

2.3 Social Robots

As defined by Hegel et al. [32], a social robot consists of both a physical robot and metaphorical social interface, the latter of which encompasses the social attributes of the robot that a person would use to judge it as a social interaction partner. However, the expectations of this social interaction typically differ depending on the robot's form.

Anthropomorphic versus Zoomorphic

People tend to have higher expectations for the capabilities of humanoid social robots compared to zoomorphic ones [22, 51], and these expectations are also reflected in the functions that particular social robots are intended to perform.

Humanoid robots are designed to act in the place of actual humans, and may fulfil roles such as customer service representatives, tour guides, or playmates [93]. Interactions between humans and humanoid social robots are linguistic, relational, and normative: humanoid robots communicate with humans in familiar language using relational pronouns (e.g., "Can I help you with this?") and following social constructs, such as turn-taking [93]. Humanoid robots can also emulate human expressions and emotions via the manipulation of facial features such as eyebrow or mouth movement, however, attempts to create overly realistic humanoid robots can lead to the "uncanny valley" effect whereby the robot is viewed by people as unsettling or creepy [58].

Zoomorphic robots, on the other hand, are less likely to induce the "uncanny valley" effect since people generally have less strict expectations for what an animal or creature must realistically look like [22]. Additionally, people tend to expect the social interaction between a person and zoomorphic robot to be similar to "owner-pet" relationships, companions, or therapy animals [22, 74]. One example of a zoomorphic therapeutic social robot is Paro [96], a robot modelled after a baby seal intended to support older adults with dementia. Compared to the direct nature of communication with humanoid robots, robots like Paro facilitate a subtler form of connection via companionship or comfort, yet they can also offer tactile affordances (such as petting or holding) that may seem awkward in interactions with a humanoid social robot.

Caricatured versus Functional

In addition to anthropomorphic and zoomorphic social robots, Fong et al. [22] also define two additional social robot categories: caricatured and functional. Caricatured social robots make use of unrestrained, potentially unrealistic aesthetic designs to draw attention to or distract from specific robot features, or to imply particular affordances—as such, the Haptic Creature [74], while also zoomorphic in nature, could be considered a caricature given its abstract design that incorporates animal-like elements such as fur, ears, a tail, and breathing motion, but does not attempt to realistically replicate any particular animal, such as the Sony aibo dog [2]. This more unrestrained approach to design can often be more effective, as users are likely more willing to ignore imperfections in a caricatured robot compared to a more realistic one [22].

Finally, while most social robots have some kind of functional purpose, the physical attributes of robots belonging to the functional category are specifically designed to accommodate the tasks the robot must perform. For example, the social robot Huggable was designed to specifically provide socio-emotional support to children in pediatric care who are often nervous or intimidated when in the hospital, and thus takes on a toy-like teddy bear form that is familiar, would appeal to children, and could be used in a hospital setting [39]. Similarly, robots designed for autism therapy must take specific design considerations into account, such as being visually engaging so that the child does not lose focus, but not too bright or colourful lest the robot becomes over-stimulating [12].

Telepresence

Regardless of their design, social robots can take the form of artificial agents or be controlled by and serve as a mediator for a real person in a remote social interaction. Telepresence robots are perhaps the most common example, with communication between the remote participant primarily facilitated by screen-based audiovisual interaction. In light of the COVID-19 pandemic and subsequent shift to online or hybrid activities, telepresence robots have been increasingly used in hospitals and nursing homes to allow remote visitors to visit patients, in high school and university remote graduation ceremonies, or in place of customer service workers at locations such as hotels [6]. Many telepresence robots also allow the remote participant to pilot the robot throughout a physical space, of which several examples can be found in the review by Kristoffersson et al. [47].

There has also been research into incorporating social touch in telepresence robots, such as the tactile telepresence system for conveying touch patterns on the foreheads of isolated hospital patients developed by Mostofa et al. [62] or the remote handshake system developed by Nakanishi et al. [63]. However, this remote touch is most beneficial when both participants can experience it [63], and such a setup may not be practically feasible in many cases since remote participants may not have the resources to acquire robots for themselves at home. Several devices have also been created specifically to communicate with others via haptic touch, including vibrotactile objects, smartphone-based systems, or wearables like a haptic vest [28].

However, most of these touch based systems are designed for dyadic interactions, and cannot easily support group communication. Researchers have recognized the importance of freeing HRI from dyadic interactions, particularly in the context of social interactions [34], and while there has been some past work into group communication in both the spaces of mediated social touch technology and social robots, this research tends to focus on either communicating the same message to several people at once [30], or facilitating a single human operator's control over several social robots simultaneously [26]. Social robots that specifically support and enable the dynamics of connection between a friend group have not yet been explored.

2.4 Swarm Robots

Swarm robots apply the principles of swarm intelligence to accomplish tasks: they must necessarily coordinate together, unlike multi-robot systems which can consist of independent individuals, and typically rely on distributed algorithms and local communication between robots to do so [57, 89]. An important property of swarm robots is scalability—a swarm robot system should either consist of many individual robots, or easily support the inclusion of additional robots into existing behaviours [64]. There has been extensive research on swarm robot behaviours, control, and task-based applications using several different swarm robot platforms [8, 57, 86], including both commercial and custom-made robots [64].

2.4.1 Swarm Robot Behaviours and Control

There are several standard swarm robot behaviours and swarm control methods in existing literature, typically inspired by biological swarms such as ants, bees, or birds [57]. Both Brambilla et al. [8] and Schranz et al. [72] organize swarm behaviours into five main categories: spatial organization (e.g., aggregation, pattern formation), navigation (e.g., collective exploration, coordinated motion), decision making (e.g., consensus, task allocation), and miscellaneous (e.g., self-healing, human-swarm interaction). As another example, Trianni and Campo [86] discuss fundamental swarm robot behaviours designed to address specific swarm challenges, including aggregation, synchronization, coordinated motion, collective exploration, and collective decision making.

The way that robots distribute control and communicate among themselves may also influence the success of an overall swarm behaviour [41]. Typical communication strategies include implicit/indirect and explicit/direct, where robots either communicate through their environment or send messages directly to each other, with implicit communication often providing the system with more robustness [57]. Typical control methods include centralized and distributed control, where either one robot acts as a control unit which makes decisions for the rest of the group, or each individual robot acts autonomously to make decisions on their own [57], although other methods exist as well, such as virtual structure or behaviour based formation control [92].

Notably, different swarm robot behaviours may be perceived differently depending on contextual factors, such as the total number of swarm robots present [67]. Walker et al. [89] found that rendezvous behaviours are easier to recognize given the presence of background noise compared to flocking and dispersion behaviours, and Kim and Follmer [43] found that factors such as behaviour type, speed, and smoothness can influence people's emotional perception of swarm robots, including their level of arousal, dominance, and animacy. Speed was additionally found to influence perceived valence, and smoothness influenced likeability, suggesting that even just varying parameters of the same swarm behaviour can elicit different perceptual responses. Kim and Follmer [45] also found that haptic swarm robot properties, such as the number of robots, frequency, and force amplitude can affect how users perceive robot valence, arousal, and dominance, and a user elicitation study further revealed that participants also utilize visual components and touch locations in order to help them convey specific emotions or simple messages with swarm robots. Overall, these different perceptual reactions suggest that swarm robots can indeed be used in a communicative way, particularly to evoke or convey emotions.

2.4.2 Swarm Robots as Social

Swarm robots provide a natural platform for group interactions. Interestingly, the field of social robotics began with the development and study of swarm robots—rather than focusing on the social interaction between a robot and human, the social aspect of early social robots was focused on the communication between the robots themselves [22]. However, swarm robots today are more commonly designed and used for functional tasks such as collective manipulation, self-assembly, and distributed sensing [54, 69, 91].

Only recently there has been a growing literature on utilizing swarm robots for interaction with people. Instead of isolating swarms to complete functional tasks, researchers have studied their potential to directly interact with users or their environment, such as through swarm user interfaces that react to user input [43, 46, 50, 81], or via AR applications that directly impact the behaviour of physical swarm robots, such as the bi-directional sketching interaction developed by Kaimoto et al. [40].

Swarm robots have also been used to provide haptic feedback in both real life and VR environments. For example, Suzuki et al. [82] investigated how swarm robots could dynamically move furniture to physically support changes in a virtual environment as a kind of room-scale haptic experience, and other work has explored how swarm robots can be used to form proxy objects or changeable virtual surfaces for more tangible interactions in VR [83, 95]. Swarm robots also have the potential to convey emotions via haptic feedback [44] or texture [71], and could utilize this potential to support mediated social touch.

However, while there is some work explicitly studying how swarm robots can support interactions between people, such as Siu et al.'s work on tangible collaboration [75] or Li et al.'s work on mini telepresence robots to give remote audience members embodied agency during physical skill demonstrations [53], these interactions are typically dyadic or strictly one-to-many, as in the latter example where the focus is on audience member to facilitator interaction rather than group interaction as a whole. None to our knowledge have explored and implemented the idea of using swarm robots to facilitate embodied interaction among many people in a social group context.

Chapter 3

Grounding Theory and Exploratory Workshops

In our preliminary research regarding the use of swarm robots as a means of communication and connection among friends, we set out to a) ground our initial ideas in relevant cross-cutting literature and b) explore the potential of swarm robots to facilitate embodied social connection by collecting formative data from our target user group through participatory design workshops. In general, we took this participatory design approach so that we could better understand exactly what they wanted ESSbots to be and how we should design it: that is, it should be engaging, accessible, and allow teenagers to communicate and connect with each other in the ways that they want. Additionally, by directly engaging with our target users at this early stage, we could also build the foundations for how to structure our main workshop series and identify particularly interesting aspects about ESSbots interaction in our results, which we could further explore in future workshops going forward.

We present an overview of our theoretical framework below, connect it to our articulation of the need for social technology with TMA properties, and discuss initial insights into how teens conceptualize and interact with social swarm robots from our participatory design workshop results, as well as how these results relate to our grounding theory.

3.1 Design Rationale and Theoretical Framing

Given that one of our main goals for designing a TMA-supporting technology such as ESSbots was to better support teens in remote social interactions online, and given that many existing forms of online connection, like social media, have several negative downsides, such as being highly performative and often inauthentic, we wanted to approach the design of this new kind of social connection technology in a robust, careful way. By first grounding our ideas in theories from cognitive science, we aimed to identify what aspects of connected sets of swarm robots could support a genuine sense of connection among remote friends, and ideally build something that naturally supports more positive online interactions, rather than potentially enabling negative ones. Thus, we treated our grounding theory and design rationale as a framework to structure our initial goals for ESSbots and interaction design, which we flexibly expanded on by gathering direct feedback from teens themselves in our participatory design workshops.

3.1.1 Adolescent Friendship Groups, Social Touch, and Design Rationale

Early adolescent friendship plays an important role in childhood development [14, 31], and offline social networks in particular have a positive association with adolescents' mood, self-esteem, and loneliness [90] [1]. The early adolescent brain also undergoes extensive plasticity [16], which is partly facilitated by pubertal hormones [49], meaning that adolescence is a crucial time for the development of brain systems supporting social cognition [23].

Yet, teenagers are increasingly relying upon online networks and social media platforms to connect with their friends. While online social networks can have benefits to adolescents, particularly when they facilitate support-seeking that may not be possible within local social circles, online social networks have also been negatively associated with overall subjective well-being [90]. Online interactions between friends also lack the embodied aspect of co-location, including the dynamic exchange of affective social touch [20], which can help in communicating emo-

[1] This section was primarily written by Amori Mikami and Vasileia Karasavva as part of our theoretical grounding paper, currently in preparation.

tions, shaping social rewards, and establishing secure attachments [13]. Affective touch has been proposed to play an important role in developing the social brain from infancy into the early childhood years [13], and in adults, social touch helps to reduce patterns of neural activation associated with the stress response [15].

Given that many adolescents are turning to social media as a primary communication tool and to get their social needs met [76], we envisioned the design of a new kind of physical social media that can support affective social touch, taking inspiration from both haptic technologies to support mediated social touch [35] and swarm robots [45]. As mentioned in Chapter 1, there is a large potential design space for such an idea, but we chose to initially focus on primarily synchronous interactions between an existing group of remote friends as a starting point for what ESSbots could be.

3.1.2 Affordances of Swarm Robots for Social Connection

As discussed in Chapter 2, swarm robots have several useful properties that can support tactile interactions or help the robots complete functional tasks in a physical environment. Specifically, we identified three main TMA affordances of swarm robots that we believed would be particularly useful for remote social group interactions.

These properties are:

Tangible embodiment: Because of their small size and haptic potential, they afford touch-based and manipulation-based interaction that is richly embodied.

Multiplicity and coordination: Because of their relative affordability and size, it is possible to give people multiples that can be used to operate in unison, or to represent each person in a communication group.

Animacy, agency, identity and role play: Because they are robots, they are animate and can have perceived agency in performing actions, potentially supporting interesting new forms of communication where users can utilize individual robots as proxies for themselves, or engage with the swarm as its own engaging and independent part of the interaction.

We assert that these properties together could lend themselves to supporting key communication and connection needs that are missing or substandard in current social media, including: social touch, sense of group connection/communication, and a sense of co-presence and support even in asynchronous situations. See Table 3.1 for a comparison of ESSbots' TMA properties compared to popular existing social media platforms. Of course, this only scratches the surface of social media properties—for more extensive overviews, see Kietzmann et al. [42] and Zhao et al. [94].

3.1.3 Participatory Sensemaking and Actor Network Theory

To better understand the importance of these properties and how they can be leveraged in our interaction design, we look to the embodied, embedded, and enactive cognition (EEEC) tradition of cognitive science, with a focus on the concept of participatory sensemaking (PSM) introduced by philosopher Hanne De Jaegher and cognitive scientist Ezekiel Di Paulo [2]. The PSM framework provides a context for not only understanding the properties of interactions arising between ESSbots and their users, but for understanding the interactive design process of workshopping the technology as well. We also consider Actor Network Theory (ANT), which emphasizes that agency is distributed between human and non-human actors within networks—in this case, the swarm robots.

According to EEEC, cognition *is* embodied action [85]. Its activity is dependent on the body and it emerges from the coupling of the body with the environment and other bodies, human or non-human. Meaning or sense-making is an emergent property of coupled interactions, and sense-making is intrinsically active and emotionally rich [17]. PSM extends the EEEC approach to social interactions to define an enactive theory of social cognition, and sensemaking is defined as an embodied activity that is a property of the interaction—since the coordinated interaction between agents influences the agent's process of making meaning, it also gives rise to a form of sensemaking that is unavailable to the individual on their own. Sensemaking can occur on a spectrum from individual sensemaking (for example, an individual group member may find an ESSbot gesture funny and then, in response

[2]This section was primarily written by Rebecca Todd, as part of our theoretical grounding paper, currently in preparation.

TMA *Property*	**Theory**	**ESSbots**	**Instagram**	**TikTok**
Tangible Embodiment	Gibson ecological theory [25], PSM [17], Enactive bodily experience [85]	Communicator arranges bots and deploys behaviors that remote others physically interact with.	No physicalization. Communicator interacts with others via static "posts", by taking a photo, composing a caption, sharing the photo to appear in others' feeds, and responding to others' posts with text and emoticons.	No physicalization. Communicator interacts with others via static "posts", creating short videos, adding a caption and tags, sharing videos to appear in others' feeds, and responding to others posts with text and emoticons.
Multiplicity, Coordination	PSM [17],	Communicators can have proxies for themselves that enact proxemics and social dynamics within spatially embodied clusters (simultaneous or sequential) individually or at a group level.	One-to-one mapping of person to action. Post can be shared but originates from one person.	Originates at an individual level, but posts can be layered sequentially by others via duets (new videos will appear together), or stitches (new videos will appear after the original).
Animacy, Agency, Identity, Role play	PSM [17], ANT [48]	Communicators can choreograph swarmbot dynamics that add a sense of animacy to the communication, or bots can have their own level of independent agency and move on their own.	Posts are inanimate (don't move), do not purport to have any life or identity of their own, and do not support interaction.	Posts do not have independent agency, but can be co-opted by others and may take on meaning beyond the intentions of the original creator (e.g., other creators using the audio from one video to tell similar or different stories).

Table 3.1: TMA social media affordances, their theoretical basis, and a comparison of the ESSbot TMA implementation with the closest related affordances of two current social media platforms that are popular with teenagers.

to a hesitation in response from the group, re-interpret it as stupid) to fully joint sensemaking (a shared simultaneous expression of amusement or surprise at an action of the ESSbots). Importantly, as these examples suggest, sensemaking can occur at the level of the group, such that the coordinated activity of the collective gives rise to meaning along the spectrum.

Tangible embodiment: Each TMA property can be viewed through the lens of PSM. For example, given that EEEC views cognition as embodied action, the ESSbot property of tangible embodiment is intrinsically an important aspect of sensemaking. Perception itself can be seen as a form of skill arising from dynamic online sensory engagement with affordances presented by objects in the world [25]. A view of perception as skilled action further highlights the role of touch, with a focus on the importance of the haptic system as an exploratory system [25]. According to the EEEC approach, cognitive agents do not access an objective external world with internal representations; rather, the experienced world is a relational domain enacted by the agent's mode of coupling with the environment. PSM extends this emphasis on embodied engagement to the social realm of other agents.

Multiplicity and coordination: It is also helpful to look at the property of multiplicity and coordination through the lens of PSM. In the case of ESSbots, multiplicity can refer to the human friend groups manipulating the bots or the swarms of bots themselves. PSM highlights the importance of the swarm technology element of ESSbots—that multiple bots can embody individuals within the group or respond as a collective. Beyond emphasizing the importance of embodied individuals "reading" other embodied individuals' expressive actions [17], participatory sensemaking takes the interaction process itself as its focus. It draws on dynamic systems approaches to characterize the dynamics of everyday interactive encounters of all kinds, and emphasizes their importance in the co-creation of meaning. As such, there is emphasis on dynamic processes of *coordination or coupling* between two systems, which may rise and fall over time, and are shaped by the history of the coordinated agents. For example, the shared interpretation of a moment of coordination amongst a teen friend group may be entirely based on an in-joke or other shared frame of reference. Other examples of coordination include synchronization (as when two people "fall into step" while walking) as well as mirroring, anticipation, and imitation of each other. Importantly, coordination does not describe a single individual's intentional action but a property of the interaction itself, which in turn entrains the actors, who can maintain, shift, or leave the coordinated interaction.

Animacy, agency, identity, and roleplay: Conceptually, ESSbots are not just passive objects to be manipulated; their animated movements and user interactivity can be designed such that users perceive them as having agency. They can range from moving in response to direct choreography to seeming to have a 'life of their own', allowing identity play, roleplay, and new forms of social connection with these bots as additional actors. Here we can extend the theoretical framing of participatory sensemaking to include the idea of the ESSbots as active participants in coordinated interactions by drawing Actor Network Theory's proposal that non-human agents participate in social networks [48]. ANT's primary claim that *"... it is utterly impossible to understand what holds society together without injecting into its fabric the... artefacts designed by engineers" [48] (p.70).* reflects how even passive objects, like the swarm robots, can allow or restrict human activity [48]. Beyond this, the ESSbots have active agency that can manifest itself in a range of forms, or individual users can impose their own identities on them through interaction. By expanding the notion of who or what participates in sensemaking, we open the door to an enriched and expanded world of sensemaking that includes the technology as well as the human users as active participants.

3.2 Exploratory Workshop Methods and Analysis

Based on the theoretical framework discussed above, we wanted to explore our initial idea for ESSbots with teenagers directly. We therefore conducted two exploratory workshops centered around an existing set of swarm robots, providing participants with a thought object as they conceptualized what swarm based communication might look like. We describe the swarm robot platform we used, the overall workshop approach and protocol outlining the activities we engaged in with participants, as well as our data analysis approach and results.

3.2.1 Initial Swarmbot Platform

We decided to use Zooid robots in our workshops (see Figure 3.1), due to their accessibility as an open-source and open-hardware platform developed by Le Goc et al. [50] as a tabletop swarm user interface. Each robot is contained in a small, lightweight, cylindrical plastic shell, with wheels on the bottom to allow for motion across flat surfaces. The robots can move forwards and backwards up to 74 cm/s, and can coordinate to produce complex movements via position tracking from an overhead projector [43]. Each robot also has a touch sensor and colour LED, allowing for both direct physical manipulation and additional visual feedback [50]. The robots can also be used to interact with other objects, such as to push a phone across a desk towards the user. Additionally, Zooids can be used as a haptic user interface, and can provide either normal or shear force feedback by moving against the user's skin [45].

3.2.2 Workshop Goals and Overview

For our workshops, we focused primarily on the *Zooids'* properties of tactility, multiplicity, and animacy. We were particularly interested in whether teens could make legible, communicative acts or gestures with the swarm robots, and how they made use of the robots' three primary TMA properties to communicate gestures to each other. We were also interested in how teens would situate swarm robots as a possible means of communication and connection in contrast to social media platforms that they currently use. Therefore, we structured the workshops around a series of activities meant to introduce participants to the concept of using swarm robots for remote communication, then explore with them how they might use the affordances of robots, such as motion and touch, to convey expressive messages to one another. We also investigated how they felt about communicating this way through a series of discussion questions, and explored how they might customize and personalize their robots through an interactive crafting activity (see Table 3.2 for a brief summary of activities, which are further outlined in the following section).

In total, we conducted two workshops with teenagers between the ages of 11 and 15. Each workshop was 3 hrs long, and participants were compensated for

Figure 3.1: Photo of several Zooid robots bumping against a person's arm, reproduced from [44] with permission.

their time with a $30 Amazon gift card. The first workshop included 7 participants (2 boys; 3 girls; 2 chose to not disclose). The second workshop consisted of 3 participants (1 boy; 1 girl; 1 chose to not disclose). All participants were recruited at the same time, and were split into the two aforementioned workshops to best accommodated their schedules. Since the second workshop had a smaller number of participants, any planned breakout group activities were instead conducted with the entire group. All participants were recruited via advertisements on social media,

Activity	Description
Pre-Workshop Survey	Online survey prior to workshops to collect demographic information, and information on how participants use social media
Introduction and Demo	Introduced facilitators and participants, and showed them a short live demo of Zooid robot movements
Behaviour Creation with Proxies	Participants split into groups of 3-4, and used wooden robot proxies to come up with and demonstrate behaviours to communicate simple words and phrases. They then shared examples with other participants, who tried to guess what was being communicated
Mediated Touch Demo	Participants were shown videos demonstrating the robots' haptic capabilities, and were shown a live, interactive demo of force feedback with the robots
Behaviour Creation with Proxies: Touch Focused	Participants repeated the behaviour creation activity with proxies, but were encouraged specifically to focus on incorporating touch. They then shared examples with other participants, who tried to guess what was being communicated
Discussion Questions	We asked participants discussion questions about their experiences with the robots, the behaviours they came up with, and how they might use them with friends
Crafting Activity	We gave participants crafting materials like paper, markers, and stickers, and had them decorate the wooden robot proxies

Table 3.2: Summary of activities in the exploratory workshops.

and the study was approved by the university's Research Ethics Board-B (certificate number H22-01554). Before the beginning of the workshop, the guardians of the participants were asked to read and sign a consent form in order to give permission for their children to participate in the workshop. Additionally, participants themselves read and agreed to an assent form prior to their participation, which described the goals of our research and details of the workshop activities.

3.2.3 Workshop Protocol

To begin, participants were directed to individual computers where they read and completed the assent form as well as a survey assessing their social media use and their relationship with each of the participants. Once participants completed the surveys, we introduced them to each other and the workshop facilitators. Next, we discussed the goals of the workshop and our expectations for group discussions, as inspired by the Council method [37], to foster respectful, open communication in the workshop.

We then ran a short demo to familiarize participants with the swarm robots. First, we passed a single Zooid around the room for participants to examine and then piloted the robot to showcase how it moves. Next, several robots were piloted together to help participants visualize the swarm's collective ability to synchronize and coordinate actions. We also asked participants some follow-up discussion questions to gain an understanding of their first impressions of the robots and how they thought they might be able to communicate with them.

Once participants were familiar with the robots' affordances, we split them into smaller breakout groups (N1 = 3 and N2 = 4) in the larger workshop, although we kept participants together in the smaller workshop with only three people. The groups were given a set of six wooden cylinders of approximately the same size as the bots, and each group was asked to use the cylinders to communicate emotions or short messages. The groups drew two words at random, and each group member took turns using the wooden robot proxies to emulate how an ESSbot could communicate the given message to their friends. The groups then repeated the activity with longer phrases rather than abstract emotions. Finally, each group was given a set of stickers and was instructed to use it to mark one of the casings as their own representative robot. With this new framing in mind, the groups repeated the same two communication activities with the same set of messages they had already randomly selected.

Since the robot swarms are indented to support non-co-located friend groups, we also wanted to get a sense of how well these messages could be understood by other people. We therefore had all participants come back together and use the robot shells to share some of the messages they created with the other groups (or in the smaller workshop, with other participants). After a message was demonstrated with a set of robot shells, participants from the other groups guessed what was being communicated with the robots. Each group shared two abstract emotions and one longer phrase.

To address the aspect of swarm tactility, we had participants watch a video demonstrating the haptic capabilities of the robots. We also demonstrated a single robot's movement again, this time emphasizing that it can touch people directly, or people can interrupt its motion by touching or holding the robot. Afterwards, we split participants into new breakout groups and had them complete the same series of communication activities with the robot proxies; this time with a focus on using the proxies to communicate messages via touch. As with the first breakout activity, we had participants share some of the messages they created with everyone, and non-group members were asked to guess what was being communicated.

Next, we asked the group various discussion questions about their experiences with the robots and the messages they created, including what aspects of the robots were their favourite, how they might use the robots with people they know, how that might differ from communicating with them in another way, and how swarm robot communication might compare with the ways they currently use social media.

Finally, we had participants complete a crafting activity where they personalized their wooden robot proxies with craft materials such as markers, pipe-cleaners, construction paper, and tape. We then asked them questions as to how aesthetics and robot personalization might affect how they would use the robots to communicate with friends. We also sent participants a follow-up survey the day after the workshop, in which we asked whether they had any other thoughts about the robots or any further design ideas or qualities they would like the robots to have.

3.2.4 Exploratory Workshop Data Analysis

We were primarily interested in how participants felt about the idea of ESSbots, and how they might actually use the robots in communicative ways with their friends. Thus, we analyzed both qualitative responses from our discussion questions to gain insight into how participants felt about swarmbot communication, as well as analyzing videos of how participants interacted with the robot proxies to express simple emotions and phrases to each other.

Three members of the research team collaborated to transcribe the data from videos recorded during the workshops. Once transcripts were generated and cleaned, the analysis team divided the data into sections. The team inductively coded one

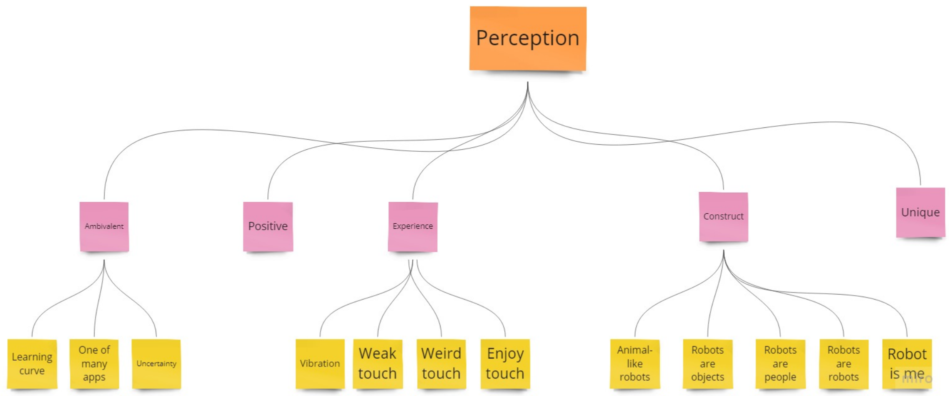


Figure 3.2: Example of code organization for the Perception codes in the exploratory workshop data analysis.

section of the data collaboratively to aid in the process of developing an initial coding framework. Once this framework was agreed upon, each team member individually coded a section of the remaining data. The analysis team then met again to discuss each code, finalized the coding framework, and re-coded their subsection of data as needed. Conflicting codes were collaboratively settled in a way that all analysis team members agreed upon, and the final set of codes were organized into a hierarchical structure according to similar categories (see Figure 3.2 for an example). However, given that the purpose of these initial pilot workshops was to assess the feasibility of the workshop format to explore the ESSbots concept, and given the small number of workshop participants, we decided not to generate themes or conduct a more robust analysis of the data beyond this categorical organization. Instead, we report summarized results from the finalized set of codes directly, as we believe they serve as sufficient initial guidance for further iteration on the concept and design of emotionally supportive swarm robots going forward. We also report summary statistics on participant characteristics and the ways they use social media below.

3.2.5 Social Media Use and Participant Characteristics

Since the goal of our workshops was to explore the initial idea for ESSbots and how teens might use it as a new kind of remote communication technology, especially in contrast to existing forms of social media, we wanted to contextualize how participants currently interact with social media in our pre-workshop survey. We found that 70% of participants used TikTok and Instagram daily, although other platforms were also popular: 50% of participants reported they use Snapchat every day, while 20% used Facebook, and 10% used Discord and Reddit. When asked how they communicate with their friends, most of the participants (90%) reported they do so in person. Among digital interactions, direct messages on social media (70%), and instant messaging or texting apps (60%) were the most popular. Finally, 50% of participants reported they often talk to their friends on the phone.

We were also interested in participant characteristics that might influence their comfort level with the robots, such as being more of a "STEM" person. Thus, participants were also asked about whether or not they saw themselves as a math or science person, with 40% reporting they definitely do, 10% they definitely don't, and 50% falling somewhere in the middle. Additionally, when asked about whether or not they consider themselves as more of a leader or a follower in their friend group, 20% reported they see themselves at least somewhat like a leader, 10% like a follower, and the rest (70%) as a bit of both.

Finally, we wanted to identify the existing relationships between participants in our workshop, providing them both the IOS scale to indicate visually how close they felt to other people both before and after the workshop, as well as asking them directly what their relationship was to other participants prior to the workshops. Most participants didn't know each other beforehand, although there was one group of three siblings and one pair of friends. After completing the workshop, almost all participants increased their IOS scale rating, with four raising their score by two points, four raising their score by one point, one keeping their score the same, and one lowering their score by one point. Notably, the latter two participants were part of the sibling group. Thus, overall, most of the participants felt closer to each other following the workshops.

3.3 Exploratory Workshop Results

We describe the qualitative results from our exploratory workshops below before linking our findings directly to our initial grounding theory in the following discussion section.

3.3.1 Appearance and Features

Participants described aspects of the robots they liked, as well as things they would like to change or improve.

