Feeling with Many: Rethinking Emotion Regulation with Swarm User Interfaces

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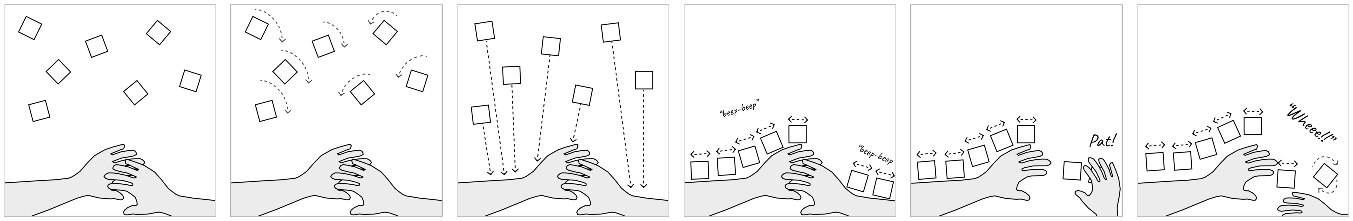
"beep-beep"
"beep-beep"
Pat!
"Wheee!!"

Robots are dispersed across the floor in idle state. | Upon user's arrival, swarm turns to face them. | Swarm rushes toward user's arms for a warm greeting. | Swarm nestles gently, seeking affection. | The user pats a robot in response. | Robot spins and beeps to express joy.

Figure 1: Storyboard of the Greeting Swarm pattern. Mimicking a pet-like welcome, the swarm rushes toward the user upon arrival, provides haptic nuzzling, and spins joyfully when patted to offer affective grounding.

Abstract

Emotion regulation (ER) is a dynamic process that often unfolds in social contexts. However, current digital ER tools predominantly rely on single-agent systems that lack the complexity of social dynamics. Swarm user interfaces present unique affordances for ER through their collective adaptability and expressive group behaviour. However, their potential in supporting ER remains underexplored. To investigate how swarm user interfaces can be designed to support ER, we conducted a series of speculative participatory design workshops with 15 participants through the Magic Machine Workshop method, where participants created and enacted interactive swarm-based artifacts with craft materials. The analysis led to diverse contexts of use, envisioned swarm framing, and interaction modes. Based on these findings, we synthesize eight interaction patterns that translate abstract user metaphors into robotic behaviors. We conclude by articulating design opportunities and challenges, positioning swarm interfaces as a novel medium for ER support.

CCS Concepts

- **Human-centered computing → User studies**.

Keywords

Emotion Regulation, Swarm User Interfaces, Participatory Design

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1 Introduction

Emotion regulation (ER), the process by which individuals influence their emotional states and expressions [37, 71], is regarded as a critical component of mental health and well-being [36, 73]. While being an intrapersonal cognitive process, regulation frequently unfolds within social contexts. This broader phenomenon, known as Interpersonal Emotion Regulation (IER) [24, 114], emphasizes that individuals often do not go it alone but instead recruit social resources to manage their affect [74]. Through IER, people leverage social interactions to dampen stress or intensify positive experiences, transforming ER from a solitary task into a dynamic, relational exchange [70].

Within Human–Computer Interaction (HCI), increasing attention has been paid to digital technologies that support ER [21, 96,

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97, 106]. Among these, tangible and embodied interfaces, such as socially assistive robots (SARs) [39, 80] and tangible user interfaces (TUIs) [64, 87, 88, 117], have shown promise by delivering in-situ, physical forms of support. While effective in dyadic settings, these interventions predominantly rely on single-agent systems, often failing to replicate these complex social dynamics inherent in human emotional experiences.

Distinct from these singular devices, swarm user interfaces, a class of embodied interfaces composed of collectives of coordinated robotic agents [53, 58], present opportunities for supporting ER by creating socially adaptive ER interventions. First, research shows that multi-robot therapy can simulate realistic multi-party social environments, enhancing user engagement and joint attention beyond the capabilities of single agents [2, 69]. Second, observing interactions between robots can help exhibit more positive psychological states [68] and reduce the cognitive and emotional anxiety often associated with direct confrontation [1, 49]. Third, multi-robot systems enable role differentiation, allowing different agents to cater to conflicting user needs simultaneously [101]. Last, swarm user interfaces can convey emotional qualities through variations in motion, rhythm, and scale [23, 53, 89], making them well-suited to represent subtle and continuous forms of affective interaction, such as fidgeting [52, 81] and perceived body extension [25, 44]. Yet, despite these potential benefits, little is known about how swarm user interfaces should be designed to support ER, or how users conceptualize emotionally meaningful interactions with collectives of robots.

To fill this gap, we conducted three speculative participatory design workshops with a total of 15 participants to explore how people imagine using swarm interfaces within their personal ER practices. Adapting a magic machine prototyping approach [8], participants created and performed swarm-based "machines" for their own ER needs using craft materials. This approach allowed participants to surface personal ER experience and strategies into imaginative technology without constraints on technical knowledge.

In our findings, we identified when/where participants needed ER support from the swarm user interface, what swarm user interfaces they envisioned being, and how swarm user interfaces could support their ER. Building on these insights, we synthesized a set of interaction patterns that translate participant-generated ideas into situated design concepts. We further articulate design opportunities and challenges, positioning swarm interfaces as a novel medium for ER support. In summary, we contribute to the field of digital ER and swarm user interfaces by providing:

- an exploration of how people imagine swarm user interfaces within their personal ER practices.
- a set of interaction patterns that articulate how swarm user interfaces could support ER.
- a reflection on the opportunities and challenges in designing swarm user interfaces for ER.

2 Related Work

2.1 Intrapersonal and Interpersonal Frameworks on Emotion Regulation

Emotion Regulation (ER) refers to the processes by which individuals influence which emotions they have, when they have them, and how they experience and express these emotions [36, 37, 56, 71]. ER is best understood as a subset of affect regulation, a broader umbrella that can include regulation of emotional states, mood, and other affective phenomena [37]. ER is not limited to decreasing negative emotions; it also includes amplifying positive emotions or even intensifying negative ones for instrumental purposes [38, 107].

One of the most influential frameworks in ER is Gross's Process Model of Emotion Regulation [36, 37], which identifies five families of strategies, each intervening at a different stage of ER process: (1) *Situation selection* refers to approaching or avoiding certain situations based on their expected emotional impact, such as choosing not to attend a stressful event. (2) *Situation modification* involves directly changing aspects of a situation to alter its emotional consequences. For example, resolving a conflict to reduce tension. (3) *Attentional deployment* concerns directing one's attention toward or away from emotional elements of a situation, such as distracting oneself during a distressing moment. (4) *Cognitive change* refers to reappraising the meaning of a situation to modify its emotional significance, like interpreting a job interview as a learning experience rather than a threat. (5) *Response modulation* occurs late in the emotion process and targets experiential, behavioral, or physiological responses, such as suppressing visible signs of anger. Each strategy operates at a different stage of emotional unfolding and varies in its cognitive demands and long-term effectiveness, shaping both immediate experience and broader patterns of emotional functioning. In our participatory design workshops, we introduced this model to participants as a conceptual tool to help them understand ER. These five strategies also serve as a key analytical lens in our study and are referenced throughout our results from the design workshops.

Beyond intrapersonal processes, ER often unfolds in social contexts. Interpersonal Emotion Regulation (IER) encompasses the use of social interaction to modulate one's own or others' emotions [24, 74, 114]. Unlike automatic affective phenomena such as emotional contagion or affective presence, IER is intentional and effortful, requiring cognitive control and personal resources [74]. IER can be intrinsic, wherein an individual seeks out others to help manage their own emotions, and extrinsic, where an individual attempts to regulate the emotions of someone else [114]. Ultimately, IER reflects the fundamental insight that emotions are not solely private experiences but are shaped, amplified, or mitigated through ongoing interpersonal processes [74, 114]. Our work considers robot-supported regulation as a potential form of IER. This framing enables us to examine how interactions can resemble social-emotional dynamics.

2.2 HCI Research on Digital Emotion Regulation

HCI research has increasingly shifted from designing for emotional experience to designing for ER. A large body of work explores how both specialized and general-purpose technologies can support ER [21, 96, 97, 106]. While these systems were developed on various platforms [86], such as mobile apps [26, 61], video games [109], augmented reality [93], virtual reality [85], and wearables [18], our work focuses on a specific form: swarm user interfaces, which can be understood as sitting at the intersection of tangible user interfaces (TUIs) and socially assistive robots (SARs).

TUIs have long been explored for their potential to support emotional expression, regulation, and awareness through embodied and material interactions [86, 87, 110, 116]. In the context of ER, tangible interfaces allow users to externalize [79, 113] and manipulate [4, 47, 64, 111, 117] affective states through physical engagement, enabling reflection and emotional expression without verbal articulation [30, 88]. However, these systems typically center on interactions with single physical objects, limiting the social and ambient dimensions of affective experience. Recent design research has begun to explore metaphor-based social robot collectives as a way to represent affect through ambient symbolism and coordinated behavior [5]. By exploring how collectives of robots can embody roles such as a choir, a fragile companion, or a spatial bridge, their work offers rich design inspiration for crafting swarm robot interactions that support ER through symbolic behavior, ambient affective cues, and relational metaphors.