Desirable features:

For the most part, participants reported they liked both the physical features and appearance of the robots as well as their capabilities. For example, participants frequently mentioned the robots' LED lights as one of their favourite features, and they expressed that manipulating the colour of the light could help communicate an emotion's valence and intensity. Participants viewed the tangibility and versatility of the robots positively—they found that the small individual robots were easy to move and manipulate, yet several robots could act in coordination to support more complex movements, complete tasks, or interact with the environment by moving objects. However, some noted as a negative the fact that the robots are highly dependent on their wheels and could get stuck, fall over, or get caught on some surfaces.

Participants also highlighted the importance of the aesthetic look of the robots and their ability to customize them to reflect their own style: "*I might make one of the robots look like me or my aesthetic or design, and make a few of them so those are kind of like mine, and then make a few others that look like my other friends*" (P8), as a way of adding additional layers of communication: "*It could have flags, like decorations, and it has many sides, they're like, showing you a question*" (P6), or as a way to indicate which one of their friends is currently "speaking" through the robots: "*[To show who's talking] you could tape someone's face onto it*" (P7). These ideas also materialized during the crafting activity when one participant customized a casing to depict various emojis (see Figure 3.3), whereas others created more abstract, colourful designs.

Feature improvements:

We also encouraged participants to think about and discuss potential changes they would like to see on the robots. Some participants described how they would add external physical features to the robots, including a screen and accessories, like a flat board with written letters that the robots could move on top of. In addition, participants noted that they would like to have the option to have a greater number of robots at hand to accomplish more complex tasks, since we only had access to two Zooid robots for our live demos. There was also a diversity of opinions among participants about how the casing material should feel to the touch, with some favoring a softer material and others a firmer casing material. In the end, participants agreed that they would appreciate the ability to change the casing according to their own preferences.

Additionally, participants discussed potential movements in the physical space they would like to see the robots perform, but that the hardware did not support at the time of the workshops, such as flipping over, jumping, or stacking on top of each other. Participants described that they would prefer stronger force feedback when the robots touched them as well, and mentioned that they would appreciate the robots having the ability to vibrate or emit sounds. The importance of adding a feature to shut off the robots so that their friends would not be able to move them remotely was also discussed. For example, participants mentioned how it would be distracting to have a friend remotely move a robot when they were trying to do some work or go to sleep.

3.3.2 Communication and Usage

Participants described the different ways they would use the robots to communicate with friends, as well as the potential challenges of communicating with swarm robots.

Who and how to communicate with swarmbots:

Most participants said they would use the robots to communicate with friends, while others believed they would use them to communicate with anyone, not only friends. Two participants also mentioned they could see the robots being used as an accessibility aid—P1 suggested using the robots to talk with someone who couldn't read, and P2 suggested using the robots to communicate with deaf people. Some participants also acknowledged that who the robots represented would change the way they responded to them. For example, they may be more willing to pay attention to the robots or send playful messages back knowing the robots represented

Figure 3.3: Decorated robot proxies from the crafting activity in workshop 2.

close friends.

Additionally, the robots being tangible and in their friends' physical space was seen as a positive, as they expressed that it would make it harder for their remote friends to ignore or not notice the notification. In the same line of thinking, some participants mentioned they could see themselves using the robots to only initiate a conversation with a friend and then move the conversation to a more traditional text-based modality. Participants also described using the robots for pranks, games, or completing tasks and manipulating their own local environment (for instance, to push objects around a table).

In general however, participants described using the robots to communicate emotions or act as a notification system, acknowledging that doing so would be easier than trying to share specific phrases or complex messages. Additionally, some pointed out that the robots could be better equipped to facilitate closeness and convey emotions more clearly than other remote communication modalities, especially text-based mediums. For example, P8 said: "*I might use like texting or whatnot to convey like, direct information, but use these to incorporate, you know, that feeling of touch, or you know, that more closeness or intimate feeling*". This attitude of viewing the robots as a means to express emotions was also observed during the behaviour guessing activity when participants tended to make guesses about *emotions* rather than *specific phrases*. When the demonstrated behaviour involved direct touch, participants tended to make more guesses that involved relational phrases or evoked feelings of closeness and social group dynamics, such as "I'm here for you", "I'm happy for you" etc.

Participants also described using the robots to try and evoke a particular emotion in others, as opposed to simply expressing an emotion themselves. Evocation was typically tied to symbolic meaning—for example, when trying to come up with a behaviour for the phrase "that's not okay", one participant suggested the robots could turn slowly while moving along the person's hand, "*like tears falling*" (P1). Another participant described making the robots react negatively when interacting with another person by backing away and hiding behind the other robots, "*like they're protecting it [from them]*" (P6), in order to communicate the idea of fear. In sum, participants appeared to conclude that the context they would use various features and abilities of robots matters. They conceded that certain features may be best suited for specific communication tasks; for example incorporating touch for relational messages and using coloured lights to underline the emotional valence.

Handling miscommunication:

Participants also recognized the possibility of misunderstandings and miscommunications arising when using the robots to communicate with their remote friends, especially when trying to convey messages that are longer or more complex. P3 described a situation where a thumbs-up symbol could be misinterpreted as a thumbs-down if their friend viewed it from a different angle, which could make them sad, and P9 noted that "*[misinterpretations] would not be okay because I don't want my friends to think I'm mad at them*". Some participants also felt that communicating messages through touch could be difficult, especially for more abstract messages, but in other cases touch would work quite well: "*I feel like touch would communicate messages like 'I'm here for you' or like 'I'm mad at you'... instead of just* *telling them what you're feeling... like you have to use a lot of symbolism in there*" (P7).

At the same time, participants acknowledged that being aware of this potential for miscommunication might make users more considerate and careful when sending their own messages. Additionally, participants easily came up with several strategies to avoid miscommunication, including using the robots to communicate shorter messages or expressing emotions instead of long and complex phrases, pre-defining what particular robot behaviours meant with their remote friends beforehand, and adding layers of meaning to clarify the valence of messages, such as coloured lights. Some also suggested taking a more literal approach when sending a message, like using Morse code through the LED lights, arranging the robots into binary strings or the shapes of letters, or using an external letter board that the robots could move on top of to circumvent the issue of potential miscommunication.

3.3.3 Perception

We describe both how participants directly responded to the robots, as well as the more indirect, subtle conceptual ways they described the robots throughout the workshop series.

Overall perception: Across the board, participants viewed the robots positively, describing them as fun, cute, or unique. They also enjoyed holding and touching the robots, although they tended to want the robots to have stronger force feedback to increase noticeability when the robots bumped up against their hands or arms. At the same time, some participants expressed some uncertainty over what the robots could do (particularly at the start of the workshop), as well as a worry that there could be a steep learning curve for new users and that the robots would quickly become just another app in an already overloaded space of existing communication platforms.

Conceptual constructs for swarmbots: In general, the participants' view of the robots varied in five conceptual ways: *robots are animal-like*, *robots are people*, *robots are me*, *robots are objects*, and *robots are robots*. The way participants' viewed the robots did not remain consistent across different contexts. For example, almost all participants described the robots at some point as having animal-like qualities, with this type of observation being more prevalent in tasks that incorporated touch in some way. For instance, P6 described their experience of touching the robot as "*it felt like you had a tiny animal inside your hand*", P1 as "*like a hamster, kind of*", and P4 as "*probably what it would feel like if like a couple [of] ants tried to push against your arm*".

Several participants also described the robots as a means of representing a person; either themselves or someone else. This conceptualization was more common not only when participants were explicitly instructed to think of the robots as representing their friends (i.e., during the behaviour creation activities), but also when they were asked to interpret behaviours created by others, or when they wanted to make it clear who was communicating a particular message. For example, P7 said it was sometimes easier to come up with messages when they had labelled a robot with a sticker to represent them, because "*it shows your emotions, right? [But] a group of them might mean something else*", and P10 described one behaviour they created as "*first the other person's robot [would flash yellow], and then mine [would move] around it*", indicating they clearly viewed the robot as belonging to them or to their friends.

Finally, some participants appeared to view the robots as objects or simply as robots, especially when coming up with potential robot behaviours. P3 was particularly interested in the hardware and possibility of programming the robots themselves, and frequently suggested behaviour ideas like using binary or Morse code to communicate literal messages with them. The perspective that the robots were like objects also came up in relation to behaviour interpretation or aesthetic appearance. For example, P2 mentioned that one robot behaviour (several robots spinning together) was like a Gatling gun, P3 mentioned the robots themselves looked like tank turrets, and P9 said that the robots looked like candles.

3.3.4 Behaviours

We analyzed and grouped the most common components that made up the behaviours participants came up with using robot proxies in order to communicate emotions and simple phrases to their friends (for a complete list, see Table 3.3), and found that participants typically utilized several features and abilities of the robots when creating these behaviours. For example, when asked to use the robots to express surprise, P5 said that they would have all the robots cluster together and form a circle with one robot in the center, and then all but the center robot would suddenly move away and touch their communication partner. This behaviour incorporates movement (robots move to a static position), speed (robots suddenly move away into a new position), touch (robots touch their communication partner), coordination (several robots move to different positions at the same time), and individual action (one robot behaves differently from the others by remaining in the middle of the circle).

Furthermore, participants often combined different components of behaviours together to add clarity, valence, and context to their messages. For instance, P8 described how basic robot actions could correspond to specific ideas or meanings that could then be combined into a more complex message: "*If I said like, flash blue, like you know blue usually can represent sadness. So that would be like a basic thing, and then when we move [the robot] away, that's another basic symbol [that] means like, I want to be left alone*".

Finally, participants proposed some types of behaviours more often than others. For example, despite guiding participants to incorporate certain elements into the behaviour creation activities, such as adding stickers to think of one robot as belonging to them, or adding an element of touch into their behaviours, sometimes they did not follow these instructions. Instead, they created behaviours that were more familiar to them, such as arranging the robots into a static symbol. While this may simply be a matter of forgetting to follow the instructions or thinking of ideas beyond the activity itself, using the robots to form emojis or other symbols was one of the most frequently suggested ideas by participants overall. Therefore, there may be certain types of behaviours that are particularly salient which participants turn to when they want to easily or clearly communicate something, such as using static symbols or adding coloured lights to express emotion.

Primary Action/Parameter	Primary Sub-Action/Parameter	Secondary Sub-Action/Parameter
Position in environment		
Speed		
Sound		
Vibration		
Lights	Colour Constant Flashing Intensity No lights	
Movement	Back and forth Continuous movement Move to static position Spin	
Swarm	Contact between robots Coordination Individual action Reaction Symbol	
Touch	Action	Spin Stroke Tap
	Location	Arm Back Face Hand Under
	Quality	Continuous contact Erratic Strong force

Table 3.3: Components of robot behaviours described by participants in the exploratory workshops.

3.4 Discussion

As discussed in §3.1, the three main TMA properties of ESSbots (tangible embodiment, multiplicity and coordination, and animacy, agency, identification and role-play) can be viewed through the lens of participatory sensemaking. Through the behaviour creation activities in our exploratory workshops, participants engaged in their own kind of participatory sensemaking as they worked together to create expressive ways to communicate with swarm robots. The results from these hands-on activities and workshop discussion questions illuminate the ways that sensemaking evolves as teenagers perceive the robots and how the interaction process itself affects this perception in a manner that unfolds over time. In particular, we note that the three TMA properties of ESSbots support a unique interaction process and sensemaking compared to other forms of social interaction, which is illustrated in the ways that participants conceptualize and react to the robots. Thus, we further discuss participant reactions to the current set of swarm robots, as well as other important insights from the workshops related to our overall motivation, such as the importance of social touch for adolescent development and the ways ESSbots could support a conceptual reframing of remote social interaction.

3.4.1 Perception of Zooids as Communicative Swarm Robots

We first reflect on how the three TMA properties of ESSbots may have influenced the way participants perceived and reacted to the swarm robots in our workshops, as well as how their reactions reflect our grounding theories.

Tangible embodiment: Overall, participants were receptive to the idea of using swarm robots as a new way to connect and communicate with remote friends. In particular, the property of tangible embodiment played an important role in how participants perceived the robots as a communicative platform. For example, they enjoyed the tangibility, size, and versatility of the swarm robots we used in our workshops, and believed the robots would be particularly useful to share emotions with their friends. They also mentioned other forms of social interactions they might engage in through the robots, such as playing pranks or games together, and noted that the robots' tangible presence in their physical space could provide other benefits, including attention-getting through physical movement, and increased feelings of closeness.

However, while participants generally reacted positively to the current feature set, it is important to note that the *Zooid* swarm robots we used in our workshops are not necessarily the final hardware goal for what ESSbots should be. Zooids are limited to motion on flat surfaces, and lack features such as vibrotactile feedback, sound, and vertical motion, all three of which participants mentioned as desirable. Yet the lack of these and other features does not mean that Zooids cannot be used in a communicative way, or that the final version of ESSbots must incorporate additional features to be successful. Instead, we must assess whether the existing feature set allows participants to communicate with the robots in a embodied and expressive way, and whether adding additional features either fulfills or detracts from this goal. For example, one participant suggested adding a screen on top of the Zooids, which could potentially be used to show emojis or even text messages. However, it is possible that users may rely too heavily on the screen for communication, thus minimizing the important interaction of embodied and tangible communication. Thus, a final feature set that does not include a screen may be more aligned with the overall sensemaking and interaction style we want ESSbots to support.

Multiplicity and coordination:

Participants also appreciated that several small robots could be used in coordination to support more complex tasks, and many of the communicative behaviours they created often incorporated elements of swarmness and coordination to convey messages. Notably, rather than always desiring additional features to make communication clearer, participants also came up with their own ways of increasing message clarity by working within the boundaries of the current feature set. These strategies included layering different types of behaviours together, pre-defining what particular behaviours mean with their friends, utilizing the multiplicity of swarm robots to provide further context for individual robot actions, or simply sending messages that participants believed lent themselves well to swarm robot communication, such as emotions.

This willingness by teen participants to experiment with and adapt swarm robot behaviours suggests that the current robot feature set is expressive and communicative to at least some degree. Further, while participants were not always able to precisely guess what another person was trying to communicate with a specific behaviour, they were often very close to the general emotional aspects underlying a given message, such as by guessing “happiness” for the more specific feeling of “amazement”; in fact, perfectly clear and robust communication need not be the goal of communicating with ESSbots at all. Thus, while future work is needed to understand whether the given set of features is sufficient for emotional expression, these proof-of-concept workshops do reveal that teenagers are willing to engage with the current set of swarm robots as a form of thoughtful embodied communication.

Animacy, agency, identity, and roleplay: Given that individuals also conceptualize the robots differently in different situations, such as by viewing them more as objects or as animal-like, it is also worth noting that the robots themselves may play a role in interpretive meaning. Indeed, if we view the robots through the Actor Network Theory framework as being their own participants within the group social network, sometimes they act more as facilitators for human expression and other times they act as nearly independent agents of their own, and their particular role can have a strong effect on the overall meaning of a shared message. For example, when the robots are viewed as more animal-like, messages may take on additional layers of meaning that would not be present if the robots were perceived more as objects. When P6 modelled a behaviour for fear as one robot hiding behind the others, there is an implied level of agency and independence for the robots in this situation. In this case, the overall message of “fear” may not make sense if another person viewed the robots simply as objects moving into a pattern on the table; the robots’ implied agency plays an important role in the semantic meaning of P6’s message. Thus, the ways in which individuals react to not only the semantic meaning of messages but to the influence of the robots themselves on those messages, how new behaviours are created via the robots, and how that effects an individual’s conceptualization of the swarm and their reaction to a given message as a whole is also worth exploring in future work.

Participatory sensemaking: Finally, much like how friend groups develop their own unique communicative dynamics such as “in jokes” in person, it is possible that the way that remote groups communicate using the robots can evolve over time as individual group members influence the way messages are sent and are interpreted by the rest of their friend group. For example, two different friend groups might employ a similar strategy of layered, pre-defined robot behaviour components in order to send more complex messages to each other, yet each group may define those pieces and combine them together differently. On the other hand, a different friend group might use a different strategy entirely, where the accuracy of communication is de-emphasized in favour of an evolving and abstract interpretation of swarm robot gestures. Even within the limited context of the workshops themselves, this in-group specific communication can be seen through consistently similar approaches of robot communication among the sibling group, who frequently suggested using the robots as a means of pranking their friends and often suggested literal communication strategies like Morse code noticeably more often than the rest of the participants.

3.4.2 Social Touch and Swarm Robots

The physical, tangible nature of Zooids allowed us to explore how affiliative social touch might be used by teens in order to communicate messages to each other with swarm robots, and we were particularly interested in how participants reacted to this property of the robots. In general, participants described their experience of touching the robots positively, often comparing it to holding a small animal. They believed that while it would be difficult to send long or complex messages using touch alone, touch-based communication could be particularly beneficial in order to get their friends' attention or to create a stronger feeling of closeness and intimacy. Some participants also described using touch as a way to facilitate physical emotional support, such as using the robots as a proxy for a "small hug" (P7), or as a way to provide comfort when they aren't there in person (P10).

However, one participant described the experience of the robot touching them as "weird", though they elaborated that it was not a positive or negative experience per se. This kind of reaction is significant in the sense that touch based communication may not always be wanted by everyone. Openness to touch is highly context-dependent [70], and some people may be more or less comfortable with social touch in-person, let alone when it is mediated through technology. Since we did not ask participants how they currently perceive affiliative touch in their own social circles, or how they believe mediated touch through ESSbots would differ from that, the intricacies of how ESSbots might support social touch needs further study, especially since young people may not be naturally conscious of the role social touch plays in their day-to-day interactions with friends and others.

Additionally, while our results do indicate participants are open to using the robots to convey and receive positive and comforting social touch, it is unclear how often participants would actually utilize these features in practice. Given the frequency with which participants created familiar robot behaviours, such as emoji-like symbols or explicitly tying coloured light to different emotions, it is possible that more abstract forms of communication such as touch-based gestures would be used infrequently over time. However, our participants falling back on familiar communicative methods is not unexpected, and can also be attributed to the legacy bias that frequently occurs in gesture elicitation studies [46, 60].

Therefore, the more unique affordances of swarm robot communication, like mediated social touch, might be used more often over time as friend groups experiment with the robots together, or it may appear more frequently in particular situations, such as providing comfort or when a friend is highly stressed. While we further explored how participants felt about using the robots as a form of mediated social touch in our main workshop series, which we discuss in Chapter 6, we note that future work on emotionally supportive swarm robots may benefit from a longitudinal approach in order to understand the role of mediated affiliative touch within a friend group over time.

3.4.3 Conceptual Reframing of Social Interaction

We hypothesized that adding elements of physicality that might normally be present in in-person social interactions to remote communication could help reduce the focus on some of the more performative elements of social media, instead placing emphasis on genuine connection and affective communication. The results from our workshops show support for this idea. For example, some participants explicitly compared swarm robot communication with existing remote communication technology, describing the former as more expressive and easier to show emotional connection than the latter. In general, participants frequently mentioned using the robots to communicate emotions and evoke emotional responses in others, and they believed that touch in particular could create increased feelings of closeness with their friends. Participants found that swarm robot communication worked best for these highly emotional contexts, which stands in contrast to existing communication technology that often works well to convey specific direct messages, but can fall flat in terms of emotional expression or feelings co-presence.

It is also important to note that participants believed ESSbots would serve more as a secondary and supportive addition to existing communication platforms—that is, ESSbots would not replace other ways they communicate with each other remotely. Given that the strength of swarm robot communication is emotional connection and communication, it makes sense that teens would continue to use a more robust form of direct communication (such as text messages) for general situations, and rely on ESSbots when they wanted to show additional emotional support for their friends or when they wanted to connect more tangibly with each other, such as by playing pranks or games using the robots.

3.4.4 Workshop Takeaways

Overall, the *Zooids'* set of swarm robot features supported workshop participants in crafting thoughtful, emotional communications with each other. Participants were open to the idea of swarm robot communication, and came up with several strategies to communicate understandable messages. They seemed interested in the robots, and many were open to the more technical aspects of using robots to communicate, such as programming robot behaviours themselves. Yet, the ways that individuals perceive and interact with swarm robots is often unique, suggesting that ESSbots have the potential to be more than just one conceptual thing, either within an individual friend group as the roles of the robots evolve over time, or between different friend groups as they each create their own unique shared meaning with the robots together.

Thus, the exploratory workshops provided evidence that our initial idea shows promise, which we further pursue through the series of iterative participatory design workshops discussed in the following chapters.

3.5 Summary

In this chapter, we discussed the three main TMA properties of tangible embodiment, multiplicity and coordination, and animacy, agency, identification and roleplay as they apply to ESSbots, and how they are supported by our grounding theory of participatory sensemaking and actor network theory. We described two exploratory workshops we conducted with ten total participants in order to investigate our initial idea for ESSbots, and discussed how participants perceived and conceptualized swarm robot communication. We described how participants interacted with wooden robot proxies to share emotions and simple expressions with each other, and summarized the resulting behaviour components in Table 3.3. We further described how our workshop results tie in to our grounding theories, as well as important workshop takeaways that provide evidence teens are interested in and open to communicative swarm robot technology.

Chapter 4

Iterative Design Workshops

To further explore the concept and design of ESSbots, we conducted a series of thematically focused participatory design workshops with a returning group of participants so that we could iterate on their design suggestions and explore important aspects of the technology with them. In this chapter, we describe our methodological approach to this series of iterative workshops, report participant demographics, and discuss important takeaways and participant feedback about the workshop series' methodological success. We also note that we further discuss specific outcomes and results from each workshop in Chapter 6, organized by each primary workshop concept in turn.

4.1 Methods

We approached the iterative workshops in a structured but flexible way. Based on our grounding theory and initial exploratory workshop results, we identified four major aspects of ESSbots that we wanted to explore further: familiarization and conceptualizing ESSbots; customization and control; social dynamics; and communication. We then minimally planned a series of four workshops to focus on each of these important concepts in turn. However, we did not plan specific workshop activities until the previous workshop in the series was complete so that our activities could better reflect participant feedback and design suggestions. Towards the end of our process, we decided to include a fifth workshop to assess the generalizability of our design—that is, we wanted to know how well the ESSbots concept, prototype, and remote communication and connection would translate for an entirely new group of participants who did not help in the design process.

We note that we wanted to engage with our returning group of approximately seven teen participants as an "advisory board", who could provide guidance as co-designers as we developed and iterated on the interaction design for ESSbots. Participatory design with children and teenagers has occurred for over 25 years [19], and the roles that children can take on during the design process has been extensively described—they can act as users, testers, informants, and design partners [18, 27]. In the last case, children are involved in the design process throughout, rather than brought in at specific points in the process as design informants [27].

More recent work has called for participants to take on an even more empowering role as design protagonists, where the primary focus is not necessarily on providing good products, but rather on helping children develop design competence and the ability to reflect on technology in their lives [36]. Our teen advisors are situated somewhere between design partners and protagonists: that is, we engaged with them and incorporated their feedback throughout the workshop series, however, we also wanted to explicitly develop ESSbots as a technology that they could eventually co-opt for themselves as we gave them better access to working swarm robots and more experiences to control them.

All workshops were conducted in person, given the importance of interacting with physically present swarm robots to contextualize the design goals, and each workshop primarily consisted of interactive demos, hands-on activities, and group discussion questions. As we iterated on the prototype for the ESSbots interface, we gradually gave participants more direct access to control the robots on their own (for a complete list of workshop activities and discussion questions, see Appendix A). Notably, the workshop series is a highly cyclical process, where the workshops serve as an elicitation tool for participant feedback, which in turn informs the interaction design of ESSbots and a prototype system and interface that we further test in future workshops. Additionally, this process works in the opposite direction: participants can only react to the interface and activities we present to them, but we can also update our planned activities in future workshops based on participant reactions and feedback (see Figure 4.1).

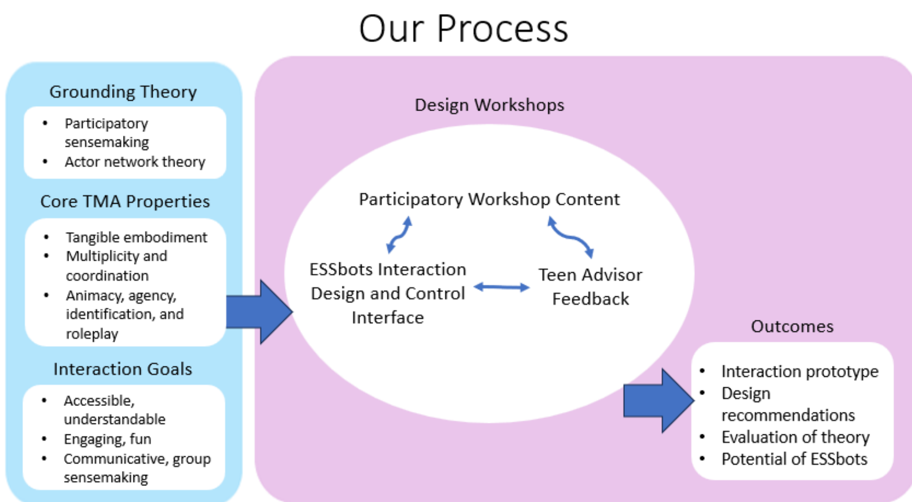


Figure 4.1: Iterative approach to the participatory design workshop series—participant feedback, workshop activities, and interaction and interface design all inform and influence each other.

We decided to use Sony toio™ [78] robots for the iterative workshop series—not only are the robots a commercial product intended for children, they are also supported with an open source development kit for Unity [59], and do not require an overhead projector for tracking robot positions. Instead, toios™ utilize a mat to track positions, making them a more accessible option for hands-on workshops with teens (see Figure 4.2). toios™ have many similar features to the Zooid robots we used in our exploratory workshops, including motors that support horizontal movement up to 35cm/s and rotation up to 1500deg/s, and LED lights located on the bottom of the robots. However, these features are slightly different than Zooids: the maximum speed for toio™ robots is much slower compared to Zooids, and the lights are more difficult to see on the bottom of the robot rather than the top. They also have sensors to detect magnetic force, cube posture angle, collisions, and motion interactions including double-taps and shakes, as well as a programmable button on the bottom of the robots. Finally, unlike Zooids, toios™ can also play MIDI sounds [79].

Participants for the workshop series were recruited via advertisements on social

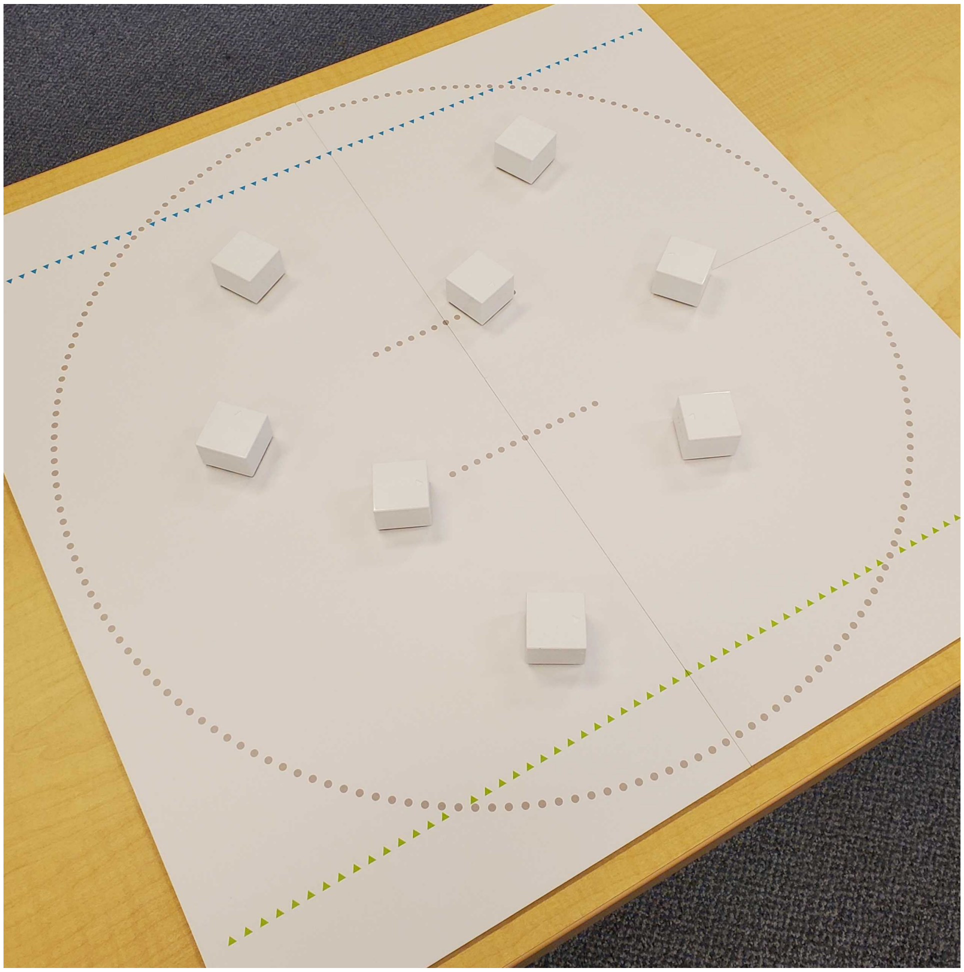


Figure 4.2: Several toio^{TM} robots on a position tracking mat.

media, and the study was approved by UBC's Research Ethics Board-B (certificate number H22-01554). Before the first workshop, participants and their guardians were respectively asked to read and sign assent and consent forms which described the goals of our research and the general structure of the workshop series, with specific activities for the first workshop included as an example. Participants were encouraged to attend as many workshops in the series as possible, which were held approximately three weeks apart. Participants were paid $40 CAD (or, if preferred, a $40 Amazon gift card) at the end of each 2-3 hr long workshop to

Workshop	Goals	Participants
W1 (Conceptualizing ESSbots)	Familiarize participants with the concept of ESSbots and swarm robot features, learn how they want to express themselves with the robots and how they might want to control them	P1–P12 (12)
W2 (Customization & Control)	Provide participants with multiple robot control methods and discuss their preferences and design suggestions, explore how situational context might affect how they use and control ESSbots	P1–P3, P5–P7, P9–P11 (9)
W3 (Social Dynamics)	Explore how in-person group dynamics are translated through ESSbots (reacting and responding, interruptions or co-opting of robots, mediated social touch, and showing personality)	P1–P6, P10, P11 (8)
W4 (Communication)	Test remote communication with a working ESSbots prototype, reflect on the workshop series and major takeaways for participants (what they learned, how their perceptions about ESSbots changed)	P1–P6, P11 (7)
W5 (Design Generalizability)	Evaluate the remote communication prototype and ESSbots concept with a new group of participants, reflect on how workshop participation and influence on the prototype design could affect participants' perception of the ESSbots system	P1–P3, P5, P6, P11, P13–P16 (10)

Table 4.1: Summary of workshop series activities and participant attendance. Note: P1, P5, and P8 also attended one of our exploratory ESSbot workshops.

compensate them for their time. Participants were also asked to complete a pre-workshop survey before the first workshop they attended, which asked them about their demographics, their relationship to other participants, and how they currently use social media. In total, we had 16 participants attend at least one workshop: 12 participants (6 boys; 5 girls; 1 non-binary) in the main workshop series, and an additional 4 participants (2 boys; 2 girls) for the final generalizability workshop—see Table 4.1 for a summary of participant attendance and the main content for each workshop.

4.2 Data Analysis

We video recorded all workshops, generated auto-transcriptions for each, and manually reviewed the videos and transcriptions to update them as needed for accuracy. All discussion activities were then collaboratively coded together by three researchers after each workshop. We followed a hybrid approach of inductive and deductive coding, similar to approaches described by Fereday & Muir-Cochrane [21] and Proudfoot [68], where our initial deductively generated codebook was based on the codes we identified in our exploratory workshops. We then further inductively coded any material that did not fit into the existing codebook. As the workshops were iterative and intended to be run in close succession, we aimed for a more lightweight initial coding approach in which we primarily coded semantically, and did not iterate or reduce our initial set of low-level codes until the entire workshop series was complete. Following the final workshop, we reviewed the entire set of codes for agreement and iterated and reduced them to a final set—at this stage, we also coded an additional set of latent codes specifically related to how participants conceptually perceive the swarm robots. Finally, rather than follow a more robust thematic analysis approach, we organize and discuss our codes in Chapter 6 under domain summaries following our workshop series main concepts. As noted by Braun & Clarke [9], these domains are not fully realized themes, and instead aim to structure our discussion around the diversity of responses to each ESSbots concept in turn. For a complete list of codes and their distribution across the exploratory workshops and workshop series, see Appendix B.

Additionally, we directly documented activities that were more hands-on, such as a card sorting activity in the first workshop, and took additional notes on our main observations from each workshop. We also calculated summary statistics from surveys we gave participants, including the pre-workshop survey and SUS survey [10] used in *W4 (Communication)* and *W5 (Design Generalizability)*.

4.3 General Results and Methodological Reflections

We report results from our pre-workshop surveys and general feedback from participants about the workshop series itself. For detailed results relating to our design prototype and participant reactions to the ESSbots concept, see Chapters 5 and 6 respectively.

Instagram was the most commonly used social media platform, with 81% of participants reporting they used it daily, followed by TikTok (63%) and Snapchat (50%). Other platforms participants used at least once a day included Facebook (6%), Reddit (6%), YouTube (6%), and Netflix (6%). On average, they reported using social media 3 hrs a day (min = 0, max = 5), with 63% percent reporting they used it more during the COVID-19 lockdown period. They typically used social media to relax, watch funny videos or memes, stay updated with their friends' and family's lives, and find information (see Figure 4.3). Participants reported talking to their friends most often in person (94%), over DM's on social media (63%), or via texting or an instant messaging platform (63%). One participant also reported talking to their friends over online games.

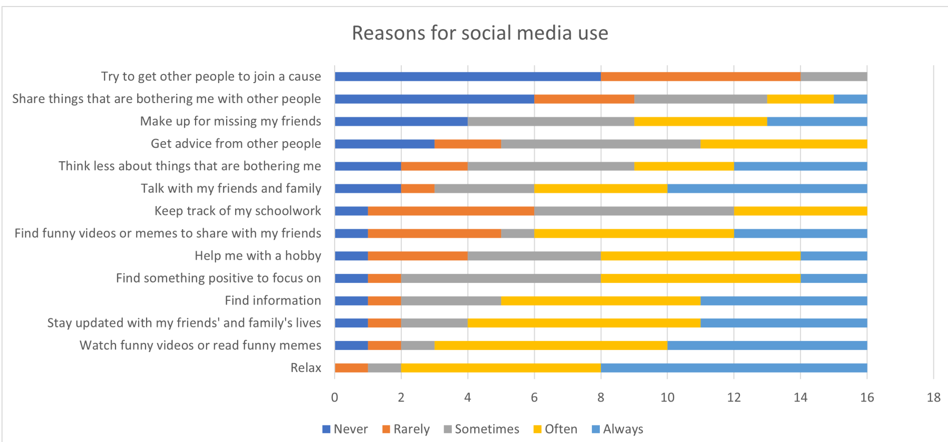


Figure 4.3: Frequency of different reasons participants use social media.

We asked participants what their relationship was to others in the workshop: seven people reported they were already friends with at least one other participant, two reported only knowing a sibling who was also attending, and three reported not knowing anyone in the group. We note that there was a second pair of siblings who also had some friends attending the workshop as well. Among the group of participants who attended only the design generalizability workshop, two reported they had at least one friend already attending the workshops, and two reported they did not know anyone attending.

We also gave participants a survey at the end of *W4 (Communication)* to assess their overall engagement with the workshops and how comfortable they felt interacting with swarm robots following the workshop series. 6 of the 7 participants reported that they learned something new by participating in our workshop series, including more about how robots work, how to control them, and how to communicate with others using the robots. They found that their favourite workshop activities involved directly controlling the robots themselves or sending messages with the robots to others—they enjoyed having fun with the robots, seeing how other people responded, and choosing the exact movements they wanted to use.

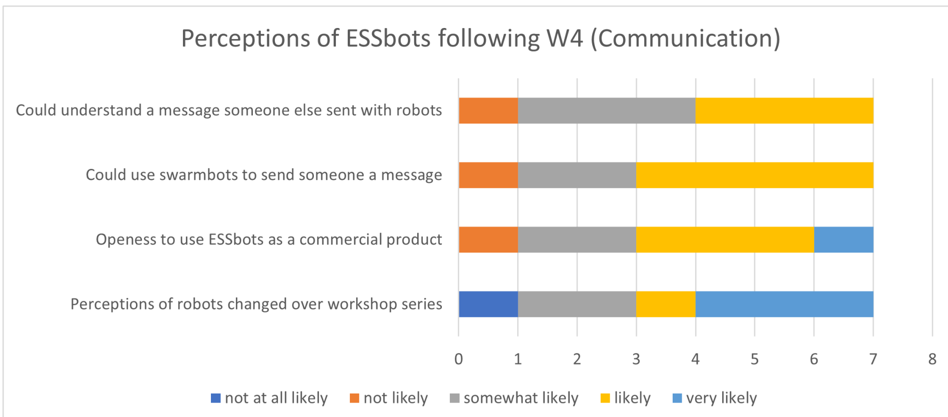


Figure 4.4: Summarized results from *W4 (Communication)* survey on interacting with ESSbots.

Several participants indicated that their perceptions of the robots had changed over the course of the workshop series, and most reported that they would be at least somewhat open to using ESSbots technology if it were a commercial product. The majority of participants also felt as though they would be able to use a swarmbot to send someone else a message, however, they were somewhat more hesitant that they would be able to understand a message someone else sent to them (see Figure 4.4 for a summary of these results).

4.4 Summary

In this chapter, we describe our iterative approach to our main participatory workshop series, in which a returning group of participants interacted with prototypes of the ESSbots system and discussed several important concepts about the technology, including conceptualizing ESSbots, customization and control, social dynamics, and communication. An additional group of participants were also invited to a design generalizability workshop to help us evaluate whether our design ideas and interface would translate well for an entirely new group of users. We summarize the main workshop series structure and activities, and describe the features of the Sony toio^{TM} robots used throughout the workshops. We also report participant demographics and social media usage, and feedback from participants regarding the workshop series itself—overall, participants enjoyed using the robots in our workshops and learned something new about swarm robots and how to control them.

Chapter 5

ESSbots Interaction Design and Control Interface

In general, we wanted to explore various important aspects of the ESSbots interaction design with teens, including how to provide teens easy access to control the swarm robots and get them to express the things they want, what behaviours and features are important for remote communication, how to incorporate personality and identity into a group swarm, and how to promote tactility and social touch through our design. Notably, our final design is not only influenced by participant feedback throughout the main workshop series, but is also additionally grounded in our initial theory and exploratory workshop results.

In this chapter, we describe our conceptual model for ESSbots, the final prototype, interface evaluation, and important findings relevant to our design that arose throughout the workshop series. We further describe how teens used our prototype to communicate and share expressive behaviours in Chapter 6, and discuss design recommendations and how our design reflected our grounding theory in Chapter 7.

5.1 Conceptual Model and Interaction Design Approach

We begin by considering three important elements of interacting with ESSbots:

1. Group interaction: How does a remote friend group use sets of connected swarm robots to communicate, connect, and socially relate to one another?

2. Individual interaction: How does an individual interact with their specific set of swarm robots and program them to get them to do what they want (e.g., send a message to their friends)?

3. Robot control and system structure: How is the system itself structured, and how does it support access to robot control and behaviour creation?

These three elements build on one another from the bottom up: while we are primarily interested in the group interaction with ESSbots and how they can support social connection, individuals must first have a shared understanding of what the robots' movement means and how they can interact with them in order to communicate with their friends. Of course, in order for people to actually use and communicate with the robots, the system itself must support it. That is, the underlying system structure must technically support the interactions that participants want to have with the robots, and the interface itself ultimately enables that access. In particular, we initially wanted to ground our system in a robust, adaptable structure that could first support us as researchers in the participatory design workshop series to quickly demo participant requested robot behaviours, and later evolve through the addition of accessible robot control methods so that the teenagers themselves could author robot behaviours on their own.

A sketch of the overall conceptual model for ESSbots interaction is given in Figure 5.1 illustrating these three important aspects of ESSbots interaction. At a low level, robots are programmed via combinations of atomic actions, modifications on those actions through parameters, and swarm elements to facilitate coordination among several robots. Individual users can interact with the robots tangibly and by sending messages to their remote friends via one of two main control methods, and in turn, friends can respond back with their own robots. Finally, the system manages these messages and synchronizes each remote swarm.

We discuss each element of our conceptual model in turn, beginning at the lowest level to describe how our underlying system structure supports both individual and ultimately group interaction with ESSbots.

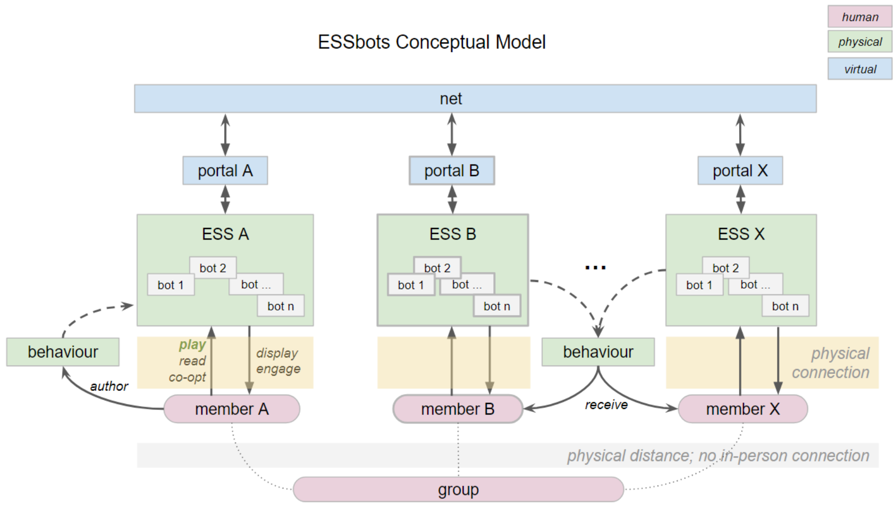


Figure 5.1: Conceptual model for ESSbots, outlining the three important elements of interaction: group interaction, individual interaction, and robot control and system structure. Primary concept objects include individual group members, the group as a whole, emotionally supportive swarms (ESS) composed of individual ESSbots, and individual portals linking each person to the overall network of connected swarms.

5.1.1 Atomic Behaviours

We based our initial conceptual model of the ESSbots system on the idea of motion primitives, or "atomic behaviours", where we consider an atomic behaviour to be the most basic version of a complete action that an individual robot can perform. This approach is similar to Xu et al.'s [92] behaviour-based formation control of swarm robots, where an overall behaviour is considered to be the combination of several sub-behaviour vectors, albeit more complicated ones like wall-following or obstacle avoidance. It is also similar to the approach taken for the Buzz programming language developed by Pinciroli and Beltrame [66], which promotes behavioural composition through single-robot and swarm-based motion primitives. However, we wanted our atomic behaviours to specifically reflect and support the ways that teens interacted with the robots in a way that they would find understandable and easy to use, and thus wanted to identify our own set of relevant atomic behaviours based on our workshop results, such as horizontal motion (move to position), rotation, turning on LED lights, playing sound, and vibrating.

Components of atomic behaviours:

In addition to atomic *actions*, that is, the most basic versions of individual behaviours that could be modified in various ways such as the speed at which they are executed, or the number of robots that enact that behaviour, we identified three other main components that can be combined with these actions in order to create more complex swarm behaviours: *parameters*, *swarm elements*, and *event* sensing (see Table 5.1 for several examples).

Actions and parameters: We wanted to keep these atomic actions cohesive and "complete"—that is, while it would be possible to consider atomic behaviours at an extremely low level, such as moving individual motors within the robots or turning on specific light colours, we instead aim to create a basis set of understandable behaviours that could be tailored and transformed via a set of applicable parameters, which could be highly specific and applicable to only one type of action, or highly generalizable and applicable to many (such as duration). For example, we can consider two main basis movements: transverse movement and rotation. We argue it is not productive to further combine these actions into one "movement" category, given the distinct difference between rotational and transverse movement and the fact that rotational and transverse movement can be combined together into a new compound behaviour of moving forward with rotation. Notably, both these actions also have similar parameters to modify the quality of the action, such as speed, duration, and direction. Another basis action, such as "play sound", may have very different applicable parameters, such as note name and loudness—thus, we do not restrict parameters to be consistent across all atomic actions, although we still aim for as much consistency as possible.

Swarm elements: Additionally, since participants in our exploratory workshops came up with expressive behaviours that both utilized robots as a coordinated group as well as individual robots that represented them and acted on their own (see Table 3.3), we also wanted to separate the factors that enable swarm behaviour from atomic actions and possible parameters. Thus, if participants wanted to have more direct control over individual robots, they should still be able to utilize the

	Exploratory Workshops	Literature Review
Atomic Behaviours (Actions)	Lights Move to position [41, 46, 72] Rotation (spin) [45] Sound Vibration/rattle	
Parameters	Brightness Colour Force strength Jitter [43] Number of repetitions (duration) Speed [46] Volume	
Event Sensing	Human contact Object/robot contact Position in environment	Magnetic force detection [79] Motion detection/orientation [79]
Swarm Elements	Animacy [44, 72] Number of robots (per action) Reaction/response	Centralized control [86, 92] De-centralized/distributed control [41, 64, 86, 92] Force coordination [45] Layered control [92] Spatial distribution [44] Stakeholder control[41] Stop [46] Synchrony of parameters (e.g., jitter, speed) [43, 86]
Common Compound Behaviours	Active piloting Back and forth movement [44] Contact between robots Symbol [46] Touch: spin, stroke, tap [44]	Avoidance: obstacles, robots, wall following [41, 86] Dispersion [43, 89] Flock [41, 43, 86, 89] Follow trajectory [46] Interact with objects: push, grab [46, 72] Maintain formation [41, 72] Random motion [43, 86] Rendezvous [43, 89] Scale up/scale down [46] Split/merge [46, 72] Touch: pattern [45] Torus [41, 43]

Table 5.1: Atomic behaviours, parameters, swarm elements, and common complex behaviours found in our exploratory workshops or literature review. Some properties were found in both our workshops and literature review—these are listed in the exploratory workshop column with references.

atomic behaviour "building blocks" to compose more complex actions for an individual robot as well as for a group. We also noted that more complex behaviour metaphors were brought up frequently in our exploratory workshops as well as in existing swarm robot literature, and therefore wanted our design to either support easy creation of these complex behaviours, or provide some of them directly to users.

Event Sensing: Finally, we note the importance of robot "sensing" to both individual and swarm behaviours. As an example, in order to move a single robot to a new position, it must have a sensor in order to read its current position on the play mat and navigate to the correct final position. Similarly, a swarm behaviour where several robots flock to the same position also requires each robot to know where it is in on the mat, and in addition, also requires each robot to know where the others in the swarm are so they do not crash into each other when moving. Thus, we treat event sensing as its own important category, since different sensors are essential for specific tasks, but cannot be considered base actions, parameters, or swarm elements in their own right.

Evaluating the atomic behaviour set:

In order to establish a complete list of necessary atomic actions, parameters, swarm elements, and sensing components, we organized possible candidate behaviours into each aforementioned category based on the behaviours participants described in the exploratory workshop activities, as well as on standard swarm robot behaviours found in the literature, as shown in Table 5.1. We then evaluated our organizational structure with participants through a card sort activity in *W1 (Conceptualizing ESSbots)*: participants were given cards for atomic actions, parameters, swarm concepts, and common complex behaviours, and then asked to sort them into groups.

We found that most participants grouped concepts based on similar actions, and frequently included swarm concepts or parameters related to those actions in the same groups. For example, P8 and P12 decided to cluster their cards into categories for light, sound, movement, where robots are, and control over robots, P1, P3, and P4 clustered their cards into movement, number of robots, actions, light, and sound, and P5 and P6 created clusters for lights, movement, sounds and vibration, groups of robots, and technical elements. However, some groups placed more emphasis on actions and parameters—P2 and P7 created pairs of cards with an action and a parameter, such as sound and volume as one pair and rotation and speed as another, and P9, P10, and P11 clustered their cards as actions, motion, how robots work as a group, volume, and colour, distinctly separating out the latter parameters from the actions they would correspond to.

Additionally, when we gave participants additional cards with more complex swarm behaviours (such as robots form a symbol or avoid running into obstacles), most described the original set of action, parameter, and swarm element cards as more basic and fundamental, and the new complex behaviour cards as an expansion of what the robots could do. Some participants added the new cards into existing groups, such as P5 and P6, but most created new clusters for at least some of the new cards, such as P9, P10, and P11 adding a cluster for "human intervention".

Overall, participants recognized many of the same action and parameter groupings as we did—therefore, we continued to follow our atomic behaviour structural concept as we further developed our system and interface.

5.1.2 ESSBot Control and Individual Interaction

After establishing the fundamental structure of our conceptual model for ESSbots as a platform that utilizes atomic "building blocks" of robot behaviours to create more complex expressions that teens can share with each other, we must also establish how teens actually interact and access these building blocks. At the system backend, all forms of control are ultimately enacted by combining functions corresponding to specific atomic actions described in Table 5.1. However, it is possible to give teens more or less transparency to actually see the building blocks for themselves.

First, we focus on how each individual in a friend group would interact with ESSbots in order to describe our design space for possible control methods and establish a basis for the overall group interaction. Imagine a group of four remote friends: let's assume Friend A is feeling sad, and wants to share their emotion with their friends (see Figure 5.2). In order for their friends to receive this feeling through their own set of robots, there must be some way for Friend A to either a)

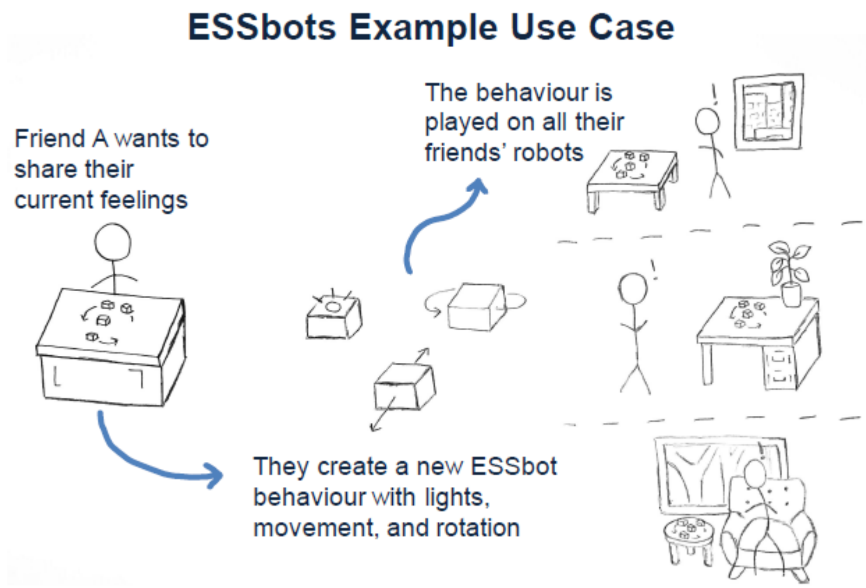


Figure 5.2: Example ESSbots use case—Friend A shares their current feelings via the robots, which move synchronously for each of their remote friends.

indicate to the robots that they are sad, which will in turn mediate their feelings via a swarm behaviour and be repeated for each remote friend's set of swarm robots, or b) directly program or pilot the robots themselves in order to communicate their feelings to their friends—as in the first case, this programmed behaviour will be sent and repeated on each friend's set of swarm robots.

In order for this communication or control to take place, we identified three important dimensions that form one possible design space for ESSbot control: directness, discreteness, and customizability. First, given that the robots are tangible, it is possible for people to directly interact with individual or multiple robots to control them (e.g., move them around a table) or control them indirectly (e.g., via an interface or game controller). Control can also be highly discrete and structured, closely following our backend system structure of atomic behaviour building blocks and pre-built actions, or can be freeform and continuous, such as by fully specifying robot movement trajectories via path-drawing or a controller. Finally, a control method can be minimally or highly customizable: users can either adjust several

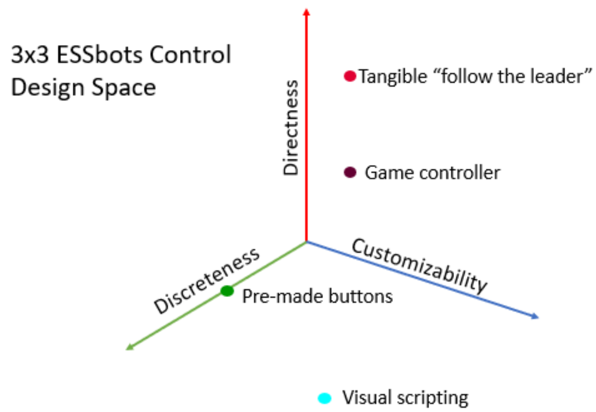


Figure 5.3: 3x3 design space for ESSbot control methods. Prototypes of the various methods we tried in the workshop series are plotted according to their directness, discreteness, and customizability.

specific aspects of behaviours, or have very little control over high-level behaviour presets (where robots may also appear to behave more autonomously). Figure 5.3 illustrates these different dimensions of interaction and control we prototyped as examples for participants, so we could better understand how they wanted to interact with the robots.

Based on participant feedback in *W1 (Conceptualizing ESSbots)* and *W2 (Customization & Control)*, we ultimately focused on two main control methods in our final prototype: visual scripting, in which teens use draggable blocks representing atomic actions that can be linked together to create a series of specific, highly customizable behaviours for individual robots, and emotion buttons, where teens simply click on buttons that trigger pre-built behaviours that play a pre-made, potentially complex behaviour on the robots. We also tested an additional control method in *W5 (Design Generalizability)* that we didn't initially have time to evaluate in our main exploration of control in *W2 (Customization & Control)*: tangible "follow the leader" path following, which teens responded positively to as well. For further discussion on how teens reacted to each of the control methods we tried, see Chapter 6. Here, we simply note that each control method comes with advantages and disadvantages, and a system which gives access to more than one control method allows teens to be flexible and use whatever method is most appropriate for them in a given situation.

5.1.3 Group Interaction

Finally, we consider how the system works as a whole to support remote group interactions. Each individual has access to control either individual or multiple robots, which is in turn repeated for everyone's swarm. We can consider again the situation where Friend A shares a "sad" emotion with their friend group—in response, individuals in the group may want to *respond* to this emotion with their own robots. These responses must be mediated through the system in some way: for example, if two people want to use the same robot in a custom behaviour at the same time, the system could either usurp one entire behaviour with another, facilitate a combined behaviour with elements of both, or deny access to both parties. Similarly, we can consider a situation where one person sends a behaviour, and another wishes to interrupt or co-opt it for their own behaviour. Again, the system must mediate how individual interactions affect the connected swarm as a whole.

Ultimately, our final prototype approached this problem in a more naive way, where individual robots continue to enact a behaviour unless they are stopped or directly co-opted in a new behaviour by another. However, participants came up with several useful design recommendations to support the idea of co-opting and consent, which we further discuss in Chapter 6 and 7.

Additionally, the system itself could also facilitate synchronous interactions, asynchronous ones, or both, although we decided to focus specifically on synchronous interactions to limit the scope of our design space. Notably, the extent to which the system can synchronize robot movements for different remote swarms is influenced by the ways that individual people interact with them: if, for example, one person picks up a robot and its position can no longer be tracked by the system, then that robot may not perfectly match the same position or timing as that same robot would in the other remote swarms even if it is set back down, since an individual could potentially move it to a different location in their own local space. In general, physical interaction with the robots will introduce imperfect synchrony, as some robots may be blocked by objects or individual people's hands in some remote swarms but not in others.

The degree to which the system synchronizes all the robots can potentially differ in different scenarios as well. For example, if a complex behaviour incorporates random movement by the swarm, the specific positions individual robots move to could be synced across all remote swarms or not. In situations where groups of friends primarily observe and react to shared behaviours, it is likely less important that individual robot locations are perfectly synced. However, in instances where individuals each control their own robots to interact with the others, then the specific locations of individual robots is much more important in order to truly facilitate ongoing, collaborative group interaction. Indeed, both methods are incorporated in our final prototype: in the case of pre-made behaviours, some positions, like random locations, are not perfectly synced across remote swarms. However, for the visual scripting control where individual robots can all be controlled by different users at the same time, positions are consistently synced, although it is still possible for some robots to "drift" out of sync if they are tangibly interacted with by local users.

5.2 ESSbots Prototype Interface

We developed a fully functional prototype in Unity to both evaluate our design as well as explore how teens might actually use ESSbots to communicate with remote others. We note that this prototype is merely one way to provide access to robot behaviours, and that the behaviours that teens want to enact with the robots are an independent, fundamental part of the interaction that could be implemented in a number of different ways. This prototype gives teens one way to access the atomic building blocks of the behaviours they came up with on their own during our workshops, so that they could hopefully author and share these behaviours in reality with our system. Thus, returning to the three main elements of our conceptual model, the prototype:

1. Facilitates remote group interactions with ESSbots by supporting remote connection over a local network and manages how individual robot behaviours are synchronized and shared over that network

2. Provides access to local sets of swarm robots to individuals through an inter-

face with two kinds of robot control methods: visual scripting and pre-made behaviour buttons

3. At the backend, is structured based on combinable atomic behaviour functions, to which the interface provides either direct or indirect access to users

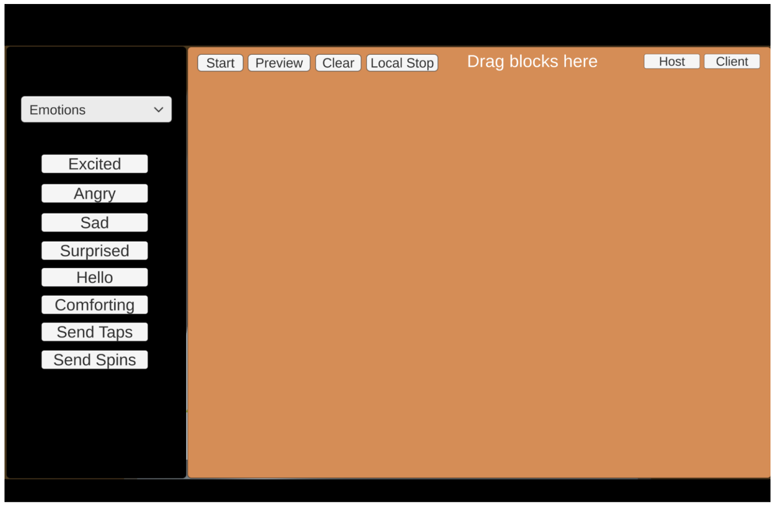
The prototype requires at minimum two Bluetooth enabled Mac computers to run, as well as two toio^{TM} play mats and six toio^{TM} robots (three for each "swarm"), however, it is possible to easily scale up to support a larger number of robots or play mats.

Figure 5.4 shows the final prototype interface. The prototype can run over a local network via the host and client buttons in the top right corner, which allows behaviours to run synchronously on two different connected swarms set up in different rooms. Users can select between two different control methods via a dropdown menu on the right: emotion buttons (Figure 5.4a) or visual scripting (Figure 5.4b).

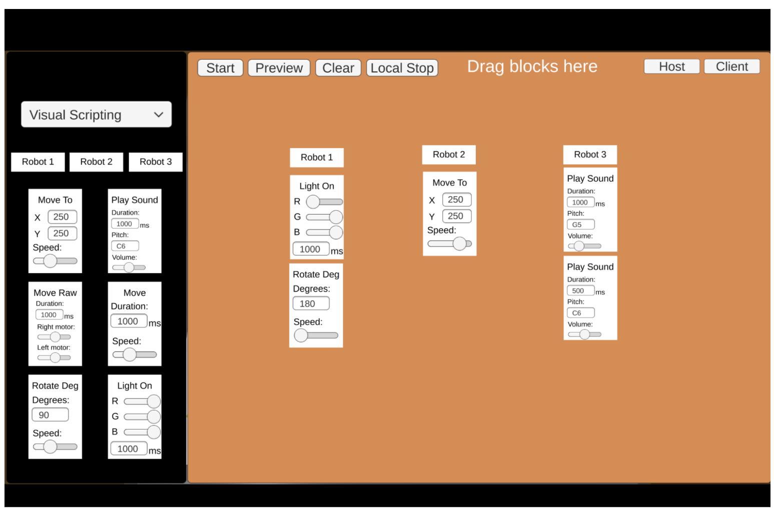
While there were several other versions of this prototype that we explored during the workshop series, the final prototype was chosen to best reflect participant feedback around situational access to fine-grained control (in general, participants want to get the robots to behave exactly how they want, but recognize there are times that quick access to pre-made behaviours is also beneficial and useful). We also structured our final interface prototype around the communicative aspect of ESSbots specifically, since we wanted to explore whether participants could actually use the remote system to communicate and relate to each other with the bots. We summarize other interface features and control methods we demonstrated in the workshop series in Table 5.2 (see Appendix C for more detailed descriptions and figures of these methods) and further describe the two important control methods we integrated into our final prototype below.

5.2.1 Visual Scripting

The visual scripting interface, as shown in Figure 5.4b, allows users a high level of specific control over each individual robot. By dragging and dropping blocks from the left panel into the main workspace area on the right, users can assign actions to specific robots and adjust the parameters of those actions in real time to modify



(a) Emotion button interface. Users can click on buttons to play pre-built behaviours.