In parallel, SARs, or social robots, have been developed to provide emotional and cognitive support through social interaction [28]. These robots have demonstrated therapeutic value in mental health contexts, especially among children [46, 48, 77, 83, 112], older adults [10, 43, 65], and individuals with cognitive or emotional disorders [22, 76]. Through affective presence, social cues, and conversational engagement, SARs aim to help users recognize, process, and regulate emotions [17, 92]. Their designs often rely on anthropomorphism or zoomorphism to elicit empathy and trust [17, 46, 80], but typically operate in dyadic, one-to-one interaction settings.

Swarm user interfaces offer a promising design space that bridges the material immediacy of TUIs with the affective resonance of SARs. This dual capacity enables new forms of affective interaction that are neither fully object-centered nor dependent on anthropomorphic embodiment. Building on this direction, our work proposes a swarm user interface for ER that distributes emotional expression across space and agents.

2.3 Swarm Robotics & Swarm User Interfaces

Unlike traditional interfaces or single-agent robots, swarm robots are composed of multiple autonomous agents whose collective behavior unfolds through local coordination inspired by natural swarms. Swarm user interfaces have recently been proposed as a flexible and expressive medium for HCI. Small, mobile robots that operate collectively on a tabletop surface have been used in data visualization [50, 58, 59, 104], educational tools [34, 63, 118], non-verbal communication [19, 35, 100], embodied interactions [25, 44] and haptics feedback [27, 54, 67, 102, 103, 115].

Beyond these applications, the use of swarm robots for emotion-related interaction has recently gained traction. The movement of robot swarms has been shown to communicate affective qualities such as valence and arousal, simply through variations in parameters like speed, synchronization, and smoothness [23, 53, 89]. Even the swarm robots' mere presence affects human cognition and affective states [51, 68]. Notably, the SwarmFidget project introduced programmable, actuated swarm robots that respond to user touch and gestures, enabling personalized fidgeting experiences [81] to help ADHD adults regulate anxiety and concentrate. Participatory design work in this space has shown that users value the customizability, responsiveness, and tactility of swarm interactions, suggesting a promising role for swarms in supporting ER needs. This project explored how users envision emotionally supportive interactions with swarm robots. Our findings extend prior work by framing swarm interfaces not only as expressive displays or manipulatives, but as dynamic, embodied, and social agents capable of supporting ER in everyday life.

2.4 Speculative Participatory Design Workshops

There is growing interest among HCI community in adopting speculative approaches in participatory design [90] to explore values, imaginaries, and possible futures beyond immediate utility or feasibility [14, 40]. Within participatory design, speculative methods shift the focus from requirement elicitation to imaginative engagement, allowing participants to envision alternative socio-technical relations [9, 14].

Our study builds on this tradition by adopting the Magic Machine Workshop method developed by Andersen and Wakkary [8]. The Magic Machine Workshop is a speculative design workshop format that shifts the focus of design inquiry from collective problem-solving toward the expression of personal, embodied design knowledge [6–8]. Unlike traditional HCI workshops that often prioritize data extraction for research agendas, the Magic Machine Workshop centers on the individual participant's imagination, commitment, and internal concerns, allowing them to radically construct personal visions of technological artifacts, or "magic machines," that may or may not be realizable. The method has been applied in a variety of contexts, including participatory workshops with older adults [13, 105], LGBT community [31], and refugees [3, 98]. In the context of ER, it has also been applied to explore interactive technologies for meditation [20], mindfulness [62], and peer support for loneliness and isolation [41].

Given that both the concept of swarm user interfaces and emotional support robots are far from people's real lives and may not be perceived by users, applying the Magic Machine Workshop method is promising for our goal. By encouraging "making in the hypothetical," the workshop avoids the barriers of technical expertise, instead opening a space where the act of creation and subsequent interpretation become performative and introspective [6, 7]. In addition, the moment of presenting and naming the machine transitions the participant from introverted making to extroverted reasoning, prompting emergent narratives about use, meaning, and interaction. This performative shift helps us understand both the latent thinking embedded in the making process and the personal meaning ascribed to the artifact [8].

3 Method

We conducted a series of speculative participatory design workshops to explore how participants imagine integrating swarm interfaces into their own ER practices, thereby revealing speculative mechanisms through which swarms could support ER.

After two rounds of pilot studies, we finalized the protocol for our participatory design workshops. This study was approved by the institution's ethical committee.

3.1 Pilot Study

Before conducting the formal workshop, we carried out two pilot studies to explore and adapt the Magic Machine Workshop method to our research context. These pilots served primarily as methodological tests rather than data collection sessions.

Both pilots followed the original format proposed by Andersen and Wakkary [8]. However, we deliberately kept the structure flexible, allowing space to observe participant engagement, material interactions, and timing constraints. First, they responded to a prompt designed to recall their personal experience in ER. Then, using low-fidelity and intentionally obstructive materials, they constructed fictional "machines" that could support their personal ER. Without prior notice, participants were asked to perform and narrate their machine's function in front of the group. A short group discussion followed, treating each machine as real to elicit further interpretation. Finally, participants self-staged their machines for documentation, choosing how their creations would be represented visually.

Each pilot was conducted as a one-hour participatory design workshop involving three participants, for a total of six researchers across two sessions. The participants came from diverse HCI subfields, including mental health, human-robot interaction, tangible user interfaces, artificial intelligence, and creative design. Their participation was voluntary without compensation.

Through informal debriefings and observations, we identified key refinements for the formal workshop. For instance, we revised the language of the prompt to avoid emotional discomfort triggered by the original version, which unintentionally led participants to recall emotionally painful experiences. The updated prompt encouraged reflection on successful ER experiences instead. We also adjusted the material set to stimulate open-ended creativity better and reduced reliance on prior technical knowledge, which had previously constrained imagination. In addition, we removed a storyboard worksheet intended for preparation, as it conflicted with the goal of keeping the performative presentation spontaneous. Finally, we noted that three participants per session did not generate sufficient peer interaction, informing later decisions about group size.

3.2 Formal Study

In the formal study, we conducted three speculative participatory design workshops to elicit personal and imaginative engagements with ER and swarm user interfaces. Our approach adapts the Magic Machine Workshops [6] to foreground participants' lived experiences and creative ideation around ER, while enabling rapid material exploration and performance-based walkthrough. Following Andersen and Wakkary [8], our workshop design preserved the structured flow that creates the conditions for introspective, imaginative engagement, while ensuring that the creation of the Magic Machines remained entirely open-ended and unconstrained by technical feasibility.

3.2.1 *Participants.*

We used posters, social media, and word-of-mouth referrals to recruit participants. The recruitment criteria for this study are: individuals who speak fluent English and are 18 years of age or older. We conducted three participatory design workshops with 15 participants (7 males, 5 females, and 3 non-binary individuals, aged 19–53). None of them were diagnosed with mental illness or received therapy. Table 1 provides an overview of their backgrounds. Each participant was rewarded 30 CAD for contributing to the project.

3.2.2 *Procedure.*

Workshops were held in a quiet room with tables suitable for tabletop interaction, and a digital screen showing slides for instructions. Each workshop comprised seven stages. Two facilitators co-led all stages. To facilitate meaningful discussion while minimizing fatigue and maintaining the quality of qualitative data, we organized participatory workshops with groups of four to six participants and limited the workshop duration to two hours.

Stage 1: Introduction. Facilitators introduced themselves, welcomed participants, introduced the purpose of the study, and obtained informed consent. We explained that this was a creative design workshop, and they would be able to create their own magic machine that supports their emotional health.

Stage 2: ER Prompt. To deepen our participants' understanding of ER based on their own experience and knowledge, the facilitators invited the participants to recall their ER moments individually. They were prompted with a simplified definition of ER and the ER process based on prior work [37, 71] for easier understanding. Specifically, they were asked to sketch or write about their initial emotional states, the actions they took, and their ultimate emotional states, which were their ER goals. To avoid hurting feelings and to make the process of self-disclosure easier, we asked about their successful ER experience. We used the following prompt:

"Think of at least one moment when you managed to shift or control how you were feeling. Please draw or write down:

- What were you feeling at first?
- How did you want to feel instead?
- What did you do?"

To help participants consider a wider range of emotions, we presented 15 emotion examples (Figure 2) through the Circumplex Model of Affect [78, 84] on the slides.

Each participant received an A4 sheet with the prompt and a pen. Additionally, they were told that sharing with other participants was optional to reduce disclosure pressure. After participants finished recalling their own ER experiences and strategies, we then introduced the concept of ER and explained five ER strategies [37] with concrete examples in real-world scenarios.

Stage 3: Swarm Exploration. Magic machine workshop method introduces the prompt to both situate making within a thematic context and provide an accessible "red spot" on-ramp that establishes confidence through an achievable initial commitment [8]. Having thematically anchored the workshop in participants' lived ER experience in Stage 2, we further provided them with a red spot experience: a short, achievable, low-stakes activity that helps participants quickly build confidence and a shared experiential reference point before open-ended making.