(b) Visual scripting interface. Users can drag and drop blocks from the left into the workspace on the right to create combinations of modifiable atomic actions, preview behaviours locally with the preview button, and share them with a remote group with the start button.

Figure 5.4: ESSbots prototype interface. Users can choose between emotion buttons or visual scripting to control the robots and send messages to others remotely after connecting over a local network with the host and client buttons.

Theme	Purpose	Prototype/Demos
Conceptualizing ESSbots	Used in *W1 (Conceptualizing ESSbots)* to demo participant requested behaviours	Atomic Behaviour Selectable Combinations
Customization and Control	Used in *W2 (Customization & Control)* and *W5 (Design Generalizability)* as interactive demos for participants to try these control methods	Visual Scripting V1 Emotion Buttons and Game Controller Tangible Control: "Follow the Leader"
Social Dynamics	Used in *W3 (Social Dynamics)* and *W4 (Communication)* to explore things like individual vs. group control, co-opting, mediated social touch, and showing consent	Robot Dance Party Emotion Co-Opting Mediated Touch Interactions Showing Consent
Communication	Used in *W4 (Communication)* and *W5 (Design Generalizability)* to see how participants would actually communicate and use the robots in a remote setting, and evaluate usability and generalizability of the design	Remote Prototype V1 Remote Prototype V2 (Final Prototype)

Table 5.2: Summary of different prototypes and demos we showed participants throughout the workshop series.

their behaviour. Users can also clear all blocks from the workspace by clicking on the clear button, or they can remove specific blocks by dragging them to the left panel, where they will disappear.

Actions are run sequentially according to vertical position in the workspace and are assigned to a robot based on their position under the robot assignment blocks (Robot 1, Robot 2, or Robot 3). For example, in Figure 5.4b, Robot 1 first turns a turquoise light on for 1000 ms, then slowly rotates 180 degrees. At the same time, Robot 2 moves to the center of the mat (at position (250, 250))—if the robot is picked up by a user, it will return to the same point on the mat. Finally, Robot 3 plays a G5 MIDI note for 1000 ms, then a C6 for 500 ms. If, for example, a user wanted to change the colour of Robot 1, they can simply slide the RGB colour value bars and see the colour update immediately. Any changes in parameter values will also be sent over the network and updated on the remote swarm.

Each block is based on our original set of atomic actions in Table 5.1, with some modifications. For example, we included the block "move raw", which allows for low level control of each wheel. While this was not one of our original atomic actions, we found that it was difficult to support the torus behaviour (robots move in a donut or circle) without this basic behaviour block. We also included two separate blocks for "move" and "move to", separating the idea of transverse movement forward and transverse movement to a specific location.

All blocks include important parameters relevant to their action, however, the visual scripting control method for the most part does not incorporate swarm elements directly into the design. Instead, the robots act more as a multi-robot system—with the exception of the "move to" block, each robot acts independently and does not account for other robots positions when navigating. We primarily structured the system this way because our participants wanted access to at least one method that gave them complete control over the robots: they should be able to, for example, have the robots intentionally run into each other if they desire. Additionally, this structure would still allow participants to use the set of atomic behaviour blocks to author several common swarm behaviours, such as dispersion, aggregation, or flock, as the "move to" block incorporated swarm avoidance and navigation.

Finally, in order to "play" a behaviour and send it over the network, users must arrange at least one robot assignment and behaviour block on the main workspace area, then press start. The behaviour will then run both locally and on the remote set of toio™ robots, until either the other remote user starts their own behaviour with the same robots, thus interrupting the current behaviour, or the original user presses the stop/start toggle button. Additionally, if either party wishes to stop their own swarm robots without affecting the remote swarm, they can press local stop, which will only stop their own set of swarm robots. Users are also able to test behaviours locally without sending them to the remote swarm. Rather than pressing the start button, they can click on the preview button, which will start the behaviour locally so that they can make any adjustments before sharing it to their friends' robots.

5.2.2 Emotion Buttons

The emotion button panel allows users to play pre-made complex behaviours corresponding to six possible emotions or simple relational phrases—in contrast to the visual scripting panel, interacting with these buttons is quick and easy, but does not currently give users any specific control over the behaviours they send with the buttons. The pre-made behaviours we created for each button are based on participant suggestions from our first workshop, where we asked participants to come up with different robot behaviours for the words on the buttons. Table 5.3 describes the behaviours for each button in more detail.

We also created two additional buttons so that users can send touch based messages to each other. These buttons were based on participants' preferred touch based behaviours in *W3 (Social Dynamics)*: send spins and send taps, and are labelled based on function rather than a specific emotion so that users could potentially feel more creativity to use the touch messages however they wished. In contrast to the other buttons, where clicking one will automatically play the behaviour on all remote swarms, the touch based buttons require explicit interaction from the remote user in order to run, and will not play the behaviour for the "sender", since the force required to interact with the receiver's hand would cause the robots to crash into each other if no one was explicitly interacting with them. Instead, if one person clicks send taps, then one reference robot will light up green on all remote swarms. If the robot is picked up by a remote friend, the sender's robots will all light up white, indicating their friend has received the message. Once the friend places the robot back on the mat, they can hold their hand over it and the other two robots will approach their hand and gently bump against it in a sequential tapping motion before automatically stopping after a few seconds. Similarly, the send spins button will cause two robots to spin on either side of the receiver's hand, applying shear force feedback against their skin.

5.3 Prototype Evaluation and Results

Throughout the workshop series, we assessed our existing prototypes based on qualitative participant feedback in order to make improvements and incorporate their design suggestions going forward.

Button	Description
Excited	All robots turn on continuous yellow light while moving quickly and erratically to random positions on the mat.
Angry	Two robots beep loudly (a dissonant major 2nd - B5 and C6), then all robots turn on continuous red light while moving quickly and erratically to random positions on the mat.
Sad	Two robots remain stationary while one slowly moves to the center of the mat, turns on a blue light, and slowly rotates in place.
Surprised	All robots slowly move towards the center of the mat, then suddenly turn on a purple light and quickly disperse to the edges of the mat.
Hello	One robot moves at a moderate speed to another robot, beeps once when it reaches it, then spins with a white light on.
Comforting	One robot slowly moves to the top corner of the mat. A second robot then moves to the same corner, turns on a continuous white light, and slowly moves in a circle around the first robot.
Send Taps	One robot lights up green. If this robot is picked up and placed back down, then the other two robots will approach the hand holding the initial robot. When they are close enough, they will take turns bumping up against the hand, while the remote set of robots will light up white to indicate the message has been received.
Send Spins	One robot lights up green. If this robot is picked up and placed back down, then the other two robots will approach the hand holding the initial robot. When they are close enough, they will both spin in a back and forth rotational motion against the hand, while the remote set of robots will light up white to indicate the message has been received.

Table 5.3: Descriptions of each pre-made button behaviour in the final prototype.

5.3.1 Evaluation throughout Workshops

In *W2 (Customization & Control)*, we gave participants early versions of our visual scripting and pre-made emotion button interfaces, as well as an additional control method where they could directly drive robots around using a game controller. Based on their suggestions, we improved the visual scripting interface to make it easier to assign behaviour blocks to different robots, and combined the visual scripting and pre-made buttons together so participants could easily switch between these two control methods, since they viewed both as important. We also came up with a different, more tangible version of path following to show participants in *W5 (Design Generalizability)*, since they felt that the game controller was difficult to use, yet they generally enjoyed interacting with the robots in tangible ways.

We also note that beyond evaluating things like usability and engagement, we also used demonstrations as a way to investigate different aspects of what interacting with ESSbots might be like, such as mediated social touch or the idea of co-opting and showing consent. Thus, we further discuss these results in Chapter 6, and focus our discussion here on how participants reacted to our final ESSbots prototype, which they were able to use in separate breakout groups to communicate with each other remotely.

In addition to the qualitative feedback participants gave us about our final prototype, we also wanted to determine whether they felt the prototype was usable in a more quantitative, validated way. Therefore, we decided to use the System Usability Scale (SUS), a validated scale developed by Brooke [10] as a "quick and dirty" method to measure the usability of a system. Since the scale is only ten items long, we felt it was a useful and accessible way for us to get more feedback from our teen participants in the context of our participatory workshops, and reserved its use for the final two workshops once the prototype had been more fully developed and felt more complete. Using the SUS at this stage was also an opportunity for participants to give us feedback about the prototype in an anonymous way, so ideally they could feel more open to share their opinions than they may have during group discussion questions. We were also able to give this survey to both returning and new participants in *W5 (Design Generalizability)* so that we could better compare how well our design might generalize to a new group of users.

In both workshops, each group was given approximately 10 minutes to freely try out the prototype while the other group watched the resulting robot movements and answered some discussion questions. Participants were also asked to use the touch buttons to send and receive touch messages to one another. Finally, we gave participants simple emotion or phrase prompts and asked them to use the interface however they wanted to communicate those messages to the other group, who were then asked to use the robots to respond. Prompts included a mix of existing pre-made emotions or phrases, like "surprise" and "sad", as well as words that had no pre-made button, such as "playful" and "that's not okay", to encourage participants to utilize the custom visual scripting control method.

Following this activity, we provided participants with the system usability survey (SUS) [10] and asked them questions about the things they liked and disliked about the interface, which we further discuss below.

5.3.2 Participant Feedback

Participants in *W4 (Communication)* generally described the interface as easy to use, but they did have several suggestions to improve it. For example, the version of the interface we showed participants in *W4 (Communication)* had a semi-transparent background so that it was easy for us to test the robots in the toio™ Unity simulator. However, participants found this background confusing, particularly because the simulator robots do not move on screen when real robots are connected via Bluetooth. Therefore, we changed the background to solid colours in the final interface that we showed participants in *W5 (Design Generalizability)* (as shown in Figure 5.4) so the simulator would be completely hidden. We also added the preview button based on participant feedback in *W4 (Communication)*, since they wanted a way to test out behaviours before sending them to their friends, as well as the "move to" position block, which they specifically requested.

Participants in *W4 (Communication)* also requested features that we did not include in the final interface due to time constraints: a save feature, so they could author behaviours using the visual scripting panel and save them for quick future use; a colour wheel picker for the "light on" block, so that choosing light colours would be more intuitive; and additional control methods or features, such as directly controlling the robots' trajectories with a mouse or adding more sensors so the robots are aware of objects in their physical space.

In *W5 (Design Generalizability)*, the returning participants still found the interface easy to use, although they generally needed a few minutes to re-familiarize themselves with its functionality. They were also pleased to see the changes we implemented based on their suggestions in *W4 (Communication)*, such as the preview button and the new "move to" position block. The new group of participants also found the interface easy to use—they found the visual scripting control was easier than they had first expected it to be, and pre-made button behaviours seemed reasonable even though they hadn't influenced their design.

Both new and returning participants also had similar suggestions to improve the prototype as in *W4 (Communication)*, such as adding a feature to save behaviours or edit existing pre-made behaviour buttons, or adding additional features to the robots, such as the ability to send audio messages. Participants also had several new suggestions, such as improving the visual scripting interface by auto-linking blocks together, similar to a commercial visual scripting product like Scratch [73], or adding visible axes to the toio™ mat so that programming the "move to" position button would be easier.

5.3.3 System Usability Scale Results

Finally, results from the SUS scale in both workshops show that participants indeed found the interface reasonably easy to use, although there is clearly still room for improvement as mentioned above. Since individual scale items are not meant to be taken out of context (the scores for individual items are not considered meaningful on their own) [10], we report results for the overall scores from this scale. Due to the small number of participants in each workshop, we only report summary statistics—on average, our *W4 (Communication)* prototype received a SUS score of 63.6/100 (N = 7, min = 50, max = 87.5), and in *W5 (Design Generalizability)* the final prototype averaged a score of 73.3/100 from returning participants (N = 6, min = 57.5, max = 87.5), and 70.6/100 from new participants (N = 4, min = 50, max = 82.5). See Figure 5.5 for a boxplot comparison of these results. Further, to put these results into context, most systems evaluated with the SUS receive an average score of approximately 70/100 [7], putting our system on par with that.

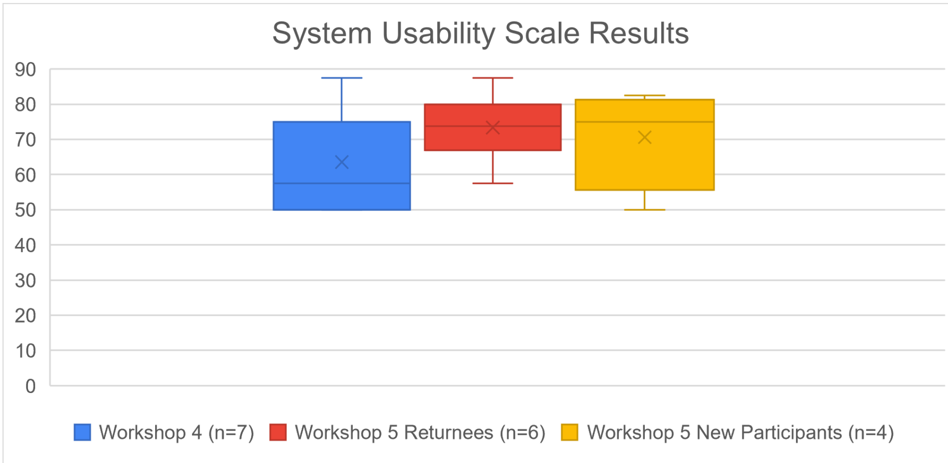


Figure 5.5: Boxplot showing results from the system usability scale in *W4 (Communication)* and *W5 (Design Generalizability)*.

5.4 Summary

In this chapter, we describe our approach to the interaction and interface design for ESSbots. We show how the important elements of group interaction, individual interaction, and robot control and system structure influenced our final conceptual model, which allowed us to develop a system that first supported us to show participants interactive demos during our early workshops, and then later provided participants themselves with a fully functional prototype where they could control the robots on their own. In particular, we describe how the concept of atomic behaviours helped us to develop a robust system structure, where behaviours are built up from simple "building blocks" that participants can directly or indirectly access via different robot control methods.

We describe our final prototype, which we developed over the course of the workshop series based on isolated demonstrations of different aspects of ESSbots interaction, such as early versions of control methods we showed participants in *W2 (Customization & Control)*. Our final version of the prototype focuses on providing participants with accessible access to different forms of robot control so that they can express themselves through robot behaviours remotely, and features two main control methods: visual scripting, a highly discrete and highly customizable control method where participants drag and drop atomic action blocks in order to author new complex behaviours; and emotion buttons, a moderately discrete but minimally customizable control method where participants click buttons to play a pre-made complex swarm behaviour corresponding to simple emotions or phrases, such as hello, surprise, or angry.

Finally, we describe how we evaluated our final prototype and report results from our usability survey, which allowed us to directly compare the usability of our prototype with both our returning group of workshop participants as well as a new group of participants in *W5 (Design Generalizability)*. Based on these results, we found that the usability of our prototype generalized well for new users, as both participants who had contributed to the design throughout the workshop series as well as new participants who had not influenced the design gave our prototype similar average scores on the survey. We also note that our results were similar to those obtained in previous research using the SUS to evaluate systems, thus putting our prototype on par with most other interfaces. Participants also mentioned that they appreciated seeing their design suggestions incorporated into the interface, and the increased average score from our SUS from *W4 (Communication)* to *W5 (Design Generalizability)* may reflect the improvements we made to the system between these workshops, although the change in score is not significant and based on a smaller number of participants who may have simply viewed the interface slightly more positively than the first group.

However, there is still room for improvement. Participants suggested adding additional features to the robots to help them communicate with others in different ways, such as by adding audio messages, as well as functional suggestions for the prototype, like adding the ability to save new behaviours or adding axes to the toio™ play mat so they can use the move to position block more easily. We also note that there are several important qualitative findings related to ESSbots interaction design that we further discuss in Chapter 6, as well as a final set of design recommendations discussed in Chapter 7.

Chapter 6

Analysis and Discussion: Perception and Potential of ESSbots

We discuss our findings from the workshop series, including how participants reacted to the technology, what they think ESSbots should be, how they want to control the robots and communicate with one another, important social dynamics that ESSbots can mediate and support, and the overall generalizability of our design to teens who didn't influence the participatory design process. As discussed in Chapter 4, we organized the results of our qualitative analysis into domain summaries according to our main workshop topics (outlined in Table 4.1), which we discuss in turn below.

6.1 Conceptualizing ESSbots and Interaction Design

In general, we found that participants were open to the idea of ESSbots throughout the workshop series, and were excited to interact and play with the robots. They often asked questions about how the robots worked, how we programmed them, and whether they were available to buy. Participants were the most engaged during activities where they could interact with the robots directly, and were curious to try and push the boundaries of what the robots could do. For example, P2 experimented with a water bottle in *W5 (Design Generalizability)* to see whether or not the robots could sense objects in their environment and navigate around them.

Notably, participants in the main iterative workshop series and *W5 (Design Generalizability)* described the robots in ways that were conceptually similar to how participants in our original exploratory workshops described them. They also described how they would use the robots in similar ways as well, although we do note that three participants were present for both the exploratory workshops and iterative design workshop series. However, this level of consistency across all workshops still suggests that the conceptual idea for what ESSbots interaction might look like is relatively consistent for different people, and may additionally be somewhat independent of the robot design, since we had participants use proxies and view demos of Zooid robots rather than toio™ robots in the exploratory workshops.

6.1.1 How Participants Use ESSbots

We begin by considering how well participants understood the robots, their features, and how they might use them. Participants seemed to have a good sense for what the robots' features were and what they might use them for right from the beginning of the workshop series, although their opinions still shifted somewhat as they became more familiar with the robots. For example, when we first introduced participants to the robots in *W1 (Conceptualizing ESSbots)*, they felt like they would use them to communicate short messages or play games with their remote friends, which they consistently brought up throughout the workshop series. They also believed that the robots would help them feel closer to their friends compared to other remote communication technology, especially when they can't see their friends often in person. As P5 mentioned in *W1 (Conceptualizing ESSbots)*: "Some of my friends are far away and I think they need a hug or something, and I can't [hug them], and if I text 'hugs' it'll be kinda weird. I think the robots can be a bit clearer what I meant to do. Even if you text them 'hope you're okay', with the comforting action with the robots it'll be a bit better".

Some participants in *W1 (Conceptualizing ESSbots)* suggested using the robots as a kind of notification system to easily get their friends' attention, similar to what a different set of participants in the exploratory workshops suggested. A few participants wanted to use the robots in other contexts as well, such as to complete tasks in their own local space. However, as the workshop series progressed, participants generally focused on three main types of usage: connect and feel close to others, express emotions and personality, and play games or use the robots in playful ways.

We found that participants were able to recognize the embodied nature of ESSbots from the beginning of the workshop series as well: “It’s more capturing than phones because people get desensitized by how many dings they have on their phone ... [the] notification doesn’t have meaning, it’s just a banner. But this has meaning because it is in front of you” (P10, *W1 (Conceptualizing ESSbots)*). Similarly, when we introduced touch-based messages in *W3 (Social Dynamics)*, most participants enjoyed the way the robots felt when they bumped or spun against their hands, especially if they commonly engaged in playful affective touch.

However, whether or not they would actually want to use the robots to send remote touches to their friends was highly individual and situation dependent—participants were less inclined to want to use the robots this way with strangers or friends that they wouldn’t normally touch in person. Yet, as they became more familiar with touch as a modality for communication, participants quickly became more open to it in *W4 (Communication)* and *W5 (Design Generalizability)*, and some even found sending touch-based messages to be preferred over movement-based ones.

6.1.2 How Participants Perceived ESSbots

We also explicitly asked participants to compare what they thought about the robots in *W1 (Conceptualizing ESSbots)* to what they thought about them by the end of *W4 (Communication)*. Overall, participants described what they thought the robots could communicate very similarly (emotions, simple messages), as well as how they would interact with them (playing games, expressing themselves, controlling the robots, mediated touch). However, when asked to compare what they thought the robots could do at the start of *W1 (Conceptualizing ESSbots)* with their perception of what they could do by the end of *W4 (Communication)*, they described their initial thoughts as more task-focused (move, fight, jump, play), and their thoughts following *W4 (Communication)* as more communication-focused (communicate, comfort, express emotion and feelings). Given that participants otherwise seemed to understand the robots' features and the goals for ESSbots, perhaps this difference reflects their confidence in the robots' actual ability to be communicative and expressive—by the end of *W4 (Communication)*, they may have felt more confident that the robots could actually be used in those ways.

Participants' describing the robots as more communicative as time went by may reflect the different ways they perceived the robots, and how that perception shifted over time. Similar to our results from the exploratory workshops, we found that participants talked about the robots in the same conceptual ways, where robots could be seen as objects, as representing themselves or other people, or as having animal-like qualities and characteristics. Notably, participants typically described the robots more like objects when they discussed using the robots to play games or complete tasks (e.g., as chess pieces). On the other hand, they used more personal language when describing robot behaviours or communication, sometimes explicitly identifying the robots as representing them or their friends. Given that the focus of our workshop series was to design ESSbots to support connection and communication remotely, it makes sense that participants ultimately focused more on these aspects of the robots rather than how they can be used as objects in a game.

Additionally, participants pointed out several differences between the ESSbots concept we presented them with in *W1 (Conceptualizing ESSbots)* and the existing social technology they use, such as the embodied nature of swarm robots compared to texting and the attention-grabbing nature of physical robots compared to screen-based notifications. The new group of participants we brought into *W5 (Design Generalizability)* identified these differences as well: "I think that it's different as in, it's obviously physical, it's not just text on a screen or something like that. So it's cool to have a new way of communicating other than just reading. It's actually physical, it's in front of you" (P13, *W5 (Design Generalizability)*).

6.1.3 Suggested Improvements

Finally, we note that participants mentioned several aspects of the robots that we could improve upon even in *W1 (Conceptualizing ESSbots)*, such as making the LED lights more visible, adding additional features like audio messages or screens, or providing different accessories for the robots, like different play mats or robot casings with different textures. Further, they noted that the robots could potentially cause problems because they are tangible and in someone's remote physical space: for example, it would be easier to annoy or distract another person with the robots. Some participants in *W1 (Conceptualizing ESSbots)* also felt like the robots would be better suited for a younger age group, however, most participants felt like they would use them and that they weren't too old for them. Additionally, participants in *W1 (Conceptualizing ESSbots)* mentioned there might be a novelty effect with the robots—however, when we asked returning participants in *W5 (Design Generalizability)* whether they found this was the case over the course of the workshop series, they instead commented that they actually found the robots more fun at the end when they could do more things and they understood how to use them better.

In general, participants seemed open to discussing how we could improve the robots or interaction design throughout the workshop series, and we discuss the suggestions they made regarding specific aspects of interacting with ESSbots in more detail in the following sections.

6.2 Giving Access: Customization and Control of ESSbots

We gave participants several different kinds of control methods to investigate how and why they wanted to interact with and control ESSbots. Interestingly, we found that the initial thoughts participants had about control shifted once we actually gave them examples of different control methods to try out for themselves, particularly when it came to the idea of directly programming the robots on their own.

6.2.1 Visual Scripting and Emotion Buttons

Initially, participants were hesitant about the idea of programming the robots, generally feeling more comfortable with the concept of pre-programmed behaviours.

They were open to integrating the robots into existing social tech or using them from their phones, and particularly liked the idea of the ESSbots coming with a pre-programmed set of emotions that they could combine together (e.g., P10 suggested that "If you have a base of fear, sadness, happiness, [and] anger you can allow them to be mixed together to get more different and more specific emotions"). However, some participants expressed interest in programming the robots directly, and we found that most participants, even the ones more hesitant about programming in general, described having previous experience with visual scripting programs like Scratch in the past. Thus, we hypothesized that visual scripting might be a more accessible way to give participants a high level of control over the robots without them having to worry about the details of a typical text-based programming language.

When we had participants try out our own visual scripting prototype in *W2 (Customization & Control)*, they were quickly able to understand how it worked and were excited to try it out for themselves. They described the prototype as easy to use, and specifically liked that it gave them more control over the robots compared to the other methods we showed them (pre-made buttons and remote control using a game controller). Most participants found that they were able to get the robots to do exactly what they wanted using this control method, and two participants in particular were very eager and suggested including additional program blocks like if statements and variables to make the system more robust. Overall, 7/9 participants indicated visual scripting was their favourite method (2/9 preferred buttons, and 0/9 preferred the game controller).

By the end of *W4 (Communication)* and *W5 (Design Generalizability)*, the group of returning participants were able to author complex behaviours with the final visual scripting prototype (see Figure 6.1 for an example), although they still sent and responded to messages using pre-made buttons in the interface (see Figure 6.2a). However, they did sometimes opt to use visual scripting during the remote sharing activity in *W4 (Communication)* and *W5 (Design Generalizability)* even in some instances where they could have used the buttons in order to be more expressive. For example, in *W4 (Communication)* one group used an emotion button to send the pre-made angry behaviour, and in response the other group tried to make an annoying song with the robots to specifically try and annoy the first group

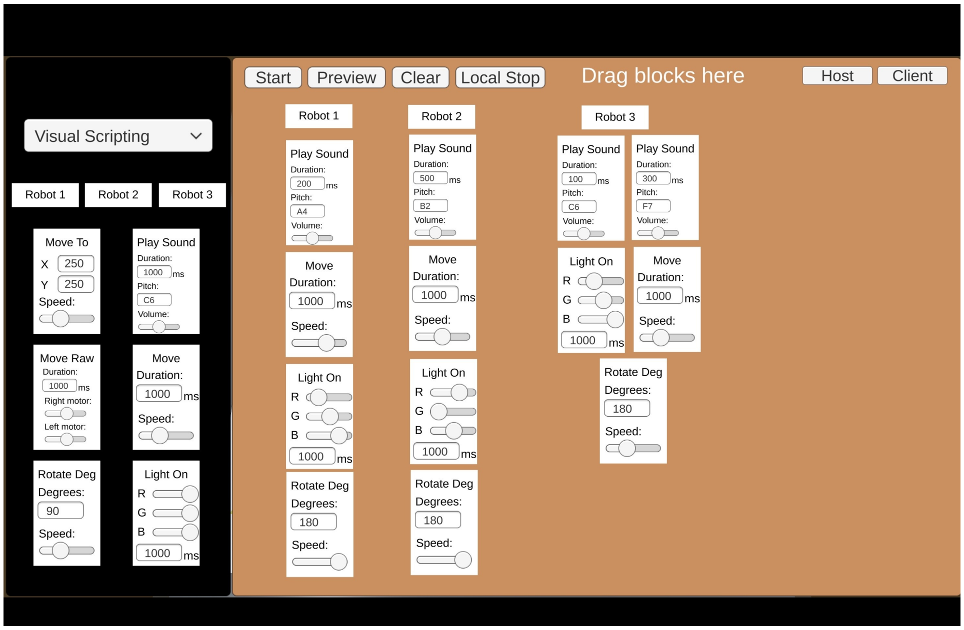
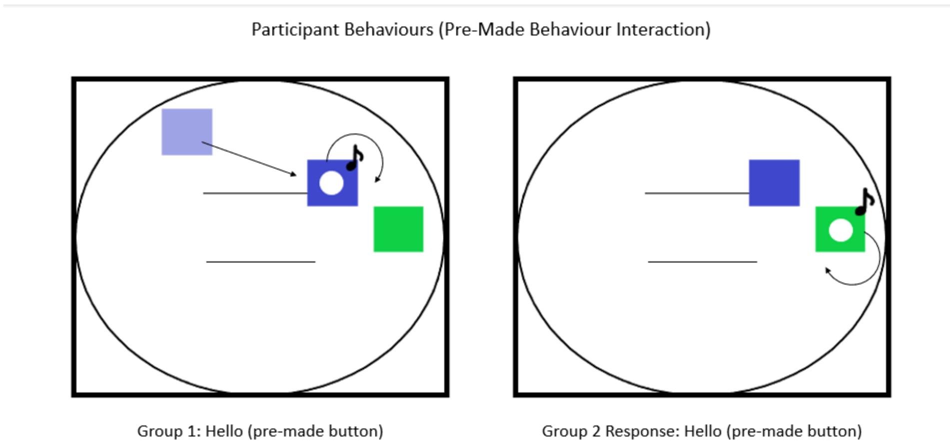


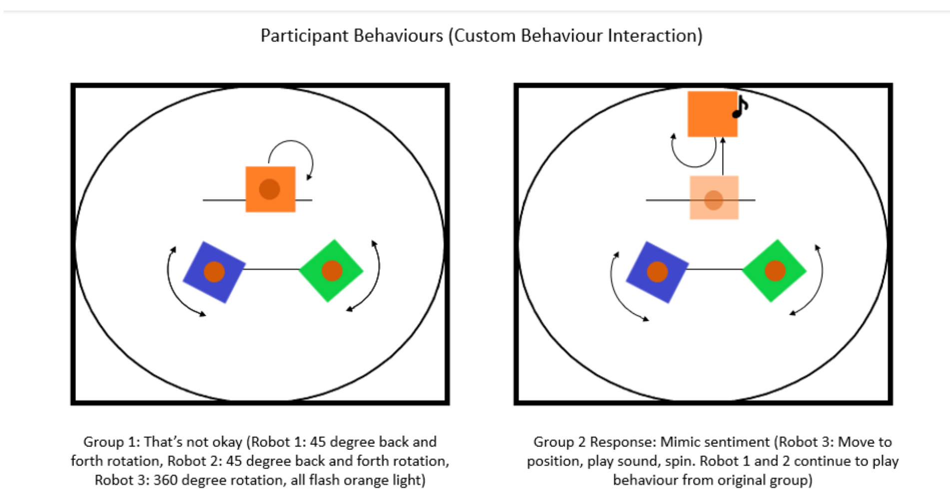
Figure 6.1: A complex behaviour authored by participants during *W5 (Design Generalizability)*. Participants have also modified parameters in several of the blocks to further customize the original atomic behaviours.

more rather than simply sending the pre-made angry response back. Participants also sent and responded to messages entirely with visual scripting, such as one example in *W5 (Design Generalizability)* where the returning group of participants used several robots to communicate the phrase "that's not okay"—the new participants weren't sure what they meant, but tried to mimic the sentiment by sending the robot that was originally spinning away from the two rotating robots before playing a sound and spinning in place as well (see Figure 6.2b).

However, just because visual scripting was the most preferred method does not mean that other control methods did not have merit, and ultimately we decided it was important to include a combination of pre-made buttons and the visual scripting control in our final prototype. This choice primarily arose because participants noted that they type of control they wanted access to was situational: visual scripting was good when they had more time available, were bored, or just wanted fine



(a) Example of reaction and response with pre-made behaviours in *W4 (Communication)*.



(b) Example of reaction and response with custom behaviours in *W5 (Design Generalizability)*.

Figure 6.2: Illustrations of behaviours participants authored in response to one another using the final prototype, where the original message is shown on the left, and the response by the other group is shown on the right.

grained control to express themselves. However, buttons were useful when they had less time or didn't want to fully program a behaviour themselves. Some participants also felt that it would be easier to communicate more complex emotions with buttons, likely because there is automatically a shared understanding of what those messages would mean and it would be harder for miscommunications to occur.

6.2.2 Tangible Robot Control

We primarily focused on interface-based control methods because of the ways participants described using robot behaviours to express themselves in both the exploratory workshops and in *W1 (Conceptualizing ESSbots)*—they explicitly described modifying actions, such as changing the colour or speed of a flashing light, in order to layer behaviours and provide context for communication. While it would be possible to enable tangible parameter adjustments, in general tangible control lends itself better to path following, which we did test with participants using both a controller in *W2 (Customization & Control)* as well as direct, tangible control via a robot itself acting as a reference sensor that the other robots could follow in *W5 (Design Generalizability)*.

We originally anticipated that participants would be more open to using a game controller to directly pilot the robots, rather than something like visual scripting, since some people seemed reluctant to try programming in *W1 (Conceptualizing ESSbots)* and a game controller serving as a "remote control" for the robots seemed like an intuitive way to give participants access to robot movement. Buttons on the controller could also map to other robot features, such as light colour, so participants could still have some access to behaviours other than just movement. However, when we gave them a prototype to try this game controller method in *W2 (Customization & Control)*, they felt that it was hard to use and overall rather limiting. For example, P1 noted that: "It's more basic, because you can only spin and change the colours [with the controller]. On the computer you can change the emotion", and in general participants didn't feel like they could get the robots to do what they wanted with the controller. However, when asked about other possible control methods they might want to use with the robots, participants suggested path drawing with a mouse or finger sensor instead, suggesting that they weren't completely opposed to more tangible forms of control.

Indeed, participants enjoyed the touch-based version of “follow the leader” robot control that we showed them in *W5 (Design Generalizability)*. Possibly this was because they could tangibly interact with the robots and have them follow their hand around the mat, and they consistently described it as easy to use, even with several robot “followers”. However, they also noted that the touch-control method was better suited to playful interactions, as it was largely movement based and would be difficult to add important layers necessary for communication, like light and sound. Thus, this control method is ultimately situational as well, and could be incorporated into a future version of the prototype to better support group play.

6.2.3 Showing Personality Through Control

Finally, we describe the importance of accessible robot control to customization and personalization. While participants described and came up with robot behaviours that both utilized the entire swarm as well as focused on individual robots, they generally felt that it was important for their friends to know who was who among the robots in their swarm, as well as who sent a particular message if they utilized multiple swarm robots at once. Additionally, participants sometimes treated the robots as directly representing them, essentially acting as their avatar. Sometimes this was in the context of communication, since they felt that certain messages could be better conveyed by robots acting as representatives, such as when communicating relational phrases like “hello” or “that’s not okay”. The idea of robots as avatars also came up in other contexts, like more playful interactions such as the robot dance party we demonstrated in *W3 (Social Dynamics)*, where participants wanted to use their own robot to share coreography with their friends.

In either case, if robots are meant to represent individual people in a friend group, there must be ways for their friends to understand which robot represents each person. When we asked participants in *W3 (Social Dynamics)* how they might want to show their personality through the robots, not only did they suggest aesthetic customization, like different coloured robot casings or attachable robot accessories (like hats), but they also suggested using specific behaviours to indicate who they were to their friends. Examples included different colours, sounds, or movement patterns to help indicate their own personality, such as P4 suggesting their robot should be "energetic", demonstrating this by miming a rapid zig-zag motion with their hands, or P1 suggesting their robot would spin very fast with a pink colour to indicate it was them before sharing a message.

These aspects of personality are likely best supported by control methods that are highly customizable, like visual scripting, where participants can explicitly program individual robots however they want. However, it may be useful for the system itself to manage these personal behaviour "calling cards" once individuals have programmed them on their own, so that users do not have to remember to share these messages each time they use their robots. Participants even suggested linking aesthetic customizations to an app and customizing them virtually—this could potentially be a form of AR, where participants could see who individual robots in the swarm represented by viewing them through a phone camera.

Beyond simply understanding who was who within a group, participants felt that the importance of robots reflecting their personalities well may depend on who they're communicating with: "If it's for distance friends, I would say it's important that it has her personality, and they don't see me daily, so they need to know its me. With other friends they may know who I am, but with distance friends it's a difficult thing" (P5, *W3 (Social Dynamics)*). However, participants agreed that even if it wasn't always important, it would still be fun if the robots reflected them. Notably, P11 pointed out that "if you're controlling it, it's already acting like you would, cause that's what you're already doing". Thus, giving participants accessible control over the robots is ultimately how they can express themselves and show their own personality, which is essential for meaningful social interaction.

6.3 ESSbots and Social Dynamics

Since ESSbots are composed of individual robots that can be used on their own or as a swarm, we were interested in how participants would navigate situations like individual robot identification and group co-opting, especially if each person in the group strongly identified one robot as directly representing them. We were also interested in other aspects of social interaction that could be mediated through the robots, like social touch, and whether teens felt like the robots could actually help them feel connected and supported by remote others.

6.3.1 Group Behaviours

As discussed in the previous section, participants described wanting to communicate with both individual robots that represented them, as well as several robots that acted as a swarm. Group behaviours were often considered to be useful to better communicate particular emotions, and in *W1 (Conceptualizing ESSbots)*, we specifically asked participants to try and come up with robot behaviours using either a single robot or several in order to communicate the same set of emotions. In some cases, they felt that using several robots was easier and could help them distinguish between emotions with similar states of arousal, like excitement or anger, where several robots could move around erratically with differently coloured lights depending on the valence of the emotion.

In some instances, group behaviours also combined both the idea of a collective swarm and individual robots that represent group members, such as the "comforting" behaviour: participants felt that one robot should be stationary (the robot needing comfort), and the other robots should circle around it. The ways that the robots themselves could be perceived to relate to one another is an important element of conveying meaning in these sorts of behaviours, and participants felt it would be much harder to convey the idea of comfort with only one robot in isolation.

Of course, introducing the idea of group and swarm behaviours also introduces the possibility of the system potentially managing the robots in a more autonomous way, where individual group members may have very little control over the swarm as a whole, or even individual robots in it. To explore this idea with participants, we showed them an example of a more coordinated swarm behaviour in order to investigate how they felt about their level of control over individual robots in a more autonomous group by demoing a "robot dance party" in *W3 (Social Dynamics)*, where robots could perform different dance moves that we manually synced to music.

We ultimately found that despite recognizing that choreography could be smoother if the system manages the entire swarm, participants wanted to have at least some control over their robot in the dance. Ideally, they wanted both a limited-control option, where they are able to control some parameters, but the swarm itself manages the overall dance party and music synchronization; as well as full control, where they have complete control over their robot's actions in the dance party. As P10 pointed out: "[With] no control at all, there's nothing that you chose. It's the robots' decision, but they're your robots and you should control them. It's you and your friends. So obviously it should have some spark of you and your friends in it, not just the robots decision". Thus, ESSbots should likely never act entirely autonomously, even for specific tasks that could be autonomous, like shared music listening or a dance party.

6.3.2 Co-opting and Consent

In order to explore the idea of co-opting and ownership—that is, who should be allowed to manipulate a given ESSbot (the current "owner" or individual using a single robot as their embodied avatar, or any person wanting to use the robots to express their idea for the swarm), and how the system should resolve conflicts in such instances—we first introduced participants to the idea by showing them a demo of "proximity dancing", where one robot joins in a group behaviour when it gets close to the other "dancing" robots. We also demoed a series of explicit co-opting examples, where participants were asked to imagine they used a single robot to send a behaviour (e.g., sad, happy), and then someone else used all robots, including "their" robot, to respond with either a group sad or happy behaviour.

Similar to the other group behaviour example with the full-control dance party discussed in the previous section, we found that participants wanted to retain control over "their" robot in both the proximity dancing and explicity co-opting examples, although they were more or less open to the idea of co-opting depending on the situation. In the proximity dance example, some participants said they wouldn't mind if their robot automatically joined in a dance, or if they influenced another person to dance with them: it would still make them feel good, "like my friend also wants to dance with me" (P5, *W3 (Social Dynamics)*). However, other participants pointed out negative aspects of this kind of co-opting: P1 and P11 mentioned that having their robots join in on their own might be distracting or cause problems (e.g., if one person left the room and is unaware their robot moved off the play mat). P10 mentioned that it could be problematic if their robot joined in automatically, because it might not accurately represent their current emotions—not only does it not reflect how they feel, but it could be misleading for their friends if they think they're happy or excited when in reality they are not.

Similarly, participants were open to the idea of their robot being co-opted so that someone else could use it to send a message, however, they felt like there were some situations where they wouldn't want their robot to be used this way. For example, if they sent a message and a friend responded using their robot as part of the overall response, as long as they felt as though their friend had acknowledged them and was indeed responding to the message they sent, then co-opting the robots this way would be acceptable. However, participants were much less open to the idea if they felt like their friend was talking over them: "If it was trying to like block off your original comment as insignificant, then that's a problem. That's not a good friend" (P10, *W3 (Social Dynamics)*). In order to prevent their robots being used when they didn't want them to be, participants suggested having options like a do not disturb mode, or even a notification explicitly requiring them to give consent before someone could use their robot in a group behaviour. They also suggested their robots could react and tell others "no", such as by turning on a red light or making a sound.

To further explore the idea of showing consent with the robots, we showed participants another demo in *W4 (Communication)*, where participants could consent to join in a group behaviour by lifting up their robot. We also demoed an example of a "majority vote" system, where by lifting up their robot, participants could cast a vote whether or not the group should engage in a new behaviour. If enough people agreed, then all the robots would participate. We found that participants preferred the first method: as in *W3 (Social Dynamics)*, they wanted to retain their own autonomy, and wanted to see what behaviour they were joining before they agreed to be part of it. Similar to what P10 pointed out in *W3 (Social Dynamics)*, P11 said that even though the second method was a democracy, it wasn't really fair, because: "You're communicating something you don't mean to communicate. If it was anything else, like maybe like 'what's your favourite ice cream, we're going to get ice cream', that's fine because it's not how you're expressing yourself. But you know, if you're trying to express your own emotions and someone is doing that for you, displaying their emotions and not your thing, that's not good".

6.3.3 Support, Connection, and Touch

Overall, participants felt like using the robots with their friends would help them to feel closer to them, especially when using the robots to as a form of mediated social touch. Both the returning group of participants and the new group of participants in *W5 (Design Generalizability)* felt that the ability to communicate via touch was important: "I feel like it just makes it more personal, like I'm here, not just saying it, which is why the robots are sometimes better than just messaging them, or like DMing them, cause it's got touch" (P13, *W5 (Design Generalizability)*). They also felt like using touch was a way to communicate without having to engage in a full conversation: "I really think that would be really helpful, cause sometimes I know my friends are feeling a little bit bad and I want to help them and I cant, because I'm not there. Or like sometimes I know we have little fights, and I want to tell them like everything is okay, without needing to like, text them" (P5, *W5 (Design Generalizability)*).

The way that participants wanted to use touch generally reflected the ways that they already touch their friends in person. For example, P11 described touching their friends in a playful way (e.g., smacks), and preferred the demo example where the robots repeatedly bump against their hand. P5 described similar experiences, however, they also noted that they wanted to use the robot touches to comfort their friends since they know their friends don't normally like to talk about how they feel. Other participants felt like they would be unlikely to use touch at all, mainly because they felt it was too personal and they don't typically touch their friends in person anyway.

Additionally, existing group dynamics played an important role for how connected participants felt they would be using the robots, as well as how likely they were to use features like mediated touch. For example, P11 mentioned that they would likely use the robots in very different ways depending on whether they were communicating with close friends or acquaintances, and P1 mentioned that they would be more cautious sending touch messages in general since they would be unsure whether the person on the receiving end was comfortable with it—again, consent was an important aspect of these interactions as well.

Notably, when we had participants send remote touch-based messages to one another in *W4 (Communication)*, even participants who were initially hesitant about using the robots for mediated touch were more open to it. This change was largely due to the fact that the person receiving the touch had to explicitly consent to it by picking up a robot first—thus, participants felt there was less risk that the other person would feel uncomfortable with a touch-based message.

When we asked participants in *W4 (Communication)* whether or not they felt sending touch messages to the remote group made them feel closer, several participants preferred touch messages to movement-based ones, and felt like that they helped them to feel closer to the other group. However, some participants pointed out that if they already felt close to their friends, then the touches from the robots wouldn't increase that connection. On the other hand, when we had the returning group of participants send and receive the same touch based messages with the new group in *W5 (Design Generalizability)*, they had a very different reaction. They still felt comfortable sending touch messages to people they didn't know that well, since there was a built-in element of consent to the touch message interaction: participants would have to pick up the robot in order to receive the message on their end. However, the returning participants all said that in this case, the touch messages did not help them to feel closer to the other group. As P2 said: "If we're sending each other messages, like [the people from the workshop series], I feel like it helps me. But I don't know [the new group] as well, so I don't feel a connection, really. I don't feel it". The new group of participants also commented that they would only use the touch messages with people they knew well, rather than strangers, because "you're making the robot touch them" (P14, *W5 (Design Generalizability)*), similar to an in-person experience of "randomly grabbing a stranger's hand that you just met" (P14, *W5 (Design Generalizability)*).

Thus, we ultimately found that touch was an important element of interacting with ESSbots: it could help participants feel closer to one another, and could support them to interact remotely via mediated touch in similar ways to how they might interact in person. ESSbots can also reflect other kinds of social dynamics and relatedness common to in-person group interactions. In particular, aspects of respectful in-person interaction, like consent and active listening, were important to participants when using ESSbots to communicate with others. Existing group dynamics between those using the robots is also quite relevant—not only does it change how individuals want to express themselves with each other, but it also affects whether or not they feel comfortable and connected to their communication partners at all, especially when communicating through mediated touch.

6.4 Communicating with and Through ESSbots

Throughout the workshop series, participants identified simple messages and emotions as the most effective type of message to communicate with ESSbots. They frequently described using ESSbots in a playful way rather than trying to share specific messages with one another, which also influenced how they described responding to messages others might send them with ESSbots as well.

6.4.1 Effective ESSbot Communication

Participants came up with several ways to avoid miscommunication and communicate well with remote others.

Context through simple layered actions: Similarly to our findings in the exploratory workshops, participants in the workshop series felt that the robots would be particularly useful for communicating and expressing their emotions, but would not be well suited for complex messages or conversations where they needed to share information and provide context. However, they felt like features such as the LED lights would help them to add layered meaning to the messages they authored with the robots, which could potentially minimize miscommunications. Some participants also mentioned that if they were confused by something their friend sent them, they would likely switch to a different communication platform (like text messaging) to explicitly ask their friend what was going on.

Participants found that the simple actions the robots could do both helped and hindered communication: on one hand, they felt that the robots were easy to control, and it was possible to express themselves creatively with movement, lights, and the sounds that the toio™ robots can make. On the other hand however, some participants found the actions too simple, and wanted additional features like screens or full audio message capabilities in order to be able to use the robots for longer conversations.

Interpreting approximate meaning: When participants actually tried out our prototype to communicate with each other remotely, they were generally able to pick up on the overall sentiment of a message even if they weren't able to identify exactly what it was. For example, in *W4 (Communication)*, one group used visual scripting to send one robot in a jittery line across the play mat with a red flashing light in order to communicate nervousness. The other group thought they were communicating some kind of negative emotion, and suggested that they might be having a bad day, were frustrated, or having a rough time, and one participant thought that the robot was "pacing around"—an activity common for someone who is nervous, which is indeed what the first group was trying to communicate. Additionally, participants were easily able to recognize the pre-made emotion behaviours, although they sometimes used them in unexpected ways, such as sending the "angry" behaviour when they didn't understand a message.

Situational communication: Participants also felt like they would prefer to use ESSbots to communicate in specific situations, and with specific people, as discussed in the previous section. Touch-based messages in particular could help them feel closer to remote others, and they believed that ESSbots would be particularly useful to stay in contact with friends they rarely see in person. Some participants noted other advantages to communicating with ESSbots as well, such as the ability to be more expressive than over text, and the possibility to use them for non-verbal communication, which may have less expectations or commitment if they want to briefly stay in touch but aren't able to fully engage in a complete conversation. The fact that they may need to spend more time creating messages and thoughtfully interpreting how others use the robots may also have benefits: as P13 pointed out in *W5 (Design Generalizability)*, "the fact that you actually have to like, program it [is better than texting or calling]. They actually had to do something to tell me this". As another example, P5 felt as though the ESSbots would help them be more empathetic: "Now you know how they express their feelings. So some people when they're like 'oh I want to hit everyone in the way' and there are some people with just a red light and they stay there you know. It makes you see other's personality and the way they show their emotions".

6.4.2 Reacting and Responding: Dynamic Communication

We were particularly interested in how participants would use the robots to dynamically respond to other people, which we explored in *W3 (Social Dynamics)* via wooden robot proxies as well as in *W4 (Communication)* and 5 where participants directly used the prototype to respond to messages.

Contextual responses: Interestingly, we found that in both scenarios (i.e., using proxies or the robots themselves) participants tended to respond in similar ways based on the context of the original message. For example, when the original message was interpreted as more positive, participants typically responded by mirroring the original behaviour or joining in with a similar level of energy—while they may not know the context, they were eager to show their friends they were happy too. Participants tended to mirror the "hello" behaviour as well, or behaviours they interpreted as a greeting, because in a regular conversation that is typically how someone should respond (i.e., by saying hello back).

In instances where participants perceived the original emotion to be negative, they were less likely to mirror the emotion back. Instead, they typically wanted to try and comfort the person (e.g., sending the comforting pre-made behaviour when they thought the original message was "nervous"), or cheer them up (e.g., sending the pre-made excited behaviour in response to angry). In instances where these reactions were more playful, participants recognized that it might not always make sense unless their friends knew them well and would understand why they responded that way. Sometimes participants were indeed able to pick up on this playfulness, such as when the two groups in *W5 (Design Generalizability)* sent contradicting emotions twice in a row: "they're excited that we're sad, we're angry that they're surprised" (P14, *W5 (Design Generalizability)*). Both P13 and P14 felt as though the other group was continuing the "game" they initially set up when they responded "angry" to their surprised emotion, and while P13 felt that this interaction would cheer them up, P15 pointed out that if they really were sad, then an excited response would be upsetting.

Handling uncertainty: Individual participants tended to handle these sorts of perceived miscommunications differently. For example, they sometimes tried to mirror the original behaviour even if they were unsure what it was as a way to show solidarity with their friends. On the other hand, they sometimes responded differently, such as by sending the “angry” emotion when they didn’t understand a behaviour. In the latter example, the person who sent the initial message thought the other group responded that way because they were initially unclear and the other group didn’t understand what they were trying to say. However, they did not pick up on the playful element in the “angry” response, and their own strategy for handling miscommunications was to text their friends to ask what was going on.

Thus, the overall flow of communicating with ESSbots is likely friend-group specific, and ultimately reflects how individual people in the group interpret messages. While it may not be possible to achieve perfectly clear communication, participants generally enjoyed using the robots in a communicative way, and enjoyed the playful, expressive nature of sending messages to each other.

6.5 Design Generalizability

Not only were we interested in whether or not new participants could use and understand our design—we were also interested in how they would try to communicate with ESSbots given their limited previous experience with them, and whether or not having influence at earlier stages of the design process would impact usability or likeability of the system as a whole. Thus, we decided to run *W5 (Design Generalizability)* with a combination of returning and new participants, keeping the groups separate for some activities and bringing them together for others so they could discuss things together.

We provided the new group of participants only a minimal description of ESSbots, similar to our initial introduction in *W1 (Conceptualizing ESSbots)*, since we were curious how quickly the new group would understand the technology and how to use it. However, we still helped to prepare the new group for the non-verbal style of ESSbots communication by playing a short game of charades before the workshop started so they could get a bit more familiar with other participants and start thinking more about embodied communication. Participants were then split into returning and new groups so they could try out the prototype and send messages to each other. They completed usability surveys and a survey about their thoughts on ESSbots before returning as one group for some final discussion.

6.5.1 Conceptualization and Perception

Overall, the new group of participants were excited about the prototype and eager to try it out. Similar to the original group, they liked the current features that the robots had, and had several suggestions for how to improve them, such as by adding customizable casings or LED screens. Before trying the robots out for themselves, they thought that they would be able to use them to communicate emotions and simple messages, and were all interested in interacting with them and trying out the different features. Some of the participants even decided to use their break time during the workshop to continue to experiment with the prototype and author custom behaviours with the visual scripting control.

After participants had time to use the prototype, we explicitly asked them to describe ESSbots as though they were explaining it to someone new in order to understand whether they fully understood the technology. Both the new and returning participants all described the system similarly, describing some of the robots' features and how they can be used to communicate emotions to others. For example, one of the returning participants described ESSbots as: "They are little robots that show a new way to communicate with your friends, by using emotions and commands", and one of the new participants described ESSbots as: "White, mini cube shaped robots that you can control/program to move, make sounds, light up colours and express emotions. These robots can be used to communicate your current state to a friend (e.g.: make the bots move rapidly and flash red when you feel angry)".

6.5.2 Usability and Self-Design

In addition to evaluating whether or not the system itself was usable for a new group of participants, we were also interested in whether or not having an active role in helping us to design the ESSbots interaction prototype would affect participants' overall engagement with and enjoyment of the technology. That is, if participants could engage in limited "self-design" of a system they would eventually use with their friends by acting as advisors in our workshops, would they identify any benefits from that process?

Usability: In general, the new group of participants found the prototype easy to use (see Figure 5.5), although at first they thought there may be a learning curve in order to get the robots to do more complex behaviours. While the new group of participants didn't immediately guess what the pre-made behaviours were when they watched the returning participants play around with the prototype, once they tried out the buttons for themselves they thought all the behaviours were clear and made sense.

Once they tried out the prototype themselves, the new group of participants were quickly able to author complex behaviours, and they all seemed excited to use the visual scripting control to author custom behaviours for themselves. In general they felt as though they were able to get the robots to do what they wanted, and even though it could be frustrating when they made mistakes, they described it as a learning experience and something they were willing to work through. Both the new group and returning group of participants also self-reported a similar level of comfort for interacting with the robots, as well as a similar level of confidence they they understood what the robots could do see Figure 6.3 for a summary of these results). Both the new and returning group of participants also felt that it would (or had) taken them a short amount of time to become confident using the robots and communicating with them.

Of course, the new group of participants had several suggestions to improve our interface or the robots themselves. Some suggestions were similar to those from our returning group of participants, for example, one participant suggested creating a version of the app for phones, since they felt it would be accessible to more people that way. Other suggestions included more options for different types of audio messages, moving the location of the LED light to the top of the robot so it would be more visible, or incorporating the ability to add new emotion buttons or edit the ones that are there. The new participants also came up with several suggestions that our returning group of participants did not already mention however, such as supporting concurrent combined actions via visual scripting rather than a strict sequence of events, adding axes to the toio™ mats to better program position locations, and developing a clearer way to show which physical robot was which

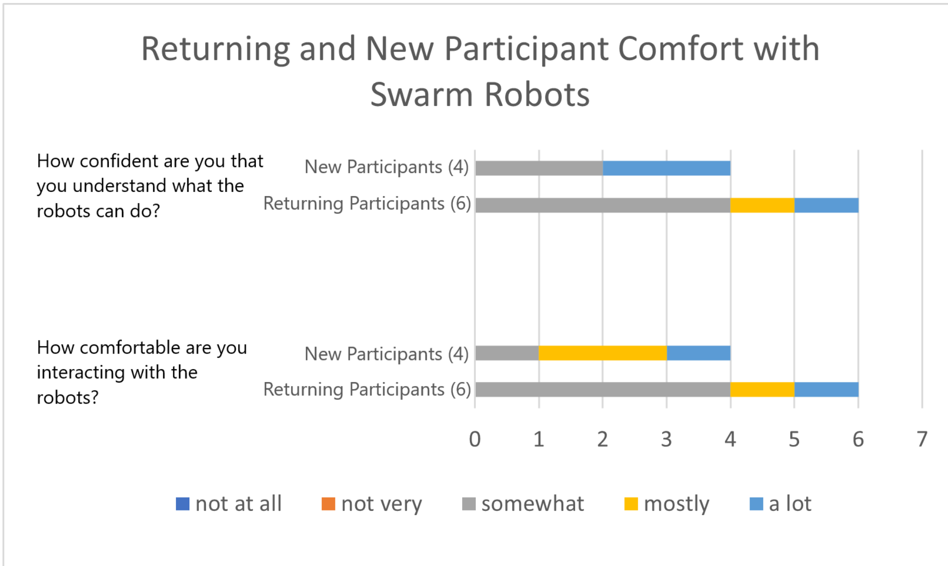


Figure 6.3: Comparison of how both returning and new participants felt about interacting with the swarm robots.

when programming instructions for them using the visual scripting blocks on the interface.

Self-Design: When we asked all participants in *W5 (Design Generalizability)* whether or not they felt as though having influence on our design process would change how they reacted to the robots, both groups agreed that it would. The new participants felt that if they had been able to make suggestions earlier, it would have been possible that the design may have gone in a different direction, which may have in turn caused them to like the final prototype more. The returning participants agreed that that this did happen for them, and once they saw us incorporate their design suggestions, they liked the overall system better. P5 explained how they felt as a co-designer as: "It does what you want them [to], and you feel comfortable. So by using our suggestions you guys managed to give everyone the opportunity to feel comfortable using the robots".

Notably, the new group of participants felt that just spending more time with the existing design could help them to become more comfortable and confident with the robots, even if they didn't design it themselves. They also felt that the group of people they first used the robots with could have an effect on how they felt about them: "I think the people you're with when you start to use them can really do it, because you might start to do one thing, and sort of learn how to do it, cause someone might show you and you figure it out" (P13, *W5 (Design Generalizability))*. However, they felt that the system was easy enough to use that they would have eventually been able to figure everything out on their own, and even if they struggled to author their own behaviours with the visual scripting control they could always use the pre-made buttons to send messages easily.

6.5.3 Communication

Similarly to the returning group of participants, the new group felt as though ESS-bots were particularly suited to communicate simple messages and feelings. They all liked having the option to send touch messages as well—one participant described it as feeling as though they were holding their communication partner's hand, and they all agreed that it made them feel closer to the people they were communicating with. However, they weren't always confident that they understood what the other group was saying, and the original group of participants also felt like it was harder to communicate with the new group because they didn't know them as well and they were unfamiliar with each other's communication style.

However, even though participants were less confident that the other group understood their messages, they were often still able to closely guess what the other group was trying to communicate. For example, the new group of participants communicated "lonely" to the returning group by having three robots move into a corner and slowly spin and turn blue, which the other group interpreted as a negative emotion, suggesting they might be sad or bored. When participants were less sure how to interpret a behaviour, they responded by sending a similar message back—for example, by using similar motions, light colour, and speed to try and match the energy of the first message.

Thus, communicating effectively with ESSbots may take time or require at least some level of existing closeness, especially when sending custom messages or responses. Additionally, since both groups of participants were interested in using ESSbots to play games with each other, adding additional features or control methods that better support playfulness is important—not only do participants want to play with their close friends using the robots, but more playful interactions can potentially transcend communication issues as there would be no need to interpret specific meaning from playful actions, like racing the robots or playing a board game with the robots as pieces.

6.6 Summary

In this chapter, we discuss our main qualitative findings from the workshop series. First, we describe how participants conceptualized ESSbots as a new technology for remote social connection: they liked the current feature set, and believed that ESSbots would be particularly useful to communicate emotions and be expressive with their remote friends. They recognized the benefits of ESSbots as a tangible and embodied technology, and often directly described the robots as representing them and their friends rather than as simple objects.

We found that participants wanted access to fine-grained control of the robots, but also recognized that other forms of control, like pre-made buttons or tangible control, were useful for particular situations. Pre-made behaviours could be beneficial for situations where someone had less time to talk, and directly piloting the robots could be useful for playing games together. Additionally, participants felt like by controlling the robots they would be able to show their personality through them. which they viewed as an important element of connecting with friends, especially friends they don't see often in person.

The idea of consent was particularly important for participants when interacting with ESSbots: they wanted to retain autonomy over "their" robot, but were open to the idea of someone else using it in order to send them a message or engage in a playful activity, like a group dance party. However, even in instances where they were open to the idea of co-opting, participants wanted to explicitly provide consent in order for their robot to be taken over by another person. Similarly, participants were more open to the idea of sending touch-based messages when they were certain that their remote communication partner would be willing to receive them, such as by explicitly consenting to receive the message.

Participants felt as though the robots could help them feel closer to one another, especially if they were using the robots with friends they were already close to. Touch messages in particular were viewed positively, however, participants did not like the idea of communicating via touch with strangers, feeling as though it would be too intimate or weird. Overall, they were able to use the prototype to send simple emotions and phrases to each other remotely, and often engaged in this communication in a playful way. They were able to react dynamically and interpret messages that others sent them, although they felt that effective communication would work best with people who already knew their communication style and how they normally reacted to things in person.

Finally, we found that the prototype we designed in our workshop series was engaging and usable for a new group of participants. They were able to quickly understand what ESSbots could do and how they could be used in practice, and were excited to author new behaviours themselves with the interface. However, they also recognized that having influence on the design process would likely improve how they felt about the prototype overall, and participants who did help design the prototype throughout the workshop series appreciated seeing their ideas get incorporated into the final design. They felt that having influence on the design process helped make them more comfortable with the technology, although even the new participants felt that the learning curve to get started with ESSbots was minor and something they would be happy to experiment with and work through on their own.

Chapter 7

Reflections and Design Recommendations

We return to our research questions and tie in our final design and participant comments to our initial grounding theory. We also reflect on the workshop series process, as well as highlight future design recommendations for ESSbots going forward.

7.1 Research Questions

Overall, participants reacted positively to the idea of ESSbots as a communicative remote social technology, and had several important insights that influenced how we approached our interaction design over the course of the workshop series. We summarize the results from our previous discussion sections on our conceptual model and interaction prototype in Ch 5 and the qualitative findings about how participants reacted to ESSbots in Ch 6, and directly address how our findings relate to our initial set of research questions. In particular, we focus on how teens conceptualized ESSbots, how they felt about controlling the robots themselves, and whether both our design and participant reactions to it reflected some of our initial grounding ideas or went beyond them in unexpected ways.

7.1.1 RQ1: Conceptualization

First, we consider RQ1: *How do teens conceptualize the ESSbots system and what they can do with it?*, including how they conceptualize their interactions with the robots, how they would use them and engage with them with their friends, and whether their perceptions about the robots shifted over time as they helped in the interaction design process.