Table 1: Demographics of the participants in the participatory design study.

Workshop	Participant	Gender	Age	Career / Major
W1	P1	Female	22	Linguistics
W1	P2	Male	19	Biomedical Engineering
W1	P3	Male	20	Software Systems
W1	P4	Non-binary	33	Mathematics
W2	P5	Male	Prefer not to disclose	Computer Science
W2	P6	Female	20	Business Administration
W2	P7	Non-binary	27	Film Photography
W2	P8	Male	25	Computer Science
W2	P9	Male	25	Robotics
W2	P10	Non-binary	19	English
W3	P11	Female	24	Political Science
W3	P12	Female	22	Artificial Intelligence
W3	P13	Female	31	Scientist
W3	P14	Male	27	Economics
W3	P15	Male	53	Psychology

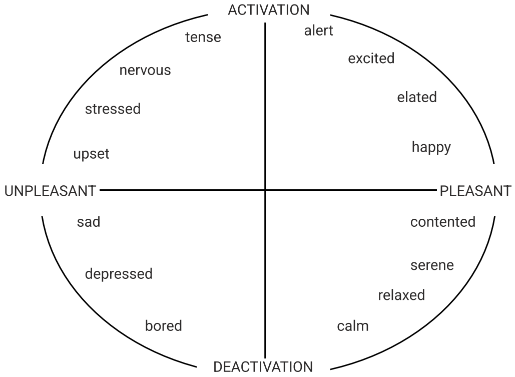


Figure 2: Emotion examples presented to the participants based on the Circumplex Model of Affect [78, 84].

In this stage, facilitators demonstrated the concept of swarm user interfaces with swarm robots, as swarm user interfaces and robot-mediated emotion regulation are unfamiliar technological domains for the participants. The phase aims to lower the cognitive barrier and establish a shared ground from which participants can imagine radically personal futures with new technologies.

To simplify the concept of swarm, we began with the metaphor of animal swarms in nature, such as fish swarms, bird swarms, and bee swarms. Then, we demonstrated swarm user interfaces using Toio, a miniature multi-robot platform developed by Sony Corporation [99]. The robot is white and cubic, measuring 32 mm × 32 mm × 20 mm. To avoid constraints on imagination, instead of referring to Toio as robots, we emphasized to the participants that these cubic robots were a swarm of "magic cubes." We then presented the abilities of Toio robots, including the ability to move on a planar surface, emit colored light, play simple digital sounds, and recognize slope. After that, the facilitators demonstrated four swarm interactions and allowed participants to try each one individually, enriching their understanding and helping them gain tangible experience with swarm robot interaction. The example interactions (see Appendix A) include *Expanding and Contracting Circle*, *Conveyor Interaction*, and two *Remote Interaction*, which were based on past research on fidgeting experiences with swarm robots [81]. Throughout this stage, we kept emphasizing that we were only showing some example abilities and behaviours of the "magic cubes," and they were open to imagining any kind of abilities and behaviours of the swarm system.

Stage 4: Material Making. By the end of Stage 3, facilitators helped participants gain knowledge of both ER and swarm user interfaces. Building on this, they were asked to create their own magic machines to support their mental well-being using "magic cubes" and "magic materials". Each participant received craft supplies for prototyping, and white cubic clay cubes to represent the robot instead of getting real Toio robots. By doing so, the "magic cubes" appeared less robotic, and the soft nature of clay made them easier to modify, reshape, and connect with other materials. It further avoided anchoring participants' imagination to an off-the-shelf platform, allowing them to depart from demonstrated behaviors and pursue speculative, personal interpretations. The default allocation was five clay cubes per participant, with additional units available upon request.

Stage 5: Presentation and Discussion. After creating the machines, the facilitators asked the participants to stand up, present their magic machines, and describe how these machines could support ER. Participants were asked to explain:

- What is the name of your group of magic cubes?
- How do your magic cubes work to support your emotional health?
- Why did you create them in this way?

The participants were not informed of the presentation beforehand, as this might limit them to coming up with only socially acceptable ideas. This performative stage marked a significant shift in energy, moving participants from an internal, wordless making process to an external, verbal improvisation that opens up shared conversation and reflection [6, 8].

Group discussions followed, during which each presentation was discussed by the group. The facilitators led a design studio critique [91], treating each machine as if it were real, posing critical questions to deepen understanding without judgment or correction. A question checklist (see Appendix B) was created based on prior works to ensure that each participant addressed the key aspects of their work. This checklist was only available to the facilitators. First, it included components of the ER delivery mechanism [96], which helped us understand how, when, and where they use the magic machine. It also incorporated tangible interaction themes [42] to provide insight into how participants interact with the machine. Last, we included prototype filtering dimensions [66] to understand the reasoning behind the material composition of the prototypes.

After the peer Q&A, the facilitators also demonstrated two researcher-designed interaction patterns based on prior literature, as if they were also participants in the workshop. These interaction patterns were selected for their strong user appeal in the pilot study and comprehensive coverage of the ER delivery mechanism components [96]. We emphasized that our designs were not the standard answer, but rather the facilitators' personal magic machines. Participants could try them and ask questions. The first interaction modified the "I like you" interaction [54], which is experiential and on-the-spot. When the user appears sad or withdrawn, the robots slowly approach the user's arm and press against it, mimicking a comforting cuddle gesture. The second interaction builds on the same movement pattern "Expanding and Contracting Circle" [81] presented to the participants in Stage 3, which is didactic and offline. In this version, the rhythmic expansion and contraction are paired with ambient music to guide a breathing exercise. Users are invited to inhale during the expansion phase and exhale during contraction, aligning their breath with the swarm's embodied rhythm.

Stage 6: Iterative Optimization. To give participants a chance to replenish and update their magic machines, the facilitators asked them to revisit and modify their machines based on ideas discussed during Stage 5. They were told that changes were optional. Facilitators then solicited opinions to capture comparative judgments. This reflective iteration enabled reinterpretation loops and minor prototyping updates, allowing us to understand which designs were universally appreciated.

Stage 7: Documentation. With the workshop officially concluded, each participant staged and approved a photo of themselves with their machines to capture ephemeral insights of narrative choices made by the participants, allowing for post-workshop reflection and analysis. Each participant was invited to pose for a photograph with their machine. This is a self-staged process where participants choose how to hold, present, and frame their artifact. Participants also approve the final photo, ensuring that the documentation respects their intent.

3.3 Data Collection and Analysis

Multiple forms of qualitative data were collected and analyzed throughout the workshops, including: (i) written prompt sheets (Stage 2), (ii) photos of the final machines (Stage 7), (iii) facilitator's question checklists and fieldnotes, and (iv) video recordings of performances and group discussions. Each participant was assigned an anonymous ID (P#) and corresponding workshop label (W#) for traceability across data sources.

We conducted inductive thematic data analysis [29] using a collaborative, multi-phase approach. Throughout the analysis, we iteratively compared and triangulated across these data types to preserve contextual richness and to surface latent meanings embedded in both verbal and non-verbal expressions. Two of the authors independently open-coded all data, using a bottom-up approach without predefined codes. During this phase, we continuously moved between data types to ensure that emerging codes reflected the multi-modal nature of the workshop. After initial coding, we collaboratively reviewed and merged codes through discussion, resolving inconsistencies and consolidating overlapping categories. Next, we each independently clustered the codes into preliminary themes, which were then discussed and refined through multiple rounds of consensus-building. In cases where agreement could not be reached, the full author team engaged in joint discussion to finalize the thematic structure.

4 Findings

Our analysis of the workshops reveals a logical progression in how participants conceptualized swarm-based ER: starting from the situational needs that trigger the desire for support (when/where), translating these needs into embodied metaphors and structures (what), and finally operationalizing them through distinct interaction modes (how). A summary of findings can be found in Table 2. Although participants were instructed to use the terms "magic machine" and "magic cubes" in the workshops, we will use "robot" in this section to present the results. Details of participants' self-regulation strategies and emotional goals from Stage 2 (ER Prompt) of the workshops are provided in Appendix C.

4.1 Discovering Contexts of Use

The design of swarm user interfaces for ER is deeply rooted in people's lived experiences. This section outlines the context of swarm-based support, mapping the emotional motivations that drive the desire for intervention and the situational boundaries that define where these intimate interactions can comfortably occur.

4.1.1 *Emotional Contexts and Motivations.*

Participants recalled specific life scenarios where negative emotions served as the primary trigger for seeking support, defining the "when" and "why" of swarm interaction. These motivational contexts spanned feelings of anxiety, loneliness, sadness, anger, fear, and lack of focus.

Loneliness emerged as a distinct context for usage, cited by four participants, particularly in solitary environments. For instance, W2P8 described the isolation of driving alone, noting a desire to simply *"talk to people"* during the commute. In these moments, the motivation stemmed from a need to fill a social void without the burden of human interaction. Similarly, W2P7 identified general loneliness and the need to alleviate the silence in a personal space as key drivers of engagement.

High-arousal states, such as anxiety and anger, were cited by six participants as contexts requiring external regulation. Participants

Table 2: Overview of our findings, including contexts of use, envisioned swarm framings, and interaction modes.

Section	Themes	Key Findings
Discovering Contexts of Use	Emotional Contexts and Motivations	Addressing states such as anxiety, loneliness, anger, and lack of focus.
	Situational Contexts	Prioritizing private spaces (e.g., bedrooms) over public environments.
Envisioning the Affective Swarm	Creating Metaphors	Ranging from anthropomorphic, zoomorphic, artifact, and natural metaphors.
	Structuring the Swarm	Organizing swarms as centralized hierarchies or decentralized collectives.
Exploring Mechanisms of Emotion Regulation Support	M1: Ambient Presence	Offering non-intrusive companionship via background movement and sound.
	M2: Empathetic Resonance	Mirroring user energy and showing empathy to validate internal states.
	M3: Proactive Intervention	Proactively initiating support such as offering advice or fetching items.
	M4: Reciprocal Caregiving	Stabilizing agency and control by caring for robots (e.g., charging).
	M5: Playful Soothing	Releasing tension through tactile fidgeting or interactive games.
	M6: Collective Expression	Performing synchronized spectacles to visually transform the atmosphere.

pointed to external pressures, such as being *"too stressed out by your work, by your family"* (W1P1) or managing the general *"anxiety and stress you have in your real life"* (W2P9). W2P8 specifically recalled moments of feeling *"angry"* or *"upset"* as distinct emotional spikes that disrupted their baseline state.

Four participants described contexts of emotional vulnerability, characterized by sadness and fear. W3P15 recalled feeling *"lost"*, while W3P11 described states of being *"overwhelmed"* where emotional balance was difficult to maintain independently. The most visceral context was provided by W1P1, who recalled the childhood fear of sleeping in the dark and the anxiety regarding unseen threats *"underneath the bed"* or in narrow closets. In these scenarios, the motivation for use was not merely distraction, but a fundamental need for safety and grounding.

Finally, participants also mentioned cognitive regulation, especially in professional or academic settings. They described struggles with maintaining concentrated and focus (W1P3) or feeling overwhelmed by *"a lack of control"* (W1P4).

4.1.2 Situational Contexts.

All participants indicated that they would feel most comfortable using swarm robots in private or semi-private spaces. Bedrooms, personal living areas, and entire homes were cited as the most preferred settings. Participants also envisioned using them during travel (W3P14) or while driving (W2P8), suggesting that mobile contexts could benefit from ambient companionship. Many participants considered using the swarm at work (W2P5, W2P7, W2P8, W3P14), particularly in personal offices or study environments. None of the participants were comfortable using the swarm in public or socially visible spaces. Most emphasized the intimate and personal nature of their relationship with the robots, expressing unease at the idea of others witnessing or interacting with them: *"I wouldn't necessarily think about using them broadly in public. Perhaps accidentally draw attention to yourself"* (W2P5).

4.2 Envisioning the Affective Swarm

Building on the identified contexts of use, participants created diverse design metaphors and structures for their swarms. These metaphors served as the interface between the user's emotional needs and the swarm's capabilities, shaping the physical design and perceived agency of the system. Figure 3 presents all the magic machines created by participants during Stage 7 (Documentation) of the workshop.

4.2.1 Design Metaphors.

Participants projected various metaphors onto their swarms, shaping their physical design and capabilities to meet distinct ER needs. This projection is not singular but intertwined, as participants often use multiple metaphors. Table 3 summarizes the identified metaphors and their representative design features derived from workshop prototypes.

Anthropomorphic Metaphors. Five participants described their swarms as anthropomorphic companions or assistants, resembling friends, family, or colleagues. Example prototypes include "Swarm Buddies" (W1P3, W2P10), "Tenna" (W2P10), and "Triple Siblings" (W3P11). Robots were given human-like features such as clothing (W1P3, W2P10, W3P11, W3P12) or hairstyles (W3P11, W3P12, W3P15). Inspiration often came from personal relationships or media characters that they were familiar with. Some participants selected these roles to complement their existing social needs. For instance, W3P11 modeled robots after siblings not just for familiarity, but to act as a bridge to her real family, notifying them of her sadness to ensure she was *"managing emotions with both the swarm and the family"*. Conversely, W2P10's prototype was *"made one to one based on a video game character [...] just for fun"*. For some participants, these robots were not subordinates but *"more friends than pets"* (W1P3). In contrast, three participants expressed their discomfort with forming emotional bonds with *"unreal"* agents (W3P11), preferred to use them only for productivity

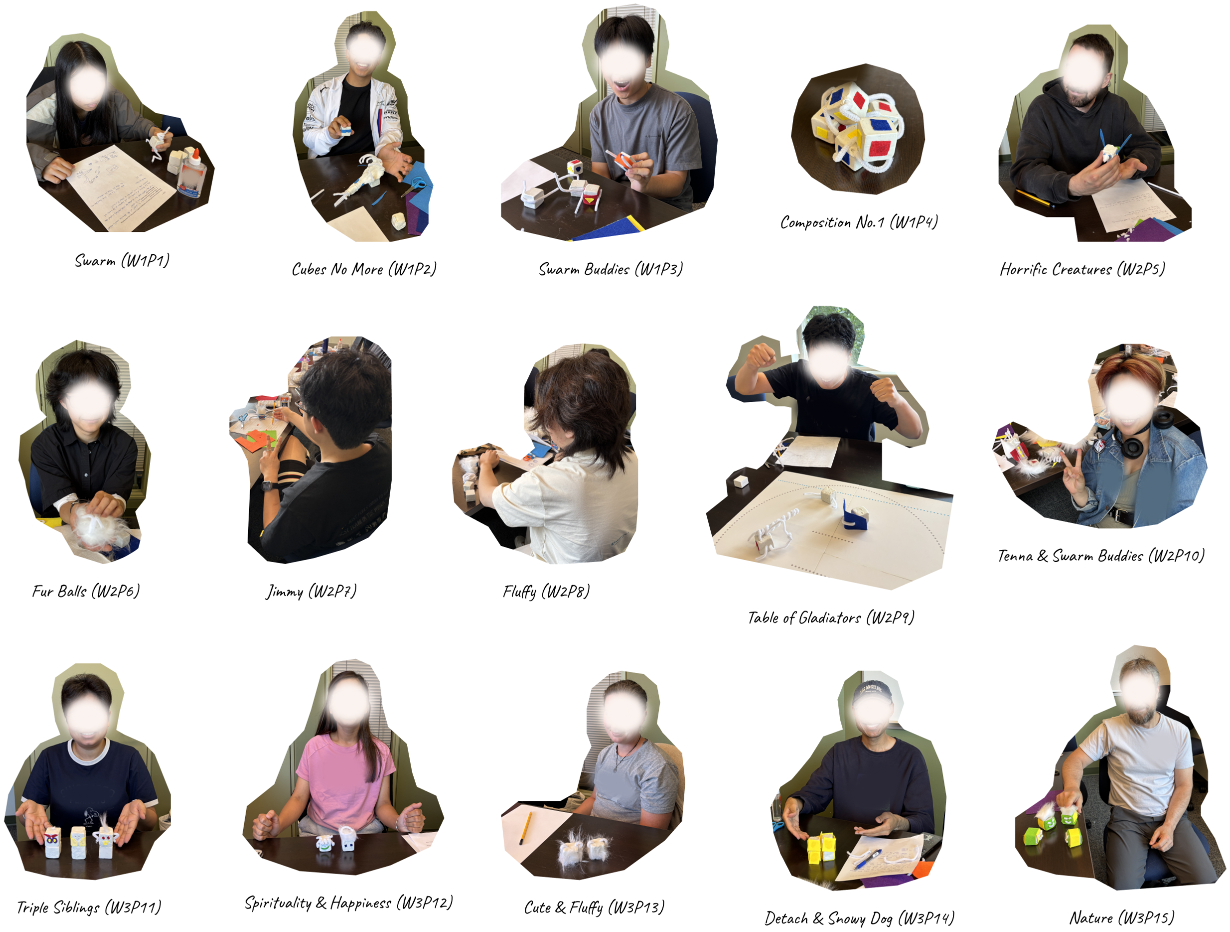

Swarm (W1P1)
Cubes No More (W1P2)
Swarm Buddies (W1P3)
Composition No.1 (W1P4)
Horrific Creatures (W2P5)
Fur Balls (W2P6)
Jimmy (W2P7)
Fluffy (W2P8)
Table of Gladiators (W2P9)
Tenna & Swarm Buddies (W2P10)
Triple Siblings (W3P11)
Spirituality & Happiness (W3P12)
Cute & Fluffy (W3P13)
Detach & Snowy Dog (W3P14)
Nature (W3P15)

Figure 3: Participants' magic machines of swarm user interfaces for ER support from participatory design workshops.

Table 3: Summary of design metaphors and their corresponding key features and representative participant prototypes.