RQ1.1: Conceptual constructs and interaction: In both the exploratory workshops and main workshop series, we found that teens viewed the robots in several different conceptual ways, including as directly representing people, as animal-like creatures, and as controllable objects. The ways that they described the robots often related to how they wanted to interact with them, giving insight into RQ1.1: *How do teens conceptualize the swarm robots and their interactions with them?*. When describing using the robots to communicate emotions and feel closer to their friends, they typically framed the robots as direct proxies for themselves or their friends, or described their behaviours as animate and having animal-like qualities.

In these instances, participants seemed to view the robots as a live, embodied part of their interaction, and felt that retaining autonomy over a robot they considered to represent them was important—if it were to act as their avatar in the group, it should accurately reflect their current emotions and require consent by others in order to be co-opted as part of the swarm by someone else. Notably, participants were open to robots having some level of animacy and agency, such as in pre-made behaviours or the robot dance party where the system manages at least some level of coordinated interaction. However, their own *autonomy* to choose when these behaviours happen or when the robots can indeed act more independently was essential.

When participants described using the robots to play games with one another, on the other hand, they tended to view the robots as game pieces, and described them in a more detached way—in these instances, the robots acted simply as objects to support the group in order to play a remote game together. However, sometimes even these playful instances could be embodied, such as when one participant suggested using the robots to play tag or race their friends.

RQ1.2: Engaging and communicating with ESSbots: To address RQ1.2 (*What* *kinds of concepts, emotions, ideas, and more interactive forms of "play" do teens want to share and participate in using the system?*), we note that in addition to desiring playful interactions with the robots, teens also wanted to use the robots to communicate and feel close with remote others. They believed the robots were best used to communicate emotions and express themselves, and felt that they would prefer to use other remote communication technology to communicate more specific messages or if they needed to avoid miscommunications.

Additionally, participants found that access to multiple robots allowed them to better express their feelings with the system, as they could use multiple robots to better convey relational meaning (e.g., robots circle a stationary robot to comfort it) or the overall level of arousal of emotions (e.g., many robots to represent excitement). The swarm itself also directly supported interesting potential ongoing reactions and responses to messages, where teens could use the robots as avatars of themselves and their friends and interact with them through the swarm (e.g., approaching a specific robot with their own to say hello). These kinds of interactions would be difficult or impossible with only one robot, and thus access to the swarm is essential to support interesting group interactions.

They also felt like the robots could be useful as a notification or attention-grabbing initial interaction with their friends: because the robots would be physically present in their friends space, they felt as though it would be harder to ignore the robots when they wanted to get their friends attention compared to something like a text message. However, the context for who and why they were using ESSbots to communicate with was important. Participants felt that they were more likely to use certain features, like touch, with close friends, and knowing their communication partners already would help them to understand each other and communicate in a playful, reciprocal way.

RQ1.3: Influence of design on perception: Finally, to address RQ1.3 (*Do teens perspectives about ESSbots change as they help design what the system can do?*), we primarily reflect on our results from the design generalizability workshop. We found that while the design itself was accessible and engaging to new participants, both the new and returning participant groups felt that having influence over the design process would make them like the final design more than if they had no impact on the design at all. They also felt that helping to design the technology made them more comfortable with it, although both groups were ultimately still comfortable interacting with the robots regardless. In general, participants also seemed to view the overall concept of ESSbots very consistently over the course of the workshop series. They repeatedly brought up the same ideas about communication, such as using ESSbots for simple emotions and utilizing features like the LED lights to provide context through layered meaning. However, participants still felt that they better understood how the robots worked and how they could be used for emotional communication by the end of the workshop series compared to the beginning.

7.1.2 RQ2 and RQ3: Providing Access

We found that the idea of atomic behaviours provided us with a useful backend system structure in order to both directly and indirectly provide teens with accessible access to different forms of robot control, and discuss how, in combination with various accessible methods of control, they could support participants to author and share expressive behaviours with one another.

RQ2: Atomic behaviour set: To answer RQ2: *What are the elements and properties of a set of swarm robot behaviours that can effectively support affective communication between remote friend groups?*, we based our initial set of atomic behaviours on the ways participants described using robot proxies to communicate during the exploratory workshops—that is, they naturally described layering different types of behaviours together, like movement and lights, to create more complex and clear meaning (see Table 5.1). We then further evaluated the structure of our proposed set of behaviours through a card sorting task in *W1 (Conceptualizing ESSbots)*.

As discussed in Ch 5, we found that separating simple actions from possible parameters and elements of swarm control allowed us to easily build more complex behaviours from simple ones, which could in turn be further modified using a robust set of parameters. These atomic behaviours also supported easy backend creation of common swarm behaviours by combining atomic actions together with swarm elements, which we used to create several pre-made behaviours, such as the dispersion behaviour in "surprise"—see Figure 7.1. Other elements of swarm con-

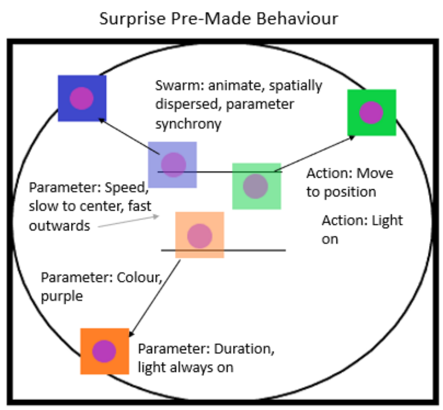


Figure 7.1: Deconstruction and illustrated version of the “surprise” pre-made behaviour into atomic actions, parameters, and swarm elements.

trol, like navigation and coordination, are managed by the system and abstracted for participants so they can focus on constructing behaviours for individual robots in the swarm. For example, participants can task several individual robots to move to different positions without hitting each other, as the swarm element of navigation is handled directly by the system.

This separation of actions, parameters, and swarmness also resonated with participants, who naturally tended to group similar actions, parameters, or control elements together in the card sorting task in *W1 (Conceptualizing ESSbots)*. Additionally, participants were satisfied with the final set of atomic action blocks we provided them in our prototype: light on, play sound, move to position, move forward, move raw (individual motor control), and rotate. They were able to effectively communicate a wide range of emotions using these simple components, including low arousal and low valence emotions like sadness, to high arousal and high valence emotions like excitement, and coordinated several robots together. However, we found that atomic behaviours alone may not be enough for participants. Providing them with a select set of pre-made behaviours is also important and useful for ESSbots communication, which we address in RQ3: *How can the*

ESSbots system support teens to author and share swarm robot behaviours with their remote friends?

RQ3.1: Robot control and behaviour authoring: First, we focus on RQ3.1: *How do teens want to control the robots and/or author new swarm robot behaviours?*. We found that for our participants, the kind of control they wanted access to was situational. They appreciated a high-level of control when they knew they would have more time to craft messages: in that case, directly providing access to atomic behaviours via the visual scripting interface was preferred, and teens liked that it could help them be creative and show their personality directly through the robots. On the other hand, they also appreciated quick and easy access to pre-made emotions. Not only did this provide teens with behaviours that had pre-existing context and could therefore not be easily misunderstood, but it also allowed them a quick way to use the robots if they didn't have time to fully program them. Finally, participants found that direct manipulation (i.e., tangible "follow the leader" control), while less useful to communicate and express emotion, would be a preferred control method for playful interaction and games.

RQ3.2: Sharing and communicating with ESSbots: Further, addressing RQ3.2 (*How do teens want to share and communicate using ESSbot behaviours with their remote friend groups?*), we found that play was an important aspect of sharing and communicating with ESSbots. Teens often reacted to messages in playful ways, and wanted to use the physicality of the robots to prank or annoy their friends. They also often used the pre-made emotion buttons creatively, such as by using the "angry" button to convey playful frustration when they didn't understand a message someone sent with the robots. Further, many participants preferred the touch based messages compared to the other pre-made behaviours, however, they were more inclined to use the robots this way with close friends rather than strangers, and in general they felt that their existing relationships to their communication partners would influence how they would use the robots to communicate with them.

RQ3.3: System design considerations: Finally, we note that for RQ3.3 (*How do these robot control and behaviour authoring preferences translate to system design considerations?*), the above findings of situational levels of control and the importance of playful expression translated into our final prototype as the two main control methods: visual scripting and pre-made emotion buttons. We also showed participants an example of touch-based control via direct manipulation, which they also enjoyed, although felt best supported playful interaction and games. They were also interested in how this control method could be integrated into the final prototype so they could control the robots this way remotely, which could be explored further in future work. Additionally, we found that participants' desire for autonomy and control over a robot that they identify as representing them implies the system must navigate issues around co-opting and consent. While we didn't fully implement this in our final prototype, we did incorporate elements of consent into our touch-based pre-made behaviours, where participants would be required to pick up a robot in order to accept and receive a touch message.

7.1.3 RQ4: Return to Grounding Theory

Finally, we consider RQ4: *How did our design and participant reactions to it reflect our grounding theory of participatory sensemaking and the three main ESSbot properties of embodiment and tangibility, multiplicity and coordination, and agency, identification, and roleplay?* Of course, the nature of participatory design itself is a kind of PSM, where by participating in and contributing to the design, the design in turn reflects how individuals in our workshops understood ESSbots conceptually. However, we found that both specific aspects of our final design as well as intermediate prototypes and demos reflected the principles of PSM and the original main ESSbot TMA properties particularly strongly.

RQ4.1: Grounding theory through design and swarmbot affordances: First, we focus on RQ4.1 (*What elements of our design reflect the principles of our grounding theory?*). We begin by considering the main affordances of swarm robots. Our prototype supports embodiment and tangibility through both the touch-based pre-made behaviours as well as the touch-control method. However, we note that participants also felt embodied though other aspects of the robots, including features like movement and sound, which they felt could help them express their personality. This idea of personal expression also relates to the properties of agency, identification and roleplay: by providing participants with fine-grained control via visual scripting, they are able to communicate expressively through the robots, identify with them, and engage in a kind of mediated roleplay with their friends by sending, receiving, and reacting to robot behaviours. The system itself also supports multiplicity and coordination among robots by handling swarm navigation, particularly in the pre-made emotion behaviours.

Importantly, the system naturally supports creating shared, participatory interactions by allowing multiple different users to control individual robots simultaneously. For example, three people could each control one robot remotely, dynamically changing parameters in real time to edit an ongoing behaviour together (see Figure 7.2. Participants could also co-opt other robots for their own behaviours—in this case, the participatory interaction shifts from shared interaction and sensemaking by all three parties, to sensemaking through observation alone for those whose robots were co-opted. How participants react in turn continues the sensemaking process, and notably, this interaction is affected both by how each person using the system interprets behaviours, as well as how the robots themselves actually perform the behaviours as instructed by participants.

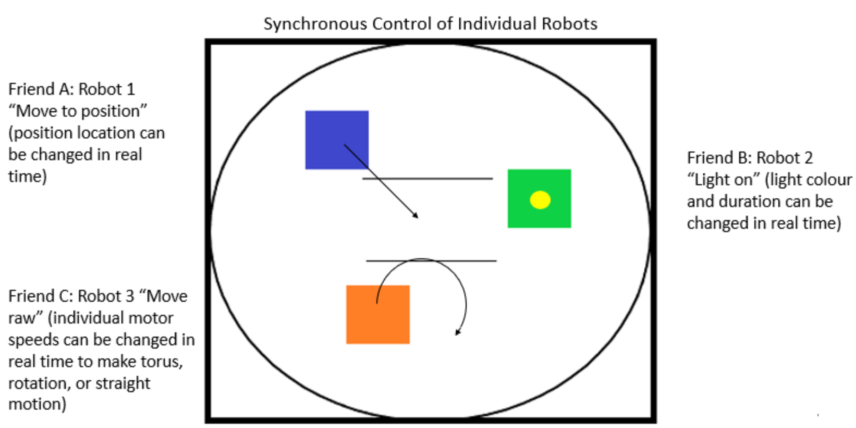


Figure 7.2: An illustration of remote participants simultaneously controlling individual robots at the same time, where behaviours can be updated and modified in real time.

RQ4.2 Participant reactions to ESSbots: Here, we can further expand to RQ4.2:

How did participants' reactions to our design and the ESSbots concept overall support or contradict our grounding theory?, and consider an example from *W4 (Communication)* that highlights both PSM and ANT. In this example, participants had been split into breakout groups in two separate rooms, and were instructed to send messages and responses to each other with the robots. The first group had tried to communicate "nervousness" by causing one robot to move in a jittery line. The second group interpreted this behaviour as "pacing around", and tried to send the comforting pre-made behaviour back. However, because the comforting behaviour did not use the original robot, the robot that group 1 was using to send their "nervous" behaviour continued to move and run into the robot the other group used to send the comforting message as it circled the original robot (see Figure 7.3 for an illustration of this interaction).

Thus, the apparent misbehaviour of the robots became part of the interaction and the final meaning both groups drew from it: they felt like the robots were having a disagreement, or that the original nervous robot was rejecting help from the other group. Had the robots behaved differently, e.g., if the first robot stopped moving before the other group responded, then the overall interpretation of the interaction would be different, where perhaps it would seem as though the original robot was accepting the second group's offer of support rather than rejecting it. The system could theoretically manage potential conflicts like this behind the scenes; however, because we aim to encourage ongoing interaction with the robots by participants, forcing the system to become a means to simply send, receive, and wait for messages limits the potential interactions participants can engage in. For example, the original group of participants may have instead *wanted* to reject the second group's offer of comfort by continuing their original behaviour, rather than by forgetting to stop it. Ultimately, if we want to support synchronous interaction with different remote robots, we must also accept that the system itself and the ways the robots enact behaviours becomes part of how individuals understand meaning, even if that meaning was not the direct intention of their friends.

Design recommendations: Finally, to address RQ4.3 (*How can both our grounding theory and participant feedback from our workshop series guide future design recommendations for the ESSbots system?*), we note that both our exploratory

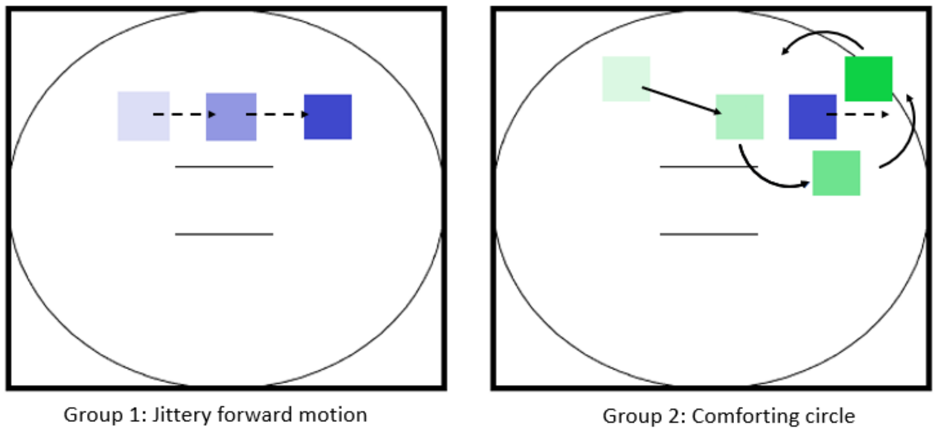


Figure 7.3: An illustration of behaviours created by participants in the remote breakout group activity: the first robot (in blue) moved forward in a jittery line with a red light to communicate nervousness. The second group interpreted this as pacing, and responded with the comforting premade behaviour (in green on the right), where one robot slowly circled another, however, the original robot continued to move forward and the two robots ran into each other.

workshops and workshop series did support our initial grounding ideas, as discussed above, suggesting that it was a useful basis for our design work. However, participant comments and feedback had a strong influence on our final design as well, and included some aspects of interacting with ESSbots that was not well supported in our initial theory, particularly their ideas about autonomy and showing explicit consent when sending and receiving messages. However, we do note that the importance of showing consent may tie into the important ESSbot properties of embodiment and identity: participants clearly were able to view the robots as avatars of themselves, to the point where they wanted autonomy over a robot that they viewed as "them". Whether this identification extends to other aspects of in-person consent, like boundary setting and personal space, is something that should be explored in future work and potentially as an important addition to our initial theoretical framework. Thus, we propose focusing primarily on participant directed design ideas in future iterations of the ESSbots system design, which we could then use to further test our grounding theories on sensemaking and social connection in other research contexts, like psychology or cognitive science studies.

7.2 Workshop Series Process

In addition to our main research questions, we further reflect on our methodological approach to the workshop series. We wanted to combine both a top-down approach to design that was grounded in our initial theory and literature review, along with a bottom-up approach based on participatory feedback from teens in the workshops. We ultimately found this approach to be successful. By grounding our initial design in theory, we were able to come up with a series of structured workshop activities to explore elements of the design we felt would be particularly important, like giving teens a reliable way to access robot behaviours in order to express themselves fully and thus in turn engage in group sensemaking with each other. Further, by taking an iterative, flexible, and participant informed approach, we were able to explore new ideas in more depth, such as the concept of consent that participants brought up in *W3 (Social Dynamics)*.

We wanted to bring in the same returning group of participants to act as an "advisory board" for ESSbots interaction design, where we could explore different aspects of the technology with them, iterate on their feedback, and provide them with updated prototypes for them to further advise upon. Overall, this approach worked well, and participants generally seemed to enjoy the workshop series, as there was very little dropout. More than half of our original participant group consistently came to all workshops in the series, and several participants were very enthusiastic about the workshops, explicitly letting us know they looked forward to attending them. We also found that participants were very open to share their ideas and feedback on how to improve the interaction design. They particularly appreciated when their ideas were directly included in our design process, and felt that they became more comfortable with the robots over time because they were able to influence the design of the system. They also felt like they learned more about the robots and how they worked throughout the workshop series, and particularly liked hands-on activities where they could control the robots themselves.

However, we note that this approach did not come without challenges or limitations. For example, a desire for a quick turnaround time for each workshop meant that we took a less robust analytical approach to our qualitative data, focusing primarily on coding for semantic meaning and potentially missing out on important nuances in how participants reacted to different elements of the interaction design. We also note that despite our best efforts to present participants with an unbiased framework to prompt their initial design ideas, ultimately what they came up with was of course constrained by the activities we engaged in with them and the ways we interpreted their feedback into our final design. For example, we could have spent more time focusing on the playful aspects of ESSbots, rather than the communicative and expressive aspects we hoped would foster social closeness.

Finally, we note that we developed several strategies to encourage participant engagement in the workshops, since we found that most participants became distracted or tired during typical "round table" discussion questions. We tried to avoid this engagement problem and create more engaging discussion questions by including active elements in the activities. For example, in *W3 (Social Dynamics)*, before asking participants discussion questions about how they would use the robots to show their personality, we gave them paper and coloured markers so they could creatively draw aspects of their personality first. While we didn't use the results from their drawings in our analysis, participants found the activity fun and it helped to keep them engaged in the following discussion, thus helping us to gain better quality data in the process. We also tried to include several demos or hands-on activities with the robots in each workshop: participants enjoyed these activities the most, and we wanted to give them as many opportunities to interact with the technology as possible.

7.3 Design Recommendations

While our final prototype reflected many important design considerations, like access to robust, accessible control and supporting complex behaviour creation through simple atomic behaviours, we discuss several further design recommendations that should be incorporated into future versions of ESSbots.

7.3.1 Bots, Behaviours, and the Swarm

First, we note that participants had several suggestions to improve the robots themselves. For example, the coloured LED lights were very important to participants, who wanted to use them in order to clarify the emotional context for movement-based behaviours. However, the LED lights on the toio^{TM} robots are located on the bottom, and can be difficult to see from certain angles. Thus, participants wanted the lights to be more visible, either by making them brighter or by putting them on the top of the robots instead. Although not specifically requested by participants, it would also be possible to add multiple LED lights to the robots in different locations, which could give more opportunity for them to use different coloured lights simultaneously or in more creative ways in order to convey meaning.

Participants also wanted to be able to customize the robots more, especially in the context of touch-based behaviours. In terms of the tactile materiality of the robots themselves, they proposed having different interchangeable outer shells of different textures, as they felt that they could additionally use texture in order to communicate different emotions via touch.

Further, they wanted the force feedback from the robots to be stronger in general, especially for instances when they wanted to engage in playful social touch with their friends (e.g., the robots act as a proxy for in-person playful touches, like slaps). Notably, this desire for stronger force was consistent in both the workshop series using the toio^{TM} robots as well as our original exploratory workshop with Zooids (which had slightly stronger motors). We also found that due to the cube shape of the toio^{TM} robots, it was difficult to apply shear force feedback, the closest approximation being the "send spins" behaviour. Adding a magnetic board under the robots may be one solution to this problem, so they have better resistance when moving close to someone's hand.

Some participants also requested several additional features for the robots, such as LED screens so they could show emojis, and audio message capabilities so they could send voice messages to family and friends who live far away. However, while these elements could indeed help participants to communicate with remote others, we note that the goal of ESSbots is to focus on tangible and embodied communication. Thus, we hesitate to include additional communication modalities in the robots in order to encourage more physical, touch based activities instead.

7.3.2 Interaction and Interface

In addition to technical suggestions, participants also had several suggestions to improve our interface and the overall interaction with ESSbots. For example, they suggested improvements to the visual scripting control method, such as adding additional control blocks to create more complex behaviours, like variables and if-statements. They also suggested adding support for concurrent actions with the same robot, as the current version of the system links individual actions in sequence rather than combining them together. This request in particular does have some existing backend support already, however, due to the nature of the toio™ library for Unity, these compound behaviours must be created specifically by us in order to correctly navigate the order of instructions sent to the robots over Bluetooth. While we have indeed already created combinations for some atomic actions into compound behaviours, we had not yet integrated them into our final prototype in order to show this capability to participants.

Additionally, participants suggested improving the usability of the visual scripting interface by automatically connecting blocks together, similar to commercial visual scripting programs like Scratch. They also had suggestions to improve parameter selection for specific blocks—for example, one participant suggested adding a colour wheel to make it easier to choose specific light colours for the robots. Given the importance of colour for participants, this change seems like an important future consideration to improve the prototype. Other suggestions included adding a grid or axes to the toio™ play mat, so it would be easier to use the "move to" position blocks, as well as more clearly identifying which robot was which in order to appropriately assign instructions with the visual scripting blocks.

Participants also had some suggestions to improve other parts of the interface, such as adding a feature to save behaviours they made with the visual scripting blocks, or adding the ability to edit and customize the pre-made emotion buttons. Thus, if they spent time creating a new behaviour, they could have easy access to it in the future if they wanted to modify it or use it again. This could also help participants better author swarm behaviours by allowing them to compose new behaviours with these saved complex behaviours that utilize several robots. Indeed, participants suggested a similar idea in *W2 (Customization & Control)*, where they felt that an option to combine different pre-made emotions together through the interface would be useful in order to communicate new emotions. Another way to facilitate swarm control more effectively would be to give participants access to parameters to modify aspects of the existing pre-made swarm behaviours without having to edit them in detail as well.

Participants suggested adding more explicit feedback in the interface as well, such as a pop-up message showing that the message they sent had been received by their communication partners. Similarly, they felt that pop-up messages would be a useful way to communicate consent if someone else in their friend group wanted to use their robot in a custom behaviour, which would be a valuable element to explore in future work given the overall desire for autonomy and consent by participants.

Finally, we note that participants enjoyed using direct manipulation as a form of tangible "follow the leader" control to pilot robots around the mat, and liked the idea of integrating it into the final prototype. They found that this more direct control method would be useful so they could use the robots to play games with their friends, suggesting options like tag, chess, or racing games. Given that participants frequently talked about using the robots in playful ways, we consider this to be an essential addition to the prototype in the future.

Chapter 8

Conclusions and Future Work

We summarize our main findings, and discuss limitations and potential future work for ESSbots.

8.1 Conclusions

Through our grounding theory, exploratory workshops, and iterative design workshops with a returning group of teenagers, we were able to investigate several important factors related to the interaction design for a new kind of social connection technology meant to foster authentic, embodied, and affective expression via the properties of TMA. In particular, we explored how teens conceptualized the idea of using swarm robots for remote social connection, how they wanted to author custom robot behaviours and control the bots themselves, how existing social dynamics might be reflected or enacted through the swarm, how teens would engage in remote communication with each other through the ESSbots prototype, and how well the design itself generalized to a new group of users who did not influence the design process.

We set out to investigate the above questions with a design context that focused on the elements of TMA, while leaving out more familiar communication styles (e.g., verbal, graphical, or audio). As anticipated, teens were not willing to forgo these forms of communication—however, we found that teens believed ESSbots could be a useful addition to existing forms of remote communication technology.

They felt that the physicality and tangibility of ESSbots supported the kinds of interactions that are more difficult or less genuine over existing platforms like texting, such as sharing emotions in an expressive way or simply feeling close to people who are far away from you. However, they also recognized that it would be difficult or impossible to communicate complex messages with the robots alone, and would still rely on texting or calling in these cases. Participants also noted that they would use ESSbots differently depending on their communication partners, preferring people they already know well as they felt that it would be more difficult—or even awkward—to communicate with strangers, especially if they were sending touch based messages.

We developed a fully functional prototype based on participant feedback to further explore how teens could use the robots to communicate with one another remotely using an existing commercial product, Sony toio™ swarm robots, which focused primarily on expressive swarm robot communication through combinable, atomic behaviours and accessible control for teens. The prototype addressed our participants' desires for both quick and easy as well as robust and fine-grained control over the robots by providing two different control methods: visual scripting, which gave teens direct access to combinable atomic behaviours via a drag and drop behaviour block interface, and emotion buttons, which could be used to play pre-made swarm behaviours for common emotions that participants came up with themselves in *W1 (Conceptualizing ESSbots)*.

We also uncovered several other important design strategies for ESSbots. These strategies included the importance of supporting embodiment and mediated social touch since participants felt that sending touch based messages helped them feel particularly close to their remote friends, enabling autonomy and explicit consent through the interface so that an individual's robot could not be co-opted by another unless the person who identified with the robot agreed to it first, and supporting playful interactions like games or pranks, where teens could freely control individual robots in creative and collaborative ways.

Finally, we found that our initial grounding theory was indeed reflected through our prototype and how teens interacted with it: they engaged in PSM as they reacted and responded to messages with the interface, and as ANT suggests, the robots themselves even became part of the interaction as participants attributed additional meaning through the ways the robots enacted the behaviours that they authored. Teens also frequently described the robots as directly represented them or their friends, and often talked about the robots as having animacy or animal-like qualities as they moved around and performed different behaviours. However, we also found that there are still important aspects of interacting with ESSbots that are not fully captured by our initial theory, such as the idea of communicating explicit consent before a robot is co-opted by another.

8.2 Limitations

We recognize several important limitations to our work. For example, we approached our workshops by prioritizing a sustained relationship with a core advisory group of teens over a longitudinal period of three months, rather than sheer numbers and diversity. This tradeoff meant that while we had 56 total encounters over our 7 workshops (where 56 is the number of participations, as opposed to unique participants), benefiting from the successive increase in understanding and involvement of our advisory team, we did not have as much breadth in our sample as if we had put forward our design ideas to a larger participant pool.

Thus, the perspectives of our teen advisors ultimately influenced our final interaction design. A different group of participants may have provided us with different insights or ideas, leading to a different possible outcome. While our final design generalizability workshop does provide evidence that our interface and interaction design generalizes well to new users, we had a particularly small number of new participants in this generalizability workshop (n=4), and therefore must treat these results carefully as to not over-emphasize the generalizability of the interface.

We also note that our timeline for the iterative workshop series meant that our data analysis approach was limited to coding for semantic meaning, and choosing to organize our discussion by domain summaries rather than conducting a full thematic analysis may have meant that we missed out on subtle nuances in how participants perceived ESSbots. Similarly, we decided to use a commercial product for our swarm robots in order to explore the properties of TMA. This limited us to the existing hardware of the toio™ robots, and thus participants may have been biased by the capabilities of the robots we used.

Had we designed the robots ourselves with direct guidance from participants, they may have had different ideas for how they would interact with the robots or how they would use the ESSbots system overall. Since participants did request some changes to the hardware that we were unable to make over the course of the workshop series, it is certainly possible that presenting them with alternative robots would have affected how they interacted with them and how much they enjoyed using the system overall. Additionally, it would be possible to consider other possible hardware designs that could implement the properties of TMA: we chose to utilize swarm robots as a natural platform to support these properties, but future work should consider other potential platforms or more custom hardware designs.

We also only had access to two toio™ play mats, which limited us to two breakout groups when testing remote communication using our prototype. We were therefore unable to fully test the remote distributed *group* aspect of ESSbots interaction, as ultimately our workshop took place in person and at most in two separate rooms with small groups of participants. While testing our prototype this way still gave us important insights into how teens would send messages and respond to them, we cannot draw conclusions about how these interactions might scale up when several individuals try to control the swarm in their own remote locations, and future work should explicitly investigate how teenagers react to ESSbots in a true remote group setting: that is, rather than gain feedback about the prototype from groups of participants interacting with the prototype together, it should be tested fully in context, where several individuals use the prototype on their own to communicate with each other.

8.3 Reflection on Larger Design Space

We also return to our context for this work as an initial exploration into a larger design space for what ESSbots could be, and recall the specific aspects we explored from the nine total dimensions we identified in Chapter 1:

1. Small groups
2. Primarily continuous interaction (many-to-many)

3. High synchronicity
4. Remote
5. Rehearsed and improvisational interaction
6. Moderate sensory sophistication
7. Small scale (3–6 robots)
8. Low portability
9. Existing swarm robot platform

While we primarily explored aspects of the design that were synchronous and intended for a single group of existing friends, we found that participants had some suggestions applicable to other elements of this design space that could be explored in future work as well.

Regarding the first dimension, group size, participants noted that even within a group of friends it would be important to include elements of consent (e.g., preventing robot co-opting) as well as the ability to turn off the robots in certain situations to avoid unwelcome distractions. If ESSbots were to be used with people beyond a familiar circle of friends, these elements of consent would likely become even more important, and should be explored in future work. Participants also seemed open to the idea of interacting with a larger community of ESSbot users, for example, via the option to share and re-use behaviours other users created with their own set of friends.

In terms of the second and third dimensions of interaction form and synchronicity level, participants liked the idea of "opening" asynchronous messages others sent to them rather than everything happening synchronously, which could also work well to support one-to-many style broadcast interactions. This desire for opening messages is also somewhat related to their desire for autonomy and consent: by actively choosing to open messages, they can decide for themselves when and if they want to see them in the first place. We did minimally implement an example of this in our final prototype via the touch control buttons, where participants would be required to pick up a robot in order to receive a message. Though not a true asynchronous interaction, since the message would expire if a robot was not picked up after a few seconds, participants liked this kind of interaction specifically because they knew their remote communication partners would have to have consented to see it. It also serves as an example of how more asynchronous-style interactions could be implemented directly through the robots themselves, so that users would not necessarily have to rely on an interface as a mediator for message playback.