Metaphors	Inspiration	Appearances	Capability	Intelligence & Agency	Examples
Anthropomorphic	Personal relationships, media characters	Clothing, hairstyles	Move, speak, manipulate	Artificial intelligence, high-level agency	Swarm Buddies (W1P3), Triple Siblings (W3P11)
Zoomorphic	Pets, animals	Soft and tactile materials, white color	Move, make sounds, fly	Moderate intelligence, moderate agency	Horrific Creatures (W2P5), Fur Balls (W2P6)
Artifact	Tools, toys, artifacts	Geometrically symmetrical or functional forms	Manipulate, roleplay, heal	Non-sentient	Composition No.1 (W1P4), Table of Gladiators (W2P9)
Natural	Trees	Organic colors	Stationary	Passive object	Nature (W3P15)

(W3P12), or emphasized that the swarm's presence should remain predictable and controllable: *"I want them to listen when I speak, like voice control or even just thinking [...] They should always respond"* (W2P7).

Morphologically, these robots were often envisioned with the ability to move and manipulate, such as having extendable arms to *"give assistance"* (W2P7) (Figure 3). Crucially, participants assigned artificial intelligence, high-level agency, and distinct personalities to individual units to support interpersonal ER. W3P11 designed her swarm to *"live in their own world "* and *"only do what they want to and when they want to do it"*. Other participants assigned different personalities or responsibilities to the robots, similar to narrative models like *"Snow White and the Seven Dwarfs"* (W3P11), where *"each could cope with different emotions"* (W1P3), or *"be a society around me [...] some are emotional supporters, some are experts [...] they work together"* (W3P14).

Zoomorphic Metaphors. Six participants likened their swarm to animals, naming them "Fur Balls" (W2P6), "Fluffy" (W2P8), or "Horrific Creatures" (W2P5). Inspiration sometimes came from their own pets (W1P1, W2P7). Designs emphasized soft, tactile materials like fur and pipe cleaners and featured animal-like forms (e.g., birds, fungi, octopuses, penguins) because they were *"very calmed by touching soft things"* (W2P8) (Figure 3). The color white was frequently used to suggest innocence and cuteness.

Beyond texture, participants altered the robots' morphology to enhance their aliveness and capacity for distraction. Modifications included adding *"bouncing flanges"* for tactile fidgeting (W2P5) or imagining them to *"hover in the air"* (W2P6). Designs in this category still include some degree of intelligence, but significantly less than in anthropomorphic metaphors. W2P6 envisioned robots with memories to develop their personalities. Several participants allowed the robots to make sounds and expressions. Most of them were satisfied with the indistinguishable zoomorphic or digital sounds, while W2P7 equipped the robot with a *"screen and microphone"* to *"chat with a pet"* and alleviate loneliness.

Artifact Metaphors. Five participants conceptualized their swarm as tools, toys, or interactive artifacts. These robots were designed to be non-sentient because participants preferred *"material that I could be in control of"* (W1P4). Prototypes such as "Cubes No More" (W1P2), "Detach & Snowy Dog" (W3P14), and "Composition No.1" (W1P4) used geometric aesthetics, symmetrical forms, and ornamental motifs. For example, W1P4 arranged the cubes to be *"a very advanced interactive fidget thing"* in symmetrical patterns to aesthetically *"break up the weight"* of the moment. Morphologically, these units were treated as functional systems. W1P2 envisioned them with medical sensors and can *"heal the hand"* during physical pain. W2P9 equips robots with weapons and shields (Figure 3), allowing them to role-play as gladiators in simulated combat.

Natural Metaphors. One participant (W3P15) adopted a naturalistic metaphor, designing the swarm as stationary natural objects resembling trees. The design utilized yellow and green colors specifically to *"bring more positive thinking"*. Unlike the mobile agents in other categories, the swarm functioned as an ambient object to *"stare at to awaken some thinking"*, supporting regulation through a feeling of being *"peaceful and connected"* without demanding active interaction.

4.2.2 Swarm Structure. Participants projected specific scale and social organization onto the swarm to shape how the system delivered emotional support. These structural choices modulated the intensity of emotional engagement and the cognitive load required to interact with the system.

Scale. Participants exhibited varied preferences regarding the ideal swarm scale. Most participants were satisfied with the provided number of five robots, frequently citing that they are emotionally supportive without becoming intrusive. Those adopting Anthropomorphic Metaphors tended to favor smaller, intimate scales to maintain distinct personalities for each "sibling" (W3P11 - 3 units) or "friend" (W1P3 - 5 units), explicitly noting that larger groups could become emotionally "overwhelming" (W1P3). In contrast, participants using Artifact Metaphors imagined larger scales (e.g., W1P2 - 10 or 11 units, W2P9 - 10 units) to serve as physical building blocks for complex structures. Just as W2P10 summarized: *The exact number doesn't matter... If you have more, then you can have it doing more things like carrying stuff"*.

W3P13 also made a compelling argument that swarm systems may reduce the risk of over-dependence compared to single-robot systems. A one-to-many relationship was described as more diluted, symbolic, and manageable:

> "A one-on-one emotional connection is too deep [...] like a relationship. But with a swarm, you're not emotionally tied to one. It's more like friendship or leadership, collective, not intimate." (W3P13)

Structural Organization and Morphology. While most participants were satisfied with decentralized, egalitarian organization, several participants proposed hierarchical structures to manage the complexity of interaction or enact specific control. Inspired by animals and human societies, this was more common among Anthropomorphic Metaphors and Zoomorphic Metaphors, where a "Leader" robot served as the primary interface for communication and control (W1P1, W2P7, W2P8), often differentiated by size, form, or capabilities, while the others followed its direction. The hierarchy provided a clear locus of control during emotionally vulnerable states, allowing the user to direct the "commander" while the rest of the swarm operated as a supportive backdrop:

> *"This one is the leader, so the others have to look identical to each other. The leader could be bigger than all of the others. Imagine the face here is a screen or LED, so it can get more output that can represent the swarm."* (W2P8)

Beyond social hierarchy, participants conceptualized morphological assembly as tangible support. Aligning with Artifact Metaphors, participants envisioned robots physically connecting to transform their capabilities. W1P2 designed robots as many *"bones"* that can connect to form a robotic *"hand"* (Figure 3), while W3P14 imagined a "Transformer" structure that can assemble to be a shape-changing robot, including a dog-like form and a human-like figure.

4.3 Exploring Mechanisms of Emotion Regulation Support

Our analysis identified six distinct interaction modes that participants imagined as ways for swarm interfaces to support ER, each corresponding to a different form of affective engagement.

M1: Ambient Presence. In contexts of loneliness or focused work, participants prioritized a non-intrusive form of companionship where the swarm offers comfort simply by *"just being there"*(W1P1) in the background. Swarm robots were designed to prevent emotional disruption and provide *"mindless comforting"* (W1P3) through peripheral, rhythmic movements or static co-presence without demanding active cognitive engagement from the user. The interaction modalities are usually visual, auditory, and spatial.

For example, W1P1 described the swarm simply *"moving around periodically on my table like birds,"* while several participants (W1P3, W2P7, W2P10, and W3P15) suggested letting robots *"play among themselves"* in ways that mimicked social play or casual interaction to create a white noise effect: *"They can interact with each other on their own, and then so you can watch it and then feel, usually you want to feel relaxed or calm, so that would be"* (W2P10).

M2: Empathic Resonance. When participants recalled scenarios of feeling down, lost, or exhausted, they sought emotional validation rather than immediate solutions, desiring a swarm that mirrored their internal states. In this mode, the interaction was characterized not just by passive reflection, but by a bidirectional feedback loop where the user and the swarm mutually influenced each other's emotional states. Participants imagined swarms with an active intent to empathize with the participants. They envisioned swarms that physically reflected their energy levels and internal states when they needed validation, thereby creating specific mappings between their emotional deficits and the swarm's behavioral responses. W2P8 described how, when he felt down, the swarm should lower its energy to match his by moving slowly and dimming lights, creating a *"gentle envelope"* of empathy. Similarly, W1P3 designed the swarm to physically enact his internal state to help him regain self-awareness when feeling lost:

> *"Remind myself of what I'm doing. [...] so it would probably represent what I'm thinking or what I'm feeling and act. The actions are based on how we feel."* (W1P3)

M3: Proactive Intervention. In contexts including sadness, fear, and anxiety, participants sought functional solutions in which the swarm provides immediate assistance to break negative loops.

Six participants (W1P1, W2P2, W1P3, W2P6, W2P8, W2P10) envisioned the robots moving closer to provide emotional support. For example, spinning and sounding cheerfully to welcome the user home (W1P1) or, as W2P8 described, "If I feel upset, I feel angry. They just come here to me, and I know they're coming. So I don't feel alone." W2P8 designed the swarm to be available for casual conversation to combat the isolation of solo driving: *"Sometimes I drive alone, and I want to talk to people, so I can just talk to him."*

The swarm also functioned as an active advisor or tool. Participants described robots nudging their attention away from rumination (W2P5, W2P8), providing health reminders when they were tired (W1P4), physically leading them to a relaxing spot (W2P10), or encouraging them and giving hope (W1P3). W2P6 explained that for slight discomfort, only one robot might react, but for deep distress: *"If you touch one of them, for example, they could all like swirl towards you"*. W3P11 designed robots *"grumpy"* and *"intelligent"* personalities to provide diverse advice, viewing them as agents capable of notifying her real-world friends when she felt stressed. Participants also envisioned the swarm performing functional actions to resolve specific stressors (W1P2, W2P8, W2P10, W3P12, W3P14). This included *"security checks"* for fear of the dark (W1P1), bringing items or tools (W1P1, W2P7, W3P14), or offering physical comforts such as bringing candies (W2P10). They also noted that the swarm's multiplicity allowed them to scale the intensity of intervention.

> *"We can have this swarm go on to narrow areas, especially for kids that is too afraid to sleep in the dark, to check underneath the bed, the closet, or any narrow area to make sure there isn't any coverage."* (W1P1)

M4: Reciprocal Caregiving. Inverting the direction of support, participants frequently derived comfort not from being cared for, but from caring for the swarm. This mode was salient in contexts of overstimulation and anxiety, where the ritual of caregiving helped participants regain a sense of competence and grounding.

When participants felt ungrounded, engaging in simple maintenance tasks provided a stabilizing anchor. W2P10 articulated how externalizing care to the robots served as a proxy for stabilizing oneself: *"If you're bad at taking care of yourself, and you take care of them, it's a good way to ground yourself, and then get you back to feeling more calm and stable."* This caregiving process helped them feel competent, needed, and emotionally connected. Participants envisioned affectionate behaviors such as petting (W1P1, W2P8) or changing robots' clothing (W2P7). Even low-functionality robots could evoke strong emotional ties if they allowed such care rituals. Crucially, it was designed to be low-burden. W2P8 noted that while real pets are *"difficult to maintain,"* swarm robots offer the emotional benefits of nurturing without the heavy responsibility.

Participants also used caregiving as a means to exert agency over their emotional environment. This is particularly evident in Zoomorphic Metaphors, where participants felt they could influence the swarm's emotional state, which in turn created a feedback loop of positive emotion:

> *"We can change their mind or influence their emotions easily. [...] Just like you have a dog, she's upset. You can change her emotions by feeding, or just walk them through the neighborhood, and people feel happy, and it will give you emotional feedback."* (W2P7)

M5: Playful Soothing. Playfulness emerged as a powerful strategy to relieve anxiety. Micro-interactions, such as squeezing (W1P2) and fidgeting (W1P4, W2P6), were appreciated as ways to manage restlessness and acute anxiety:

> *"What it makes me think of is when I was at my computer, or I would throw a pen to myself, or I would have a stinky or a Rubik's cube that I would just kind of fidget with. So I could see this being like a very advanced interactive fidget thing [which] sure could be a stress thing or an anxiety thing, but could also just be like I could make something of this, depending on how we feel about the time we have no permissions ourselves."*(W1P4)

Beyond tactile grounding, participants leveraged the swarm to create vivid game worlds and character metaphors (W1P1, W2P9, W2P10) that served as high-engagement distractions or emotional outlets. For example, W2P9 designed the "Table of Gladiators" (Figure 3), a roguelike battle arena where the spectacle of watching robots fight served to "distract you from all the anxiety and the stress you have in your real life". In a more performative and interactive approach, W1P1 proposed a "monster simulator" that inverted the power dynamic:

> *"Go into your city model so that you can play the monster. Have you heard of Ultraman Orchestra? So maybe these things are humans, and then you pretend to step on them. You can feel like a monster."* (W1P1)

M6: Collective Expression. Participants were drawn to the expressive potential of swarm collectives, imagining them "mentally or physically connected" to "form a system" that could transform space and mood (W1P4). In contexts where participants felt a loss of agency or a need for grounding, they designed interactions that emphasized the swarm's responsiveness and self-organizing capabilities. They designed scenarios in which the swarm became a performance featuring dance, musical, and comedy (W3P11), or an artifact for reclaiming control (W1P2, W1P4, W2P6). Robots moving in synchronized flocking patterns (W1P1, W3P12), or reconfiguring themselves into symbolic gestures (e.g., circles, waves, hearts) (W2P9) were seen as powerful emotional expressions:

> *"It would be kind of neat if there was like a ripple effect [...] snap my fingers and get into like a shell formation, or maybe I remove one and the rest of them kind of fill in the space."*(W1P4)

5 Speculative Swarm Interaction Patterns for Emotion Regulation

While the Magic Machine workshops allowed participants to envision emotional support without technical constraints, the resulting concepts were often abstract or metaphoric. To bridge the gap between these speculative imaginaries and realizable swarm behaviors, we synthesized the workshop findings into eight Swarm Interaction Patterns. Importantly, these patterns are interpretive, illustrative design abstractions informed by speculative workshop outputs, rather than direct workshop outcomes. They provide conceptual exemplars that show how participant metaphors could plausibly be expressed through coordinated swarm behaviors.

We categorize the eight patterns into a Venn diagram (Figure 4) based on the ER intervention strategic framework by Slovak et al. [96], which distinguishes between *experiential* vs. *didactic* mechanisms and *on-the-spot* vs. *offline* contexts. Across all patterns, swarm size ranges from 5 to 12 robots, depending on the spatial footprint and the desired expressivity of the interaction. We manually selected seven for easier demonstration of the design.

Greeting Swarm. Participants frequently described a desire for Proactive Intervention (M3), specifically wanting the swarm to come to them proactively and offer a clear, affectively meaningful sense of being noticed. Inspired by the "warm greeting" narrative (W1P1), we envision the Greeting Swarm (Figure 1) to represent an emotionally expressive welcome ritual designed to simulate the affectionate behaviors observed in domestic animals when greeting their human companions. Idle robots will orient toward the user, approach their arm, and exhibit gentle proximity-seeking behaviors reminiscent of cats or dogs. Upon being touched, robots will respond with celebratory gestures, reinforcing mutual emotional recognition. The haptic feedback was inspired by the "I like you" interaction in prior work [54]. The concept of this pattern is situated in the moment of the user's arrival, rather than in negative emotions, and relies on implicit cues such as proximity and attention rather than explicit instructions or tasks.

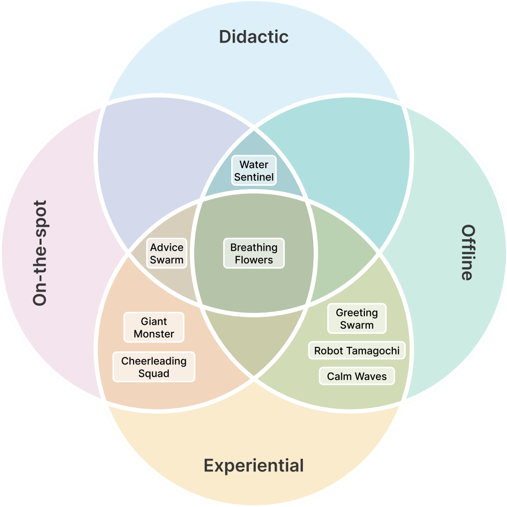
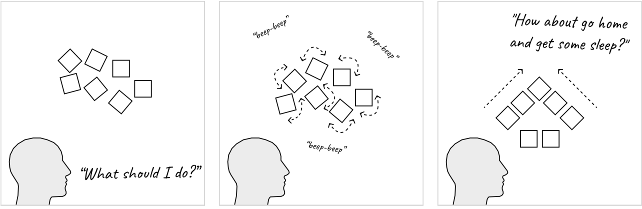


Figure 4: Venn diagram of how swarm interaction patterns are associated with the four delivery mechanisms according to the delivery mechanisms by Slovak et al. [96]. The distinct positioning illustrates the coverage of diverse regulatory mechanisms.

Advice Swarm. Several participants imagined a *"society"* of experts (W3P14) that can deliberate and encourage, aligning with Proactive Intervention (M3) and Collective Expression (M6). Building on that metaphor, we propose the Advice Swarm interaction pattern (Figure 5) in which the swarm will perform as emotionally supportive advisors by combining group movement with affective expression and verbal feedback. When prompted by voice input, the swarm will gather, vibrate, and emit subtle sounds to evoke a "group discussion," and then present a consolidated response. The system will provide a spoken suggestion while the swarm forms an expressive icon that visually reinforces the suggestion. This integration of simultaneous visual and verbal feedback draws inspiration from previous research on co-speech gesture with swarm robots [19].



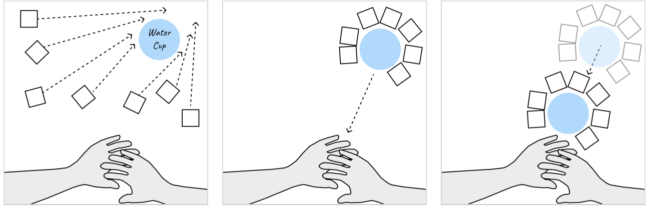
User seeks advice from the swarm.

Robots gather and have a heated "discussion."

Swarm forms a house icon, echoing the verbal advice.

Figure 5: Storyboard of the Advice Swarm pattern. Responding to a verbal query, robots simulate a heated "group discussion" before forming a semantic icon to visually reinforce the spoken advice.