In terms of dimensions 6–9, we found that participants had several requests to improve the hardware of the commercial swarm robot platform we chose, which suggests that other possible platforms or even exploring entirely different forms of novel hardware could be an important avenue for future work. Participants also explicitly pointed out that the toio™ play mats would offer low portability, and that controlling the robots from a laptop could also potentially restrict portability as well, suggesting that an interface for mobile phones could be more desirable and accessible. They also seemed open to the idea of including more robots in each swarm, although they seemed satisfied in general with the current number and size of the toio™ robots.

Finally, we note that participants' overall desire for autonomy and consent may suggest a new possible dimension to explore in future work, particularly in the context of larger social groups: level of ownership. That is, to what degree should the swarm explicitly enable individuals to use robots as avatars for themselves, and to what degree should people be able to co-opt other people's avatars to be used in swarm behaviours with no explicit identity mapping between robots and individual people? Navigating the interactions around co-opting and showing consent is a particularly important aspect of ESSbots that should be prioritized in future work, especially in conjuction with asynchronous interactions and larger groups beyond close friends.

8.4 Future Work

In addition to addressing some of the limitations above, future work should explore the possible design space for ESSbots in more depth, including asynchronous interactions and extending ESSbots beyond individual, closed friend groups. How to incorporate these elements without compromising the important focus on ESS-bots as a technology to support TMA interactions is non-trivial, particularly if we want to avoid some of the negative elements of exisiting social media, like performative interactions and lack of genuine connection. It would also be important to explore other potential hardware platforms that could support the properties of TMA beyond swarm robots, particularly those that foster tangible embodiment and showing identity, as participants found both these properties particularly beneficial to feel close to remote friends.

We also note that we focused our initial exploration into the synchronous, close friend group interaction design for ESSbots primarily on the idea of communicative swarm robot behaviours, and how to give teens access to robot control methods in order to author and share these expressive behaviours with one another. However, there are other ways that teens could use the robots with their friends, such as by using them more passively, like listening to music together and creating a shared robot dance party, or by using them as a tool for shared remote experiences, like using the robots as game pieces to play chess. Future work should explore these other kinds of synchronous group interactions with ESSbots among close friends as well, and how we can expand our prototype to better support these different types of interactions.

Ultimately, we found that ESSbots shows promise as a new kind of physical social media—it supports teenagers to share expressive and emotional messages through embodied swarm robot behaviours, and facilitates shared sensemaking as teens use the system to react and respond to messages they send one another. In conjunction with other forms of remote communication technology or through further exploration of the large possible ESSbots design space, we believe that ESS-bots can indeed help friend groups stay connected and feel closer to one another. While our initial prototype should be improved in future work to incorporate participant suggestions and to facilitate other forms of interaction, like group play, participants were indeed able to use it to send messages to one another, and found it accessible and engaging. Thus, our prototype for ESSbots interaction can provide an initial framework to further explore how embodied and tangible interactions can better support group communication and connection online.

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Appendix A

Iterative Workshop Activities

A detailed summary of each set of workshop activities and participant demographics is given in the attached document below.

*Note: the chosen method of reporting gender reflects our goal to understand the potential correlations between gender and perception/attitudes towards ESSbots, while maintaining anonymity of our teen participants.

ESSbots Workshop Series #1: Conceptualizing ESSBots

Participants: P1 - P12
Total number of participants: 12
Identified female: 5
Identified male: 6
Identified nonbinary: 1
Duration of workshop: 2 hrs 20 minutes, including 10 minute break

Activity 1: Pre-workshop Survey

Purpose: To collect data relating to demographics, current attitudes towards technology, and technology use patterns from our participant pool.
Activity Summary:

- Participants were emailed the survey (and sent a reminder email to complete it) before they attend the workshop
- For those who forgot to fill out the survey ahead of time, we provided a laptop for participants to use.
- Survey details:
    - Hosted on Qualtrics: https://ubc.ca1.qualtrics.com/jfe/form/SV_cZmvnvXijoc2LNI
    - Survey includes:
        - Demographics
        - Social media questions

Activity 2: Introduction

Purpose: To introduce participants to each other, the workshop facilitators, and outline our expectations for the workshops.
Activity Summary:

- Facilitator outlined our expectations (to listen to others and be respectful) and workshop content
- Participants completed an introduction activity
    - Introduced themselves
    - Answered Icebreaker question (e.g., what's your favourite animal)

Activity 3: Familiarization with concept and toios

Purpose: To familiarize participants with the concept of communication using small robots and the toio robots.
Activity Summary:

- Opened with discussion question:
    - ***What do you think is different when you communicate or hang out with your friends in-person vs online?***
        - prompted with examples (e.g., body language, hearing tone of voice)
- Facilitators explained the concept of ESSbots: what we're trying to design is another way for you to communicate with your friends online, but instead of texting or calling, you can use a bunch of tiny robots to send your friends messages
- Demo of toios (during demo further elaborated on ESSbots concept and design context)
    - Showed basic behaviours with one robot: movement, sound, light, rotation, vibration/rattle
    - Showed same behaviours with multiple robots (only had access to 4 for the first workshop)
    - Showed a few example molecule behaviours (e.g., more complex but potentially useful standard behaviours)
        - Touch someone's arm
        - Torus
        - Etc
- Follow-up discussion:
    - ***What are your first impressions of these robots? (Anything you like or dislike? Do they remind you of anything?)***
    - ***Prompted them to recall opening discussion question. Then, imagine you are using these robots to communicate with a group of friends who aren't with you in person. What do you think you could communicate using these robots?***

Activity 4: Familiarization with swarmness

Purpose: To familiarize participants with the concept of swarmness, and translate this concept from nature into robotics.
Activity summary:

- Prompted participants: suggested that they saw the robots in the demo move on their own, but they also saw them move as a group. This "Swarmness" is one aspect of the robots that we wanted them to keep in mind as we continued with the workshop activities.
- Showed videos of biological swarms in nature
    - Ants building a bridge
    - Angry swarm of bees
- Follow-up discussion questions:
    - ***How were the ants working together?***

        - ***Were all of the ants behaving the same exact way? Were there specific roles within the group?***
        - ***How could you tell that the bees were angry?***
        - ***How would the situation have been different if there was only one bee? How about three?***

Activity 5: Behaviour Creation Activity

Purpose: Start to conceptualize the communication of emotions using the robots.
Activity Summary:

- Facilitator explained activity:
    - We gave participants 8 emotions and relational ideas (for example, happy for an emotion, or comforting for a relational idea)
    - For each one, they described (or showed with their bodies) how they would convey that emotion to their friends in person, then how they imagine a swarm (robots, or a biological swarm) might demonstrate that emotion, then, how they would use the robots we have (toios) to demonstrate that emotion (and we will try to demo it using the robots)
- Proceeded through each step:
    - Asked participants **"How would you express this emotion or idea if you were in person?"**
        - Prompted with ideas if needed
        - Asked them to demonstrate with their body
    - Asked participants "**How would you express this emotion or idea using the toio robots?"**
        - Reminded them they can show the emotion with a single robot, or multiple
        - Provided small wooden robot proxies for participants to move around if they wished
    - Asked participants **"How would you express this emotion or idea using a swarm of robots?"**
    - Demo
        - Facilitators used toio robots to demonstrate as many of the suggestions as possible
- Following demos during the final step, we asked:
    - ***Is the demo of the behaviour what you imagined it would look like? Why or why not?***
    - ***What advantages or disadvantages do you see using multiple bots vs. an individual robot to convey this expression?***

Activity 6: Behaviour Clustering Activity and Atomic Behaviours

Purpose: Introducing the concept of atomic behaviours and the relationships between these behaviours.
Activity Summary:

- Facilitator explained context for the activity: During the next workshop, we want to have participants try out different ways of creating behaviours with the robots. We know that robot swarms are complex, so we want to make it easy to create those behaviours.
- Provided example: people dancing
    - Showed participants a video of a Kpop dance group, showing a mix of dancers dancing synchronously and some individuals doing different things from the rest of the group
    - Facilitator pointed out individual actions v.s. coordinated actions in the video, and similarities between a group of dancers and swarm robots
- Discussion questions:
    - ***If the swarm robots were dancers, and you were in charge of their choreography, are there distinct actions you would want to choreograph*** *(e.g., where to move on the table?)*
    - ***How would you tell them what to do?***
- Facilitator explained card sorting activity: We've come up with our own actions or properties we think are important to create new robot behaviours. Asked participants to organize the cards into groups, and after they had a chance to explain why they decided to group them the way they did.
- Handed out cards (based on actions, parameters, and swarmness)
- Participants had 10–15 minutes to group the cards
- Shared in group discussion with the table with a facilitator present

Activity 7: Discussion Questions

Purpose: To understand participants' attitudes towards the robots, using the robots to communicate, and their conceptualization of atomic behavours.
Activity Summary:
Participants engaged in roundtable discussion with the following questions:

1. ***What were your favourite things about the robots?***
2. ***What didn't you like about them? Do you see any potential barriers to actually using them in your day-to-day life?***
3. ***We talked a lot about using the robots to communicate emotions or relate to your friends. After using the robots and creating some possible behaviours, how do you feel about this goal? (****e.g.,* ***was it easy to do? Why or why not?)***
4. ***Aside from trying to communicate emotions, are there other things you would use the robots for with your friends? (****e.g.,* ***are there other things you want to communicate, or other activities you would want to do)?***
5. ***Think back to the activity where we demoed different robot behaviours for different emotions:***
    a. ***For example, let;s think about the angry behaviour. If you were at home, and your set of robots moved in that way (red light, moving erratically, etc), how would you react? (****prompt:* ***how would you feel? Would you do something with your own robots in response?)***

    b. ***Do you feel like reacting with the robots would be different than how you would react to things in person?***
6. ***Would you like to be able to create very specific new behaviours with the robots, or would you prefer a lot of pre-made behaviours, or both? Why?***
7. ***How would you want to control the robots and tell them what to do?***
    a. *Provided examples: e.g., program them in advance, use a keyboard or phone to directly pilot them, move them around physically, use one robot to demo and the others will copy, etc.*
8. ***What kinds of social tech do you normally use (****e.g.,* ***texting, tiktok?)***
9. ***What are some differences between the social tech you use now, and the ESSbots?***
    a. ***When might you use existing tech, vs. when might you use ESSbots?***
    b. ***Why might you use existing tech vs. why might you use ESSbots?***
    c. ***How do you think communicating emotions or relating to your friends with the robots compares to trying to communicate how you're feeling over the social tech you use now? Are there any gaps in your current tech you think the ESSbots could fill?***
10. ***How do you think you might use your existing apps and ESSbots together, and why? For example, can you think of any specific scenarios or environments where you would want to do that?***
    a. ***Do you think there are any benefits or downsides to integrating the robots with your other apps?***

ESSBots Workshop Series #2: Customization and Control

Participants: P1-P3, P5-P7, P9-P11
Total number of participants: 9
Identified female: 5
Identified male: 3
Identified nonbinary: 1
Duration of workshop: 2 hours, including 10 minute break

Workshop Activities:

Activity 1: Scenarios: Explore Effect of Context

Purpose: To understand how robot behaviours and control would differ depending on context. To answer the questions: how do different situations influence what behaviors are sent? How do different situations influence the preferred method of control?
Activity Summary:

- Participants were given several scenarios to think about. For each scenario:

- Facilitator described the scenario and answered any clarifying questions
- We asked participants:
  - ***How would you use ESSbots in this particular situation? Why would you use them this way?***
    - Prompted for: send messages, play games, etc (looking for the things that they're actually trying to do with the bots)
  - ***How would you want to control the ESSbots in order to do those things? Why would you want to control them this way?***
    - When they got stuck, gave some examples: programming (ask them: how?), buttons/pre-made behaviours, directly controlling them (like a remote control car), etc
    - Prompted them to think outside the box for other possible control methods
- Participants had access to some paper and wooden robot proxies to use to help illustrate their points
- At the end of the activity, we asked some follow-up discussion questions:
  - ***Do you think ESSbots would be particularly useful for any of these scenarios? Why?***
  - ***Are there any scenarios here where you would prefer to use other tech? Why?***
  - ***Can you think of any other situations where you would use the robots differently (either what you would want to do with them, or how you would want to control them)?***

- List of scenarios:
  - Friend availability
    - Friends that you see frequently (e.g., nearly every day)
    - Friends that you see in person very rarely (e.g., they live in another city/country)
    - Friend that you normally see in person frequently, but they have been sick
  - Time available
    - In a rush/not much time
    - A day where you aren't busy, lots of time
  - Type of interaction
    - You're sending the initial message
    - You're responding to a message someone else sent
  - Type of communicative message you want to send
    - Emotion: Positive valence (e.g., excited)
    - Emotion: Negative valence (e.g., sad or angry)
    - Phrase: Simple (e.g., hello)
    - Phrase: Complex (e.g., How are you?)
  - Physical location (if time permits)
    - At home, alone
    - At home, other people around (e.g., family)
    - In a public place (e.g., a library or at school)

Activity 2: Explore input / control modalities

Purpose: Explore different ways of creating new robot behaviours (e.g., programming heavy v.s., direct robot piloting), and explore reactions to the following dimensional space:

- **Manual-embodied** (PBD: move the bot around with your hand) vs **mediated/interface** (program it or control it indirectly, from many ways)
- **Freeform** (fully specify trajectories - sketching, driving, programming); vs **building-blocks** (building behaviors by combining atomic behaviors)
- **Highly customizable**: Users can adjust several aspects of the behaviours vs **minimal customization** Higher level presets (select a whole behavior)

Activity Summary

- Participants were split into two breakout groups to try two different demos of robot control (which explored some of the design space we anticipated to be most relevant). Each station had two robots available
    - Breakout station 1:
        - PS4 controller: behaviour is recorded from driving a single robot with the controller, and applied to the other robots (mediated/interface, freeform, medium customization)
        - Selectable presets (emotion buttons): users can use an interface to quickly “play” pre-made behaviours (mediated/interface, building blocks, minimal customization)
    - Breakout station 2:
        - Visual programming: new behaviours are created by directly programming the robots in a visual interface, specifically with the atomic behaviours (mediated/interface, building-blocks, highly customizable)

- After they tried out each example, we asked the following questions:
    - ***Were you able to get the robots to do what you wanted using this method? If not, why?***
    - ***Are there any things you would change to improve this method of controlling the robots?***
    - ***Thinking back to the previous activity, are there any specific situations where you would prefer to use this control method? Are there any situations you would not want to use it? Why?***

- Once both groups had finished, they swapped tables and we repeated the activity
- Finally, we brought all participants back to the main table for the following discussion questions:
    - ***Poll participants (had them raise their hand): Which kind of control method was your favourite:***
        - ***Using the game controller***

        - ***Visual programming (building blocks)***
        - ***Selecting existing behaviours with buttons***
    - ***Elaborate on why X control method was their favourite***
    - ***Poll participants: Which kind of control method was your least favourite?***
    - ***Elaborate on why X control method was their least favourite***
    - ***Are there other ways that you would like to be able to control the robots?*** (If few suggestions, prompt with: moving the robots around (picking them up, etc), voice control, gestures, regular programming)
    - ***Would you like to be able to customize more for the PS4 example?***

Activity 3: Integration with existing social tech

Purpose: Explore how they would imagine ESSbots interactions blending with what they use other forms of social tech for, and evaluate current prototype.

Activity summary:

- Gave QR code, participants opened Figma prototype (developed by Erin Chong for her COGS 402 project) and tested it out for a few minutes
- Facilitators presented personas (on Figma: https://www.figma.com/file/r1HSVFWmnW4c8WpyTCcHS4/Integrating-ESSbots?node-id=42%3A371&t=5xbPhHefEbvVKktZ-1 on projector with the questions), divided table sections into 4 so each group got one persona
    - Groups spent a few minutes discussing:
        - ***What they think the person might want to use the prototype for, or what other combination with ESSbots and existing tech would be best***
        - ***What are the pros and cons from using the prototype vs existing social tech***
    - Each group presented their answers to the larger group
    - Personas:
        - Long distance friends
        - Friend who is sick and can't go out
        - Friend who is going through difficult time (very sad)
        - Friend who got good news (giving congrats)

- Discussion questions:
        - ***What do you like about the prototype?***
        - ***What do you dislike about the prototype?***
        - ***Which features are you more/less likely to use?***
        - ***Is there any feature you would want that isn't shown yet?***
        - ***What are some benefits from using ESSbots integrated? Any downsides?***
        - ***Do you think the existing prototype would be useful for the persona you got? Why or why not?***

        - ***What forms of control that was explored earlier would you want to have when you would be creating a new message?***
        - ***What type of feedback would work: notifications, having to open the message, blocked if ESSbots and phone aren't linked (not nearby) - what are the benefits/drawbacks?***

ESSbots Workshop #3: Social Dynamics

Participants:P1-P6, P10, P11
Total number of participants: 8
Identified female: 4
Identified male: 3
Identified nonbinary: 1
Duration: 2hrs 30 minutes, including 10 minute break

Workshop Activities

Activity 1: Explore Reaction and Response/Group Shared Behaviours

Purpose: Explore how participants respond and react to how others use the robots to communicate, and how a group behaviour emerges and evolves as more members from the group join in (participatory sensemaking)

Activity Summary:

- Described the activity as similar to a game of telephone
- Split into two breakout groups
- Gave one person a prompt (emotion, simple phrase)
    - The first person used one of the robot proxies to try and show/achieve that prompt
- One by one, asked others (who haven't seen the prompt) to respond with their proxy/join in (so the group gets bigger as each person joins in)
    - Told them that they can change what they're doing at any point based on what the others are doing
- After everyone had joined in, asked each person:
    - ***What did you think you were responding to when you joined in?***
    - ***What do you think the final behaviour at the end represented?***
    - ***What did you try to show with your robot (what did you contribute to the group behaviour?)***
    - ***What influenced how you responded?***
        - *E.g.,* ***specific ways the other robot was moving? The way the other robots seemed to interact with each other?***

- *Had first person reveal what they started with*
    - ***Knowing this, do you feel satisfied with how the final behaviour turned out?***
    - ***Knowing this, was there anything that surprised you about how you or others responded?***
  - *If we noticed something interesting: e.g., they all responded the same or all responded differently, asked why*
- At the very end, discussed:
  - ***Did you change how you thought about responding whether you were reacting to just one robot, or you were joining in when it was almost the entire group?***
  - ***Do you think this way of communicating (reacting and responding) is similar to what happens in person when you're with a group of friends? Why or why not?***
    - ***Is it similar to any other situation or way you communicate with a group of people?***

Activity 2: Explore Swarmness and Individuality in the Context of Group Dynamics

Purpose: See how participants respond to a use-case where they would have less direct control over the robots (they are more autonomous/swarm-like), and explore how they would handle unique interactions in this particular use case (e.g., mimicry to control several robots, robot co-opting)

Activity Summary:
- Demoed an example where robots have more autonomy (more of a typical swarm) - Robots dancing to music (suggested by a participant in workshop 1)
- Discussed:
  - ***How much independence do you think the robots should get in the dance party?***
    - ***Poll: Which would participants prefer of the following:***
      - ***The robots sync up to the music, and you have no control over what any of them do***
      - ***You have limited control of the dance moves that one robot does (your robot in the group), but you don't really control when the moves happen or the speed (it still syncs with music)***
      - ***You have complete control over what your robot does, and can choose to dance to the music or not***
    - ***Why do you think you would prefer that?***
    - ***Can you think of any other way the robots might be controlled in the dance party?***

- ***How would you feel if you did have less control over the robots (e.g., situation 2 from the poll where you can control some behaviours but not completely)?***
- Demoed example of proximity dancing (you control one robot, getting close to another robot causes the other robot to mimic the first's behaviour)
  - ***How do you feel about this behaviour, where your robot dances and getting close to other robots gets them to join in?***
  - ***How would you feel if you identify with one of the stationary robots and it joins in the dance party automatically when your friend gets close? (e.g., would you want it to join in? Any instances where you wouldn't want that?)***
- Demoed different scenarios of co-opting of robots given different emotional/situational contexts
  - E.g., one robot is sad, but gets co-opted into a behaviour where everyone is trying to comfort them
  - E.g., one robot is sad, but gets co-opted into a behaviour where everyone is happy and excited
  - E.g., one robot is happy, but gets co-opted into a behaviour where everyone is sad
  - E.g., one robot is happy, but gets co-opted into a behaviour where everyone is excited
- Discussion questions after each demo
  - *Before explaining demo context, asked* ***how they would feel if they sent the original message, and then their robot was co-opted by someone else in this way***
  - *Explained context of demo -* ***they intended to show their friends they were __, and then someone in the group responded by using all the robots to show __. How would they feel?***
- Final discussion
  - ***Are there any instances where you wouldn't want your robot to get co-opted?***
  - ***How would you want to prevent it from happening in those cases?*** (If they can't come up with anything, suggest below examples)
    - E.g., in an app it's a button or toggle you can switch on
    - Via the robot itself (a certain colour light to show your friends you wouldn't want that)
    - Other ideas?

Activity 3 - Explore Touch with the ESSbots

Purpose: Explore what they think about using the robots to directly touch their friends, and how it's similar or different to how they might physically interact with their friends in person.

Activity Summary:

- Short demo where robots bump up against participants arm or hand, and spin (vibrate behaviour)
- Short demo showing group haptic touch with the robots (hug, attention, notification)
- Discussion questions about touch
    - ***How did you feel when the robots touched you?***
    - ***Can you think of any instances where you would want to have the robots directly touch your friend's hand (either these behaviours, or something else you could think of)?***
    - ***Are there any instances where you would want your friends to use the robots to directly touch you?***
    - ***In person, there are also examples of social touch - e.g., you could give a friend a group hug, pat them on the back, lightly punch their shoulder, etc.***
        - ***Do you feel like you interact with your friends this way often?***
        - ***Are there any benefits to being able to use the robots as a proxy for something like an in-person hug?***
        - ***Are there any downsides?***

Activity 4: Identification and Showing Personality Through ESSbots

Purpose: Explore how participants want to let others know who they are in the group, and what ways individual robots can have personalities.

Activity Summary:

- Provided markers and paper to participants, asked them to write down "What makes you 'you'", and "what makes you different from your friends?"
    - Reminded them that we will not be collecting these papers
- Discussion: ***How would you want to let others know that one of the robots is "your" robot?***
    - E.g., With a coloured light before it sends the behaviour
    - E.g., Aesthetic customization
        - Some followup questions about this:
            - ***How would they want to customize the robots? (e.g., pre-made decorations they could put on, do their own crafting at home, draw on them, etc)***
            - ***Do they want to customize as a group (group unboxing), or share later, or it doesn't matter? Something else?***
- Discussion: ***How do you want to reflect your personality through your robot?***
    - First asked as an open ended question, then prompted with questions below
        - ***Is it more hesitant to join others in shared behaviours?***
        - ***Does it move slower or faster than others?***
        - ***Always have a certain kind of light?***
        - ***Is it clumsy (less accurate movements? Bumps into others)***

- ***Is it important for your robot to reflect you? [maybe ask: do they want to portray a different side of themselves?]***
- ***Would it be more fun if it did?***

ESSbots Workshop #4: Communication

Participants: P1-P6, P11
Total number of participants: 7
Identified female: 4
Identified male: 2
Identified nonbinary: 1
Duration: 2 hrs 30 minutes, including 15 minute break

Workshop Activities

Activity 1: Communicate with ESSbots remotely

Purpose: Try out the prototype in a semi-remote setting. Understand how participants interpret messages sent by the other remote group, understand usability of the system overall.

Activity Summary:

- First, gave them time to play around with the prototype - they sent messages back and forth, tried out buttons and visual scripting - no specific guidance as to what they should try to send (~10 minutes - we asked the watching group questions during this time), then switched which group was sending and receiving.
    - Discussion question:
        - ***Do you feel any differently about this demo, knowing that the other group is controlling the robots in the other room, or does it feel similar to when either you controlled the robots, or we controlled them in previous demos? Why?***
        - ***How do you feel about the robots moving around without any of your direct control?***
            - *E.g.,* ***is it okay to sit and watch them, or do you want to use one or more of the robots yourself?***
            - ***If you do want to interact with them right now, how do you want to do that?***
        - ***Is there anything in particular you like or dislike about watching the robots move like this?***
        - ***Can you think of any issues that might arise when one group is sending messages remotely to your robots?***
            - *Prompts:*

        - ***Do you think it could be unclear whether the remote person controlling the bots wants you to interact with them, or just watch?***
        - ***Is turntaking more complicated in this situation, and why?***
        - *Issues with the robots in different physical spaces: e.g.,* ***objects in the way that your remote friends don't know about?***
- Then, had each group try out the touch examples - first group sent taps then spins, then second group sent both
- Discussion questions:
        - ***How did you feel when the robots touched you?***
        - ***How did you feel sending a touch based message to the other group?***
        - ***Do you feel any different watching the robots move around, vs this example where you directly pick them up or the robots touch you? Why?***
        - ***Do you think having the robots touch you or sending a touch to your friends helps you to feel closer to the other group? Why?***
        - ***Is there anything you would change to improve this touch experience with the bots?***
- Then, gave them specific emotions to send back and forth
    - Some from the list of buttons, some other ones that aren't currently buttons
        - Excited - buttons (group 1)
        - Hello - buttons (group 1)
        - Confused (group 1)
        - Lonely (group 1)
        - Angry - buttons (group 2)
        - Comforting - buttons (group 2)
        - Chill/relaxed (group 2)
        - Nervous (group 2)
    - First group sent the emotion - second group had a chance to freely respond
    - Second group sent the emotion - first group had a chance to freely respond
    - During demo, communicated with each other over slack/texting to tell them when to send messages and when to wait to avoid interference with one another
    - During the activity, asked them what they thought the emotion was each time (what was sent, what they responded with, and what they thought the other group sent them)
- Final set of discussion questions for the whole group
    - ***What did you like about the interface?***
    - ***What did you dislike about the interface?***
    - ***Do you have any suggestions for how to improve the prototype?***
    - ***What did you think of the waiting time or turn taking during the activity?***
        - ***For example, how does it compare to waiting for a text message?***

        - ***Do you have any suggestions to better facilitate turn taking?***
        - ***How might you show turn taking without relying on another channel (like audio, video, or texting your friends?)***
        - ***What would you want to do if your friend is "hogging" the robots?***
    - ***Did you feel like you could communicate well - did the other group understand you? Was it easy to respond back? Why or why not?***
        - ***What things in particular might have made it easier for them to understand?***
        - ***What might have made it harder for them to understand?***
    - ***How much agency (or, direct control) did you feel like you had when communicating?***
    - ***What features in particular do you think are most important for clear communication?***
        - ***Features of the robots themselves***
        - ***Features on the interface***
    - ***Now that you've actually had a chance to use the robots to send messages back and forth to each other, how do you think this compares to other ways of communicating with friends?***
        - ***If they need further prompting, compare to sending gifts, texting, having a zoom call, etc, and specifically ask for similarities and differences.***
    - ***What about this activity made you want to interact with the robots?***
        - ***Did the way you wanted to interact with them change when you were observing them (even if you couldn't do anything) v.s. when you were controlling them?***
    - ***How would something like this (sending messages back and forth) compare to each person freely moving a single robot remotely?***
        - ***Do you think you'd prefer one over the other? Why?***
        - ***Are there any situations that lend themselves well (to the least preferred method)?***
    - ***Do you think there are any potential benefits or downsides of using robots to communicate like this?***
        - ***Prompts if needed: For example, is it fun or boring?***
        - ***Can you be expressive, or are the messages confusing?***

- Had participants fill out usability measure
    - SUS: https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html

Activity 2: Reflect on workshop series and ESSbots concept

Purpose: Understand how participants' understanding of the ESSbots concept has changed throughout the duration of the workshop series.

Activity Summary:

- On a whiteboard, had two columns for “What I thought before” and “What I think now”
  - Participants wrote down answers to questions on post it notes and placed them in the relevant columns
  - Question: ***Think about what you thought of the robots and the idea of using them to communicate at the first workshop, vs. what you think of them now that you’ve had a chance to use them and influence some of the design. How does this affect how you think about:***
    - ***How you want to control the robots (program them, use buttons, etc?)***
    - ***What you think the robots can do (what behaviours can they do?)***
    - ***What you think the robots can communicate?***
    - ***How do you want to interact with the robots?***
    - ***To what extent do the robots make you feel closer to your friends (1 - 5 scale)?***
      - *Add a column for*
        - ***What are the best examples, or what gets in the way?***
  - ***What makes it easy to communicate through the robots, and what makes it hard?*** *(Note: not a before/after question like the above four, provided separate area of board for answers)*
    - ***How well do they express what you want them to (assuming you can control them well?)***

Activity 3: Expand on showing consent from Workshop 3

Purpose: Understand participant’s attitudes towards the concept of consent with regards to ESSBots.

Activity Summary:

- Facilitator explained the scenario: one person is trying to take over all of the robots, how do you let that person know that you are ok with your robot being taken over?
  - Demos
    - Demoed a simple touch based method - if they lift up their robot, it joins in doing whatever the original robot is doing
    - Demoed a group majority votes method - if enough people lift up the robot to agree to the co-opting taking place, all robots participate in the behaviour
- Demoed where the robot is going to get co-opted but says no - asked them how they interpreted that, did they like that way of showing that they didn’t want to join?
- Discussion questions
  - ***Out of the [two] demos, poll group about which version they preferred***

            - ***Why did you prefer this one/what about the other one didn't you like?***
    - ***[For their preferred version] How do you feel about this way of "joining in" with your robot?***
        - ***Do you think this would work well in every situation, or can you think of any situations where it wouldn't be as useful?***
            - *Prompted with examples:*
                - *Indicating it's okay to be touched with the robots*
                - *When someone wants to co-opt all the robots for their behaviour*
        - ***Can you think of any better ways to either join in or say no if you don't want your robot to participate?***
    - ***What might make you want to join in a group behaviour?***
        - ***What makes you want to engage with the robots in general?***
    - ***What might make you want to say no or not participate?***

Activity 4: Paper survey about workshop experience

Purpose: gather data on participant's experience in the workshop series.
Activity summary:

- Distributed a paper survey with question about their overall workshop experience
    - Did you learn anything new in the workshop series?
        - Yes, Maybe, No
        - Spot for them to write something they learned
    - Now that you have completed the workshop series, how likely are you to use the bots if they were a commercial product?
        - 1 Not at all, 5 a lot
    - How much has your perception of robots changed now that you have completed the workshop series?
        - 1 Not at all, 5 A lot
    - How confident are you now that you would be able to use a bot to send a message?
        - 1 Not at all, 5 A lot
    - How confident are you now that you would be able to understand a message that a friend of you that is far away from you sent you using the bots?
        - 1 Not at all, 5 A lot
    - Were there any workshops that you especially enjoyed, or any activities you did in the workshops that you particularly enjoyed, and why?
        - Spot of them to write

ESSbots Workshop #5: Generalizability

Participants:P1-P3, P5, P6, P11, P13-16
Total number of participants: 10 (6 returning, 4 new)

Identified female: 6
Identified male: 3
Identified nobinary:1
Duration: 2 hrs 30 minutes, including 10 minute break

Workshop Activities

Activity 1: Communicate with ESSbots Remotely

Purpose: Familiarize the new group of participants with the ESSbots concept, understand their first impressions of the system, and see how returning participants' experience differs when using the system to communicate with the new participants.