Water Sentinel. Participants also described supportive swarms that intervene gently in routine, especially through embodied reminders that convey a sense of care (e.g., health reminders, W1P4; bringing small comforts, W2P10). This aligns with Proactive Intervention (M3) and is oriented toward low-friction self-care. We outline the Water Sentinel interaction pattern (Figure 6) where the swarm will intervene gently in the user's daily routine by promoting self-care actions such as hydration and rest. Robots will gather behind a water cup, forming a gentle arc or nudging it forward with soft light and sound cues. In this pattern, the swarm is not portrayed as responding to an immediate emotional state but instead act on a lightweight model of care that anticipates needs indirectly, introducing gentle, embodied suggestions into the user's environment without explicit messages, rigid scheduling, or compliance pressure.



Robots notice long inactivity around the water cup.

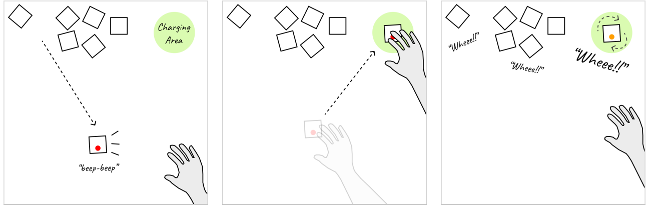
Swarm forms a gentle arc, nudging the cup forward.

Swarm gently nudges the cup forward.

Figure 6: Storyboard of the Water Sentinel pattern. Upon detecting inactivity, the swarm forms an arch behind a water cup and physically nudges it toward the user, serving as an embodied reminder to hydrate.

Robot Tamagochi. Participants described becoming calmer by Reciprocal Caregiving (M4), valuing low-burden rituals that externalize responsibility and competence. Translating that idea, we propose the Robot Tamagochi interaction pattern (Figure 7) where swarm robots could foster a reciprocal care relationship with users by simulating a low-maintenance, emotionally expressive form of artificial dependency. Depleted robots will slow down, blink red, and detach from the swarm, inviting user intervention. Upon being "fed" via charging, they will rejoin the group joyfully. This concept is not framed as a therapeutic claim, but it illustrates how designed vulnerability and recurring care opportunities could create a low-demand channel for grounding and attentional focus.

Giant Monster. Playful Soothing (M5) was a prominent way participants externalized anxiety and restored a sense of agency. W1P1's "monster simulator," for instance, imagined *"pretending to step on"* the swarm to *"feel like a monster"* as a way to transform helplessness into playful dominance. Based on this narrative, we outline the Giant Monster interaction pattern (Figure 8) to explore the emotional and psychological dynamics of playful dominance and performative control in human–swarm interaction. Triggered by a loud gesture, robots will scatter, tremble, and flee in choreographed loops until the user traps them, concluding with a victory signal. The intent of this pattern is to illustrate how a swarm's synchronized responsiveness and real-time physicality could possibly support an immediately felt shift in agency through performative control.

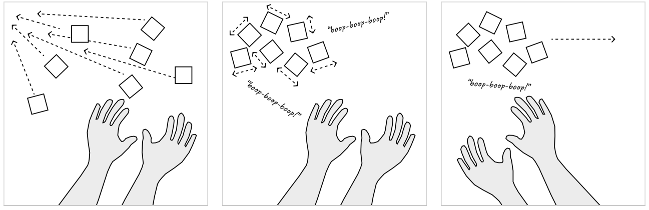

Charging Area
"beep-beep"
"Wheee!!"
"Wheee!!"
"Wheee!!"

A low-energy robot separates, blinking red.

User places it in the charging zone.

Robot recharges and celebrates with spins.

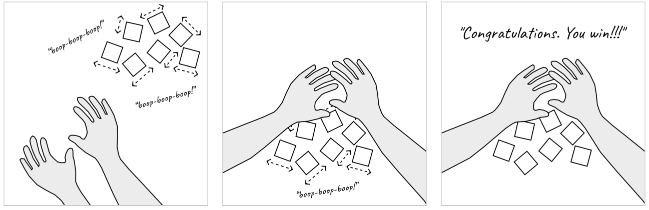
Figure 7: Storyboard of the Robot Tamagochi pattern. A depleted robot signals distress to solicit care. Once the user places it in the charging zone, the robot rejoins the swarm with a celebratory spin.


"boop-boop-boop!"
"boop-boop-boop!"
"boop-boop-boop!"

User raises arms; robots flee with "panic."

Swarm "trembles" at the edge.

User scares them again; robots flee back.


"boop-boop-boop!"
"boop-boop-boop!"
"boop-boop-boop!"
"Congratulations. You win!!!"

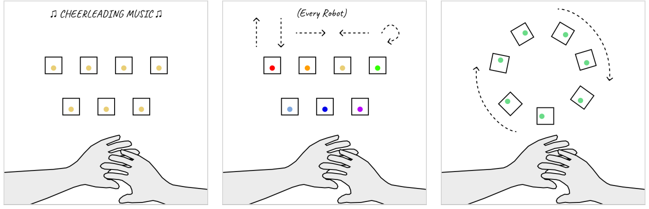
Swarm repeats the startled motion.

User traps them gently in a hug.

Swarm celebrates: "Congratulations! You win!"

Figure 8: Storyboard of the Giant Monster pattern. Users regain a sense of control by "scaring" the swarm, which scatters and trembles in simulated panic. The interaction concludes with the user gently "trapping" the robots, shifting tension into playful release.

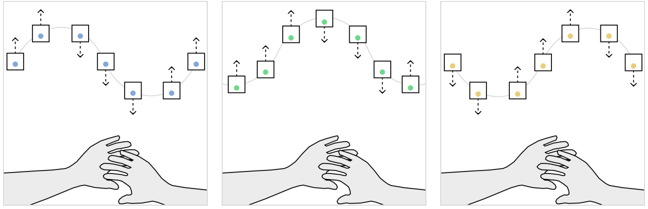
Cheerleading Squad. Participants also envisioned swarms performing spectacles to uplift mood and energize them during difficult moments (W1P1, W3P11), echoing desires of Playful Soothing (M5) and Collective Expression (M6). We propose the Cheerleading Squad interaction pattern (Figure 9) in which the swarm will perform expressive, celebratory behaviors to energize, affirm, and uplift the user during emotionally challenging moments. Through structured motion, music, and light, the swarm will perform synchronized formations and rhythmic gestures in response to user-initiated or system-triggered cues. Rather than mirroring the user's emotion literally, the swarm could offer anticipatory or situational support by simulating excitement and affirming presence.



Robots line up under flashing lights and music. They perform synchronized movements to the beats. Swarm circles joyfully in collective motion.

Figure 9: Storyboard of the Cheerleading Squad pattern. To uplift mood, robots align with flashing lights and music, perform synchronized choreography, and joyfully circle the user's hands in a collective celebration.

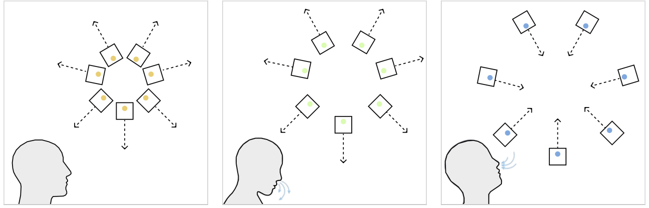
Calm Waves. Some participants asked for *"mindless comforting"* (W1P3) and *"ripple effects"* (W1P4) that can be present while working, studying, or preparing for sleep, which aligns with their need for Ambient Presence (M1) combined with Collective Expression (M6). We describe the Calm Waves interaction pattern (Figure 10) where swarm will arrange into a sine-wave formation and oscillate gently with subtle color modulation, producing a steady visual rhythm that can be attended to passively. Drawing on Empathic Resonance (M2), an optional illustratively feature will be that the swarm's movement speed and color intensity are modulated to mirror and remind the user's energy level. The key point is an always-available, low-demand affective "background" that supports attentional recalibration without requiring active engagement.



Robots oscillate in place in a sinusoidal wave, shifting color and motion rhythmically.

Figure 10: Storyboard of the Calm Waves pattern. Robots oscillate in place to form a continuous sinusoidal wave with rhythmic color shifts. This ambient motion provides a soothing visual anchor without demanding active user engagement.

Breathing Flowers. Participants also expressed interest in rhythmic, embodied guidance when exposed to an "expanding and contracting" pattern for fidgeting in prior work [82]. These inputs motivate a pattern that couples collective motion with a familiar regulation practice: paced breathing (Playful Soothing, M5; Collective Expression, M6). We propose the Breathing Flower interaction pattern (Figure 11) where the swarm will guide the user through a self-paced breathing exercise. The swarm will expand and contract radially in a slow cycle, using synchronized light and optional ambient sound to cue inhalation, pause, and exhalation. This design is intended as an ambient invitation rather than a directive: users may choose to entrain their breathing to the swarm's rhythm, or simply let it remain in the periphery.



Robots slowly expand from center, pulsing with light. Swarm expands to guide synchronized inhalation. Swarm retracts to guide synchronized exhalation.

Figure 11: Storyboard of the Breathing Flowers pattern. A radial swarm formation expands to cue inhalation, pauses, and contracts to cue exhalation, creating a rhythmic cycle to guide and entrain the user's breathing.

6 Discussion

Our study set out to explore how users conceptualize and design swarm user interfaces for ER in their everyday lives. The results of our three participatory design workshops demonstrate how participants envisioned leveraging the unique affordances of swarm robots to address their personal emotional needs.

Our analysis of the interrelations between design concepts reveals three distinct design archetypes that users adopt to navigate their emotional needs. First, primarily in private, solitary contexts (e.g., driving alone, bedrooms), users regulate loneliness or sadness by projecting anthropomorphic or zoomorphic metaphors (e.g. "siblings", "pets") onto hierarchical swarm structures to seek Empathetic Resonance (M2) and Proactive Intervention (M3). In contrast, in professional or cognitive-heavy settings, users deprioritize social agency in favor of artifact or natural metaphors (e.g., "fidget toys", "trees") with decentralized organizations, utilizing Ambient Presence (M1) and tactile Playful Soothing (M5) to manage focus and overstimulation without demanding social reciprocity. Finally, during high-anxiety states or loss of control, users construct gamified spectacles or adversarial formations (e.g., "gladiator battles," "monster simulators") to externalize distress through Collective Expression (M6), leveraging the swarm's physical performativity to shift attention from internal rumination to external dominance.

In the following sections, we first articulate three design opportunities (Section 6.1) that swarms offer. We discuss how swarms offer ontological flexibility through diverse metaphors, leverage multiplicity to structure distributed social support, and bridge interpersonal and intrapersonal regulation through multi-faceted interaction modes. We then examine three design challenges (Section 6.2), specifically addressing the contextual constraints of social acceptability in public spaces, the tension between user control and robot agency, and the complexity of personalization in balancing expressive flexibility with scalable design.

6.1 Design Opportunities for Swarm User Interfaces for Emotion Regulation

Based on the results from the workshops, we identified three design opportunities that leverage the unique affordances of swarm user interfaces. By mapping the user-generated concepts against established ER frameworks and comparing them with existing digital ER, we isolated the unique mechanisms where swarms offer novel therapeutic value beyond singular devices.

6.1.1 Ontological Flexibility. Existing tangible and embodied ER technologies often fall into two distinct categories: tool-like tangible user interfaces (TUIs) for externalizing emotion [88, 117] or socially assistive robots (SARs) for social connection [80, 92]. Our findings indicate that swarm user interfaces fluidly traverse this boundary, offering a unique ontological flexibility.

As shown in our findings, swarms have an abstract nature to support diverse user-generated metaphors (Table 3), and plural and evolving relationships that accommodate varying emotional needs and preferences. This aligns with previous characterizations of swarms as an abstract, expressive medium [23, 53]. By having different forms of expression, swarm robots can flexibly switch between anthropomorphic and non-anthropomorphic dynamics [23, 53, 68]. Participants valued the ability to shift between two modes: treating the robots as social entities (e.g., friends or pets) for comfort, or treating them as passive tools (e.g., fidget toys) for stress relief. The ambiguous forms allow users to project their specific emotional needs, whether they require the protection of "sleep guardians" or the intimacy of "siblings". This also enables users to modulate the emotional distance of the interaction: seeking active support when lonely, or engaging in mindless physical manipulation when overwhelmed, reflecting the need for adaptive interventions in daily life [73].

6.1.2 The Power of Multiplicity. Our findings reveal that the multiplicity is not merely a physical capability but a design resource. Swarm user interfaces further validate the advantages of multi-robot systems demonstrated in early human dual-robot interaction research: the ability to simulate multi-party social environments [1] and enhance engagement through collective behavior [69]. By manipulating scale and organization, the swarm can simulate complex social structures and immersive environments that single agents cannot achieve.

First, from a social perspective, the power of "many" enables a form of distributed and scalable social presence. This multiplicity allows for a parallelism in care" through role differentiation [101]. For instance, swarms can decouple social functions: while one group of agents engages in intimate, direct interaction, others can maintain a calming rhythm in the periphery. This spatial distribution allows the system to simultaneously address conflicting emotional needs, such as the desire for companionship and the need for personal space. Furthermore, this collective structure acts as an emotional safety net; the inherent redundancy ensures that the sense of accompaniment persists even if individual units fluctuate. This "diluted" one-to-many relationship reduces the intensity and potential risks of one-on-one emotional dependence, making the interaction feel more symbolic, manageable, and less intrusive.

Second, distinct from social simulation, the collective nature of the swarm functions as a dynamic ambient scaffold for sensory regulation. While TUIs and SARs often demand constant cognitive attention or social performance [21, 64, 88], a swarm can fade into the background as "living material." Interactions such as Ambient Presence (M1) and Collective Expression (M6) leverage the swarm's capacity to distribute itself spatially in the user's periphery. We argue that this form of interaction supports ER through the mechanism of soft fascination [11], a concept from attention restoration theory [75]. Just as watching a school of fish or leaves in the wind can restore cognitive resources, the collective, rhythmic, and biologically inspired motion of the swarm [89] captures attention and provides comfort effortlessly. Whats's more, the rule-based coordination of the swarm introduces a profound sense of emergent order. During periods of emotional dysregulation, where internal states often feel chaotic and unpredictable, the visible, structured logic of swarm movement provides a stabilizing external reference [16]. By transforming from a collection of individuals into a coherent, organized entity, the swarm serves as a dynamic anchor, offering a sense of certainty and environmental control that assists the user in regaining internal equilibrium.

6.1.3 Bridging Intrapersonal and Interpersonal Emotion Regulation. Our findings demonstrate that swarm user interfaces bridge the gap between intrapersonal ER and Interpersonal ER [74, 114], supporting both social connection and internal cognitive processing.

On the one hand, swarm user interfaces can support intrapersonal ER through sensory and cognitive mechanisms. The identified interaction modes show that swarm can support diverse strategies based on Gross's Process Model of Emotion Regulation [36, 37] into the physical agency domain. Unlike traditional ER tools that typically target a specific intervention stage, such as cognitive reappraisal apps [26] focusing on didactic learning, or biofeedback devices [64] focusing on experiential physiological soothing, our results show that the swarm's physical agency has the potential to support early-stage strategies like *Situation Modification* (M3, M6) by actively altering the user's environment or breaking negative feedback loops. Many swarm interactions were envisioned to support multiple strategies. For instance, Ambient Presence (M1) and Playful Soothing (M5) serve as external tools for *Attentional Deployment*, drawing focus away from distress. Yet, through their rhythmic and tactile qualities, they may also support in *Response Modulation*, directly soothing physiological arousal.

On one other hand, swarm acts as more than a tool; it functions as a quasi-social partner that fulfills the deep-seated human need for affiliation during regulatory episodes [74], transforming the regulation process from a solitary cognitive task into a relational exchange. Empathic Resonance (M2) and Ambient Presence (M1) align closely with co-regulation frameworks, which describe how emotional states become synchronized in close relationships [15, 95]. Crucially, this social dimension extends to Reciprocal Caregiving (M4). Traditional digital ER interventions often position the technology as the active provider of support (e.g., guiding breathing, offering advice). However, our findings highlight the therapeutic potential of caregiving and stewardship.

The Reciprocal Caregiving mode (M4) and patterns such as Robot Tamagochi demonstrate that users can regulate their own emotions, specifically anxiety and a sense of lack of control, by caring for "vulnerable" agents. The small size and multiplicity of swarm robots offer unique benefits for this emotional grounding. Unlike human-sized robots, a swarm of miniature agents places the user in a position of dominance and control. Participants found that "caring for" these small, fragile agents helped them regain a sense of competence and stability. Whether playing a "giant" in a game or nurturing a "pet," these interactions invert the traditional power dynamic of therapy and challenge the design assumption that SARs must always be powerful or intelligent. Studies suggest that while "intelligent" robots build cognitive trust, users often form stronger emotional bonds with robots that display fallibility or vulnerability [32]. It suggests that designed vulnerability in swarm systems can be a potent resource for regulation, allowing users to externalize their own fragility and tend to it vicariously through the swarm, a mechanism often leveraged in animal-assisted therapy [77] but less explored in robotic swarms.

6.2 Design Challenges in Swarm User Interfaces for Emotion Regulation

While swarm user interfaces offer novel potential, our analysis also revealed inherent design tensions that arise when deploying such systems for intimate emotional support. We identified three distinct challenges that characterize the complexity of this design space.

6.2.1 Contextual and Ethical Considerations. Despite their perceived emotional value, participants were largely unwilling to use swarm interfaces in public or socially visible spaces. Concerns ranged from embarrassment and social stigma to distraction and spatial intrusion. This signals a strong contextual constraint: interacting with swarm systems for ER may only be acceptable in private or semi-private environments where emotional expression is protected. Such constraints limit the applicability of swarm user interfaces in mobile or shared settings compared to screen-based apps [61, 94]. However, we argue that this resistance is not an inherent dead-end, but rather a reflection of the current novelty-driven visibility. Public attention is not inherently detrimental to ER. While some participants feared scrutiny, prior human robot interaction research suggests that robots can act as "social bridges" that facilitate positive human-human interaction [48]. In this view, a visible swarm could serve as an icebreaker, transforming the user's isolation into a moment of social connection, which is itself