Note: for this section of the workshop, the setup was as follows:

- Two rooms
- Room 1: retuning people, Room 2: new people
- Interface: both buttons, and visual scripting to select / combine behaviors

This setup allowed us to understand the first impressions of the new group with minimal influence from the old group.

Activity Summary:

- Same as workshop 4 activity: each group watched while the other group tried things out.
    - **Returnees:**
        - different words from workshop four ("surprise", "that's not okay")
        - Discussion questions during initial watching period while the new group tried out the interface:
            - ***Has your opinion changed at all since last time about watching someone else move the robots around while you wait?***
            - ***Do you feel like you want to interact with the robots right now? How?***
            - ***Are the ways you want to interact with them now any different with the new group of people (who are less familiar with the bots) than with the group from last week who were more familiar?***
        - Discussion questions during the touch activity:
            - ***How did you feel when the robots touched you? Is it any different from last time, and if so why?***
            - ***How did you feel sending a touch based message to the other group? Is it any different from last time, and if so, why?***

            - ***Do you think having the robots touch you or sending a touch to the others helps you to feel closer to the other group? Why?***
            - ***Is there anything you would change to improve this touch experience with the bots?***
        - Discussion questions during the word sending activity - same as workshop 4:
            - ***Ask them what they thought the emotion was each time (what was sent, what they responded with, and what they thought the other group sent them)***
        - Discussion questions after the specific word sending activity - still in separate group from the new participants:
            - ***How do you find communicating these new words - is it harder or easier than last week when we did the same activity? Why?***
            - ***Last time you were communicating with a group of people you already know somewhat, but this group is more unfamiliar. Do you feel like sending messages with the robots to them is any different than it was last week with the more familiar group? Why?***
            - ***Do you think that the other group would understand what you were trying to communicate as well as the more familiar group of people might have? Why?***
            - ***How do you find using the interface now, after already using it last week for a similar activity?***
                - ***Do you remember how to use it, or did it take some time to remember what to do?***
                - ***Is there anything about it you notice now that you didn't notice before?***
    - **New participants:**
        - New people watched first, while they were watching, asked them about their thoughts on the ESSbots concept - do they think they'll be able to communicate with them, first impressions, etc
        - Discussion questions during initial watching period while the old group played around with the interface:
            - ***What are your first impressions of the robots?***
                - *E.g.,* ***what do you notice about them that seems interesting?*** *Prompt with things like the features they have, the movements they do, how many there are, etc.*
            - ***How do you interpret the robot behaviours that the other group is sending?***
                - ***Are they communicating anything specific? If so, what? If not, how do you interpret their behaviour?***

            - ***What do you think you would be able to communicate to the other group with these robots?***
            - ***As you're watching the robots, do you feel like you want to interact with them at all? How, and why?***
            - ***How easy do you think it will be to get the robots to move the way the other group has been moving them?***
            - ***Before actually trying to control them yourself, how do you feel about controlling these robots? E.g., excited, unsure, nervous, neutral***
        - Then had them play around and try out the interface
        - Touch activity, the same as workshop 4.
        - Discussion questions during the touch activity:
            - ***How did you feel when the robots touched you? Is it any different from last time, and if so why?***
            - ***How did you feel sending a touch based message to the other group? Is it any different from last time, and if so, why?***
            - ***Do you think having the robots touch you or sending a touch to the others helps you to feel closer to the other group? Why?***
            - ***Is there anything you would change to improve this touch experience with the bots?***
        - Then, asked them to communicate the emotions sad and playful in the word sending activity
        - Discussion questions during the word sending activity - same as workshop 4:
            - ***Ask them what they thought the emotion was each time (what was sent, what they responded with, and what they thought the other group sent them)***
        - Discussion questions after the specific word sending activity - still in separate group from the returnees:
            - ***What did you like about the interface?***
            - ***What didn't you like about it?***
                - ***Anything you would change or improve?***
            - ***Were you able to get the robots to do what you wanted to in order to communicate the messages to the other group?***
            - ***Did you feel like you could communicate well - did the other group understand you? Was it easy to respond back? Why or why not?***
                - ***What things in particular might have made it easier for them to understand?***
                - ***What might have made it harder for them to understand?***
            - ***Now that you've actually had a chance to use the robots to send messages back and forth to each other, how do you***

think this compares to other ways of communicating with friends?
    - *Further prompting: compare to sending gifts, texting, having a zoom call, etc, and specifically ask for similarities and differences.*
- ***What about this activity made you want to interact with the robots?***
    - ***Did the way you wanted to interact with them change when you were observing them (even if you couldn't do anything) v.s. when you were controlling them?***
- ***Do you think there are any potential benefits or downsides of using robots to communicate like this?***
    - *Prompts if needed:* ***For example, is it fun or boring?***
    - ***Can you be expressive, or are the messages confusing?***

- Asked both groups to fill out usability measure
    - SUS: https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html

Activity 2: Robot behaviours, functionality, and control

Purpose: Understand how the new and old participants feel about the current set of robot behaviours, how they can control them, and any ideas to improve the design of the system

Approach: they've already been exposed to two control methods (one very closed-end, one more powerful but on-screen). Now, we offer a couple of different ways that have other properties, and turn the discussion towards control (and basis behaviors) and encourage them to further expand how they'd like to control and what basis behaviors they want.

Curious about: does the new group have different opinions about the base behaviors, and control methods, given they had far less to do with developing, attachment, etc.

Setup:
- New participants will be in a separate room from returning participants.

Activity Summary:
- Have both groups try out a simple touch control method
- Discussion questions
    - *Some about the methods they tried out in the first demo as well*
        - ***Were you able to get the robots to do what you wanted using this method? If not, why?***
        - ***Are there any things you would change to improve this method of controlling the robots?***

        - ***Do you think there are specific situations where you would want to use this control method? Are there any situations you would not want to use it? Why?***
    - ***Poll: Which control method was your favourite?***
        - ***Visual scripting blocks***
        - ***Buttons***
        - ***Touch control***
- Question just for new participants:
    - ***What do you think about the pre-made emotion buttons? Do they represent those emotions well?***
        - ***Would you want to change them yourself to something else, or are you okay with what's there now?***
    - ***What do you think about the specific blocks we have in the visual scripting example - are there any that seem to be missing, or that you would want to change?***
- Question just for returning participants:
    - ***Now that you've had several experiences with the robots - do you feel differently about using them robots going forward? (e.g., do you want to keep using them? Any novelty effect? Are they more fun now than they were before? etc)***

Activity 3: Compare conceptual learning curves

Purpose: Understand the difference in learning curves between participants who are just being exposed to the system for the first time, and those who were involved in the design of the system.

Setup: All participants colocated in the same room engaging in one discussion.

Activity Summary:
Participants filled out a survey as follows:
- How sure are you that you could get the robots to do what you wanted them to do?
    - 1, not at all, 5, a lot
- How comfortable are you interacting with the robots? (Touching them, moving them around, controlling them, etc)
    - 1, not at all, 5, a lot
- How confident are you that you understand what the robots can do? (What features they have and how you might use them?)
    - 1, not at all, 5, a lot
- How long do you think it would take you (or has taken you) to become confident using the robots and communicating with them?
    - 1, a short time, 5, a very long time

- How confident are you that you would understand a simple message someone else sent to you with the robots? (e.g., happy, sad, hello)
    - 1, not at all, 5, a lot
- How confident are you that someone else would understand a simple message that you sent with the robots? (e.g., happy, sad, hello)
    - 1, not at all, 5, a lot
- Written question:
    - In your own words, describe the ESSbots technology (as though you were explaining it to someone who didn't know anything about it).

Discussion:

- Had them all come back together and ask them to get a sense for differences in experiences between new and old people.
    - ***Ask a few people to summarize their observations on the robots so far***
        - *E.g.,* ***what they think the robots can do, what they like or dislike, etc***
    - *Then ask -* ***do you think that how people react to the robots is affected by whether or not they've helped in the design process (some of us here have been involved, and some are new and haven't)***
        - ***Specifically ask some of the newbies if they think they might react differently to the robots if they had more previous influence on the interface or what the robots can do.***
        - ***Specifically ask some of the returnees if they think they might react differently if they had had less influence on the design of the robots***
    - ***What other aspects might affect how people react to the robots?***
        - ***Experience/time with them?***
        - ***Communicating with familiar or unfamiliar people?***
        - ***Anything else?***

Activity 4: Social wellbeing, navigating social issues at this age

Purpose: Understand participant's attitudes towards wellbeing with regards to social media, and how the robots may be able to support their wellbeing.

Activity Summary:

- Discussion questions:
    - **How do you communicate to friends that you're upset? How do your friends comfort you? (what do they say or do? Is touch involved?)**
    - **When you're excited, how do you communicate this to friends? How do your friends show you they are also excited for you? (what do they say or do? Is touch involved?)**
    - **Do you think that the robots can help you and your friends express those things?**

        - **What specific things about these robots would help you feel connected or supported by your remote friends, or help you support your friends?**
            - **Prompts if they need it: the robots are physically in your space, they can touch you, they show emotion well, etc**
    - **How well do you think this would work? Meaning, how connected or supported do you think that you could possibly feel, using the robots? (really connected, so-so, not that connected). Why?**
    - **How much value do you think the robots potentially have for helping you and your friends feel connected or supported by one another?**
        - **Times or instances that using the robots would be more effective?**
        - **Times or instances that using the robots wouldn't be as effective?**
        - **How is communicating through the robots similar and how is it different from other forms of online communication?**
            - (prompts if they need it: touch, nonverbal nature)

Appendix B

Complete Data Analysis Codebook

A summary of our final set of codes and their occurrence in each workshop is given in the attached document below.

Code	Exploratory Workshop	Workshop 1	Workshop 2	Workshop 3	Workshop 4	Workshop 5
Behaviour.Interpretation	yes	yes			yes	yes
Behaviour.Lights	yes	yes	yes	yes	yes	yes
Behaviour.Mimic		yes		yes		yes
Behaviour.Movement	yes	yes	yes	yes	yes	yes
Behaviour.PositionInEnvironment	yes		yes		yes	yes
Behaviour.Sound	yes	yes	yes	yes	yes	yes
Behaviour.Speed	yes		yes			yes
Behaviour.Swarm	yes	yes	yes			yes
Behaviour.Touch	yes				yes	yes
Behaviour.TurnOff					yes	
Behaviour.Vibration	yes					
Buttons.Additions			yes			yes
Buttons.Benefits			yes		yes	yes
Buttons.Challenges			yes			yes
Communication.Benefits				yes	yes	yes
Communication.Content	yes	yes	yes	yes		yes
Communication.MessageComplexity	yes	yes	yes	yes	yes	yes
Communication.NonESSbotCommunication		yes	yes	yes	yes	yes
Communication.Quality	yes			yes	yes	yes
Communication.Responses		yes	yes	yes		
Communication.Situational	yes		yes	yes	yes	yes
Communication.Touch	yes			yes	yes	yes
Communiction.Challenges	yes			yes	yes	yes
Controller.Additions			yes			
Controller.Benefits			yes			
Controller.Challenges			yes			
Customization	yes	yes		yes	yes	yes
Features.Additions	yes	yes	yes	yes	yes	yes
Features.RobotQualities	yes					yes
Features.SystemQualities	yes	yes		yes	yes	yes
Interaction.Benefits		yes			yes	yes
Interaction.Challenges		yes		yes	yes	
Interaction.Consent				yes	yes	yes
Interaction.ControlLevel	yes	yes	yes	yes	yes	
Interaction.Device		yes	yes	yes	yes	yes
Interaction.Generalizability						yes
Interaction.Motivation					yes	
Interaction.Situational			yes	yes	yes	yes
Interface.Additions			yes	yes	yes	yes
Interface.Benefits					yes	yes
Interface.Challenges					yes	yes
ParticipantQuestion	yes					
Perception.Ambivalent	yes		yes	yes	yes	yes
Perception.ConceptualConstruct	yes	yes	yes	yes	yes	yes
Perception.Negative		yes	yes	yes	yes	
Perception.Positive	yes		yes	yes	yes	yes
SocialTechIntegration		yes			yes	yes
TouchControl.Additions			yes		yes	
TouchControl.Benefits			yes			yes
TouchControl.Challenges						yes
Usage.GamesAndFun	yes	yes	yes	yes	yes	yes
Usage.GroupDynamics			yes	yes	yes	yes
Usage.PersonalUse	yes	yes		yes		
Usage.SocialConnection		yes		yes	yes	
Usage.UserGroup		yes	yes			
VisualScripting.Additions			yes			yes
VisualScripting.Benefits			yes			yes
VisualScripting.Challenges			yes			

Appendix C

ESSbots Interaction Prototypes, Interface Features, and Control Methods

In addition to our final prototype, described in detail in Chapter 5, we developed several other features and demos that we showed participants, which we summarize in Table 5.2 and describe in more detail below.

Atomic Behaviour Selectable Combinations: Simple interface with checkboxes to select different atomic behaviours or common swarm behaviours (e.g., torus, symbol) and modify their parameters with sliders or text boxes. When multiple behaviours are selected, the resulting behaviour is a compound behaviour of those selected, such as movement with rotation to a specified position on the mat. Included a demo example of tangible control, where individual robots could be selected/deselected to engage in behaviours by picking them up and placing them on the play mat. Meant to support facilitators in *W1 (Conceptualizing ESSbots)* to demo participant suggested behaviours with the robots (see Figure C.1).

Visual Scripting V1: First version of visual scripting control. Blocks could be dragged into one of two areas on the screen in order to control one of two possible robots locally. Used in *W2 (Customization & Control)* as an interactive demo for participants to try this control method (see Figure C.2).

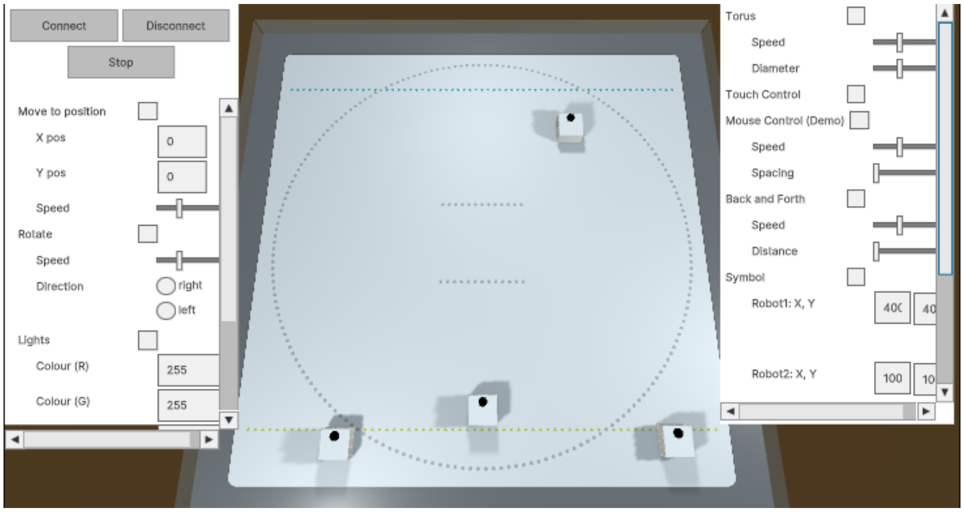

Figure C.1: Interface for atomic behaviour selectable combinations, which can run using real robots or over the simulator shown in the center of the screen. Atomic behaviour combinations can be selected on the left, or pre-made common swarm behaviours can be selected on the right.

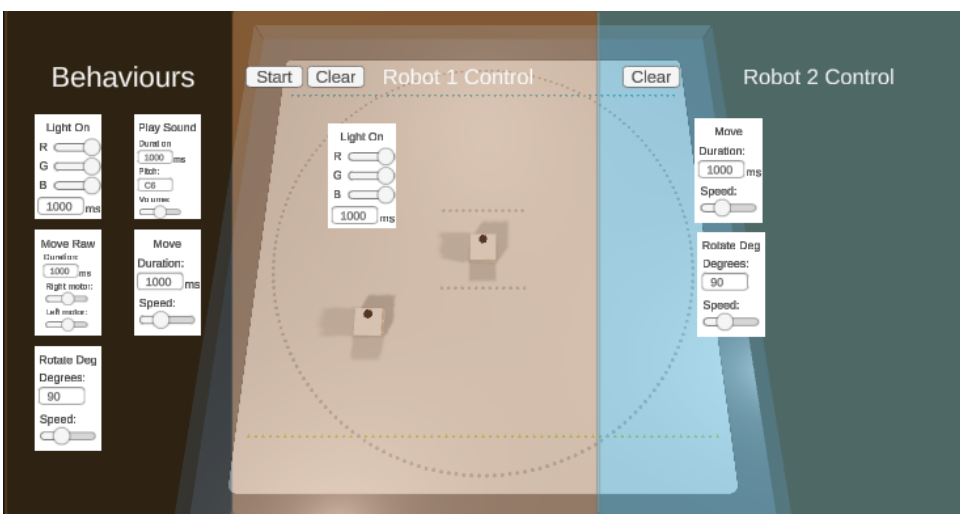

Figure C.2: Interface for visual scripting V1. Blocks dragged to the right side of the screen are played on robot 2, and blocks on the left on robot 1.

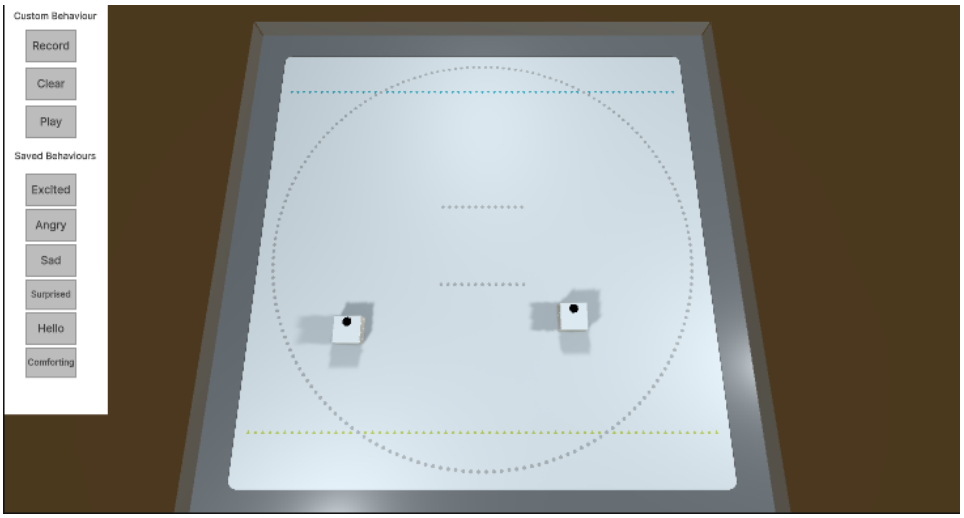

Figure C.3: Interface for emotion buttons and game controller. Clicking an emotion plays the corresponding pre-made behaviour. Clicking record when controlling one robot using a PS4 controller records all actions taken, which can be replayed on the second robot with the play button if not erased by the clear button.

Emotion Buttons and Game Controller: First version of emotion button pre-made behaviours, with additional buttons to record and save behaviours by driving the robots directly using a PS4 controller. Used in *W2 (Customization & Control)* as an interactive demo for participants to try these control methods (see Figure C.3).

Tangible Control: "Follow the Leader": By dragging the "control robot" around the mat, a selectable number of additional robots would follow and could thus be directed around the play mat in a more tangible and direct way. Used in *W5 (Design Generalizability)* to try an example of a more tangible, direct control method with old and new participants (see Figure C.4).

Robot Dance Party and Emotion Co-Opting: Simple interface with checkboxes to select different pre-made dance behaviours (e.g., back and forth movement, rotation, torus) and pre-made single or swarm behaviours of different valence levels (e.g., individual sad, group sad). Used in *W3 (Social Dynamics)* by facilitators to demo examples of individual vs. group control and co-opting (see Figure C.5).

Mediated Touch Interactions: Simple interface with checkboxes to select differ-

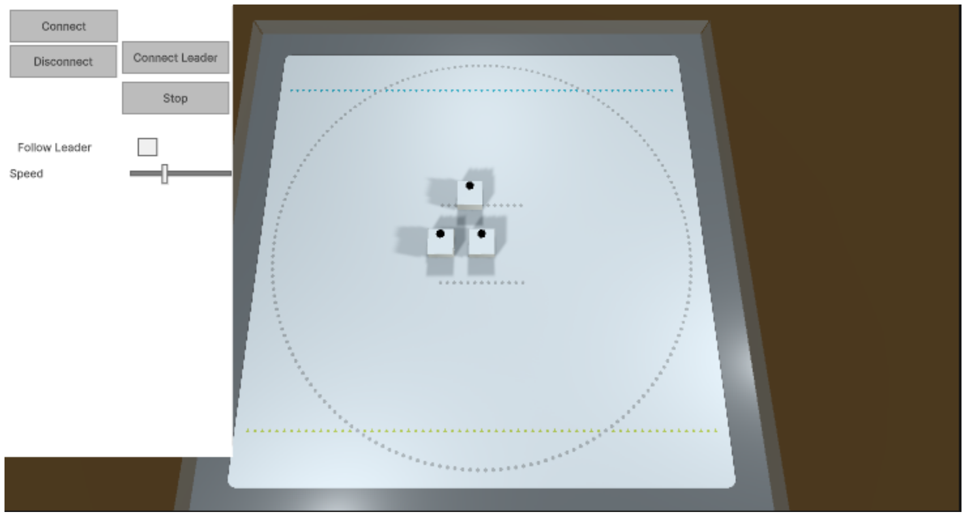

Figure C.4: Interface to support "follow the leader" tangible control, to facilitate specific connection of the leader robot and followers, where additional followers can be added one by one with the connect button. Speed can also be toggled with the speed slider.

ent touch behaviours for individual or several robots (e.g., naive back and forth movement, coordinated movement towards a participant's hand followed by a gentle "hug" (squeeze), taps, rotation, or stroke). Used in *W3 (Social Dynamics)* to demo examples of how the robots could be used for mediated social touch (see Figure C.6).

Showing Consent: Simple interface with checkboxes for pre-made examples to show robot co-opting and indicating consent (e.g., by picking up robots for a majority vote to allow co-opting to occur). Used in *W4 (Communication)* to further explore the concept of co-opting and showing consent that came up in *W3 (Social Dynamics)* (see Figure C.7).

Remote Prototype V1: Version 1 of the visual scripting and emotion button prototype that could sync behaviours over a local network for remote sharing. Similar to the final version of our prototype, but this version was missing some blocks (move to position) in the visual scripting control panel and had a less aesthetic background for the interface that showed the static Unity toio™ simulator, which did not move when running the software with real robots and was somewhat confusing for par-

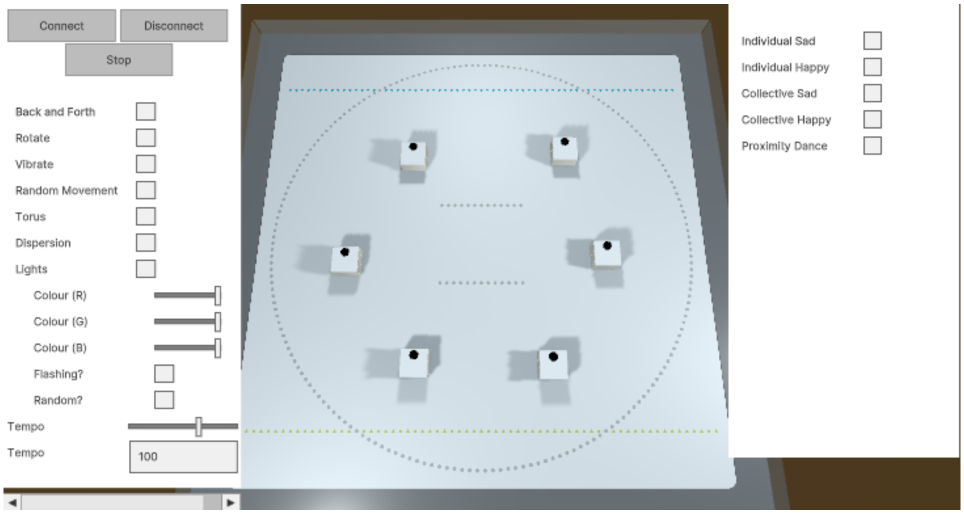

Figure C.5: Interface to run wizard of oz style autonomous dance party, where dance moves could be controlled by the facilitator using the panel on the left. Examples co-opting demos could be run from the panel on the right, as well as a proximity dancing example (one robot joins in the others playing a back and forth movement when getting close).

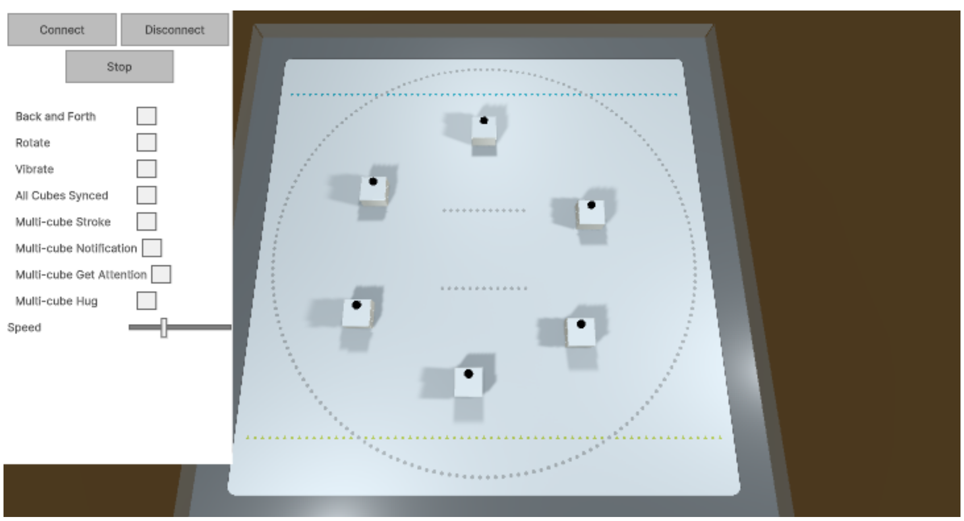

Figure C.6: Interface to run touch demo examples, including simple rotation and back and forth motion, as well as complex examples where robots approach and touch the user's hand.

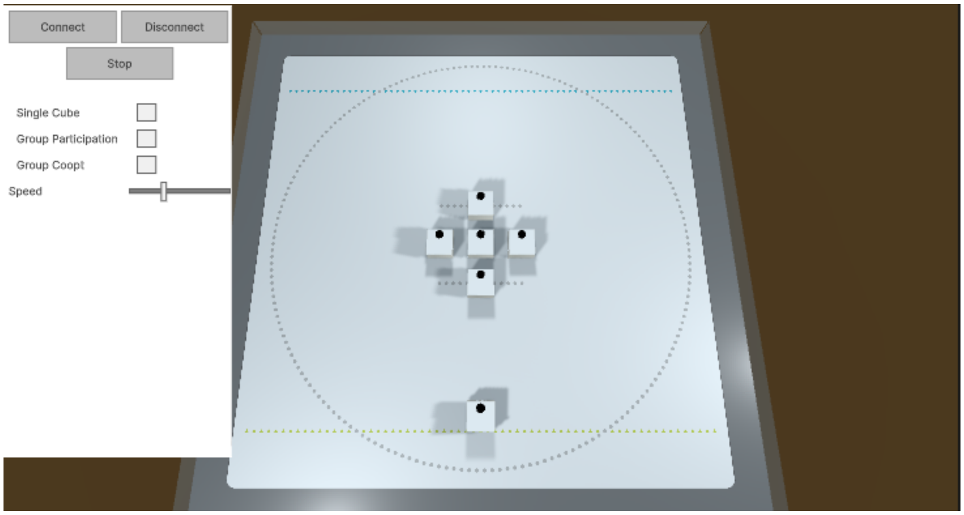

Figure C.7: Interface to run consent demos. Facilitator can select options on the left, including single robot consent and majority group voting.

ticipants. Used in *W4 (Communication)* to see how remote groups would use the interface to communicate with each other.

Remote Prototype V2 (Final Prototype): An improved version of the first remote prototype, with additional visual scripting blocks (e.g., move to position), the ability to preview behaviours, and an improved, opaque background that hid the toio™ simulator. Used in *W5 (Design Generalizability)* with the old and new participants to investigate design generalizability (see Figure 5.4 in Chapter 5).

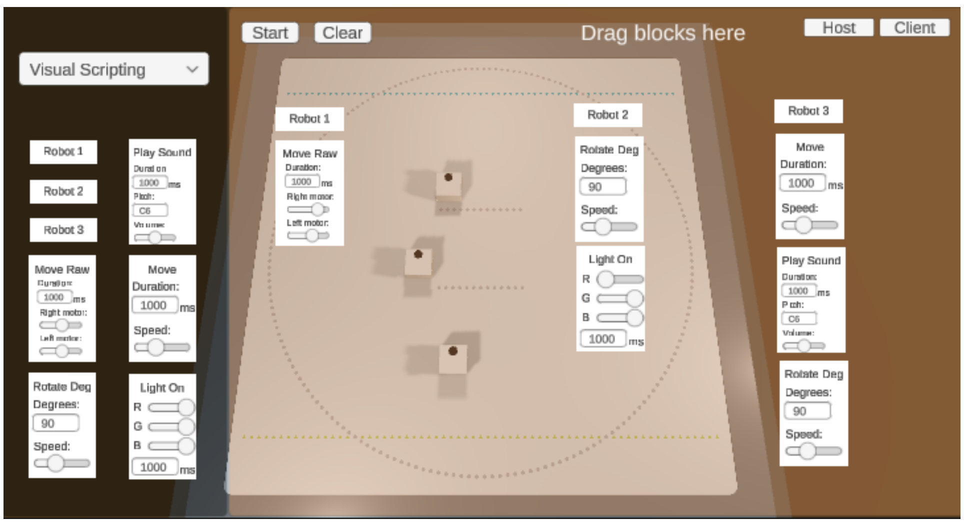

Figure C.8: Version 1 of our final prototype, showing visual scripting control with missing preview and local stop buttons and no move to position block. Emotion buttons did not change between versions and are therefore not shown here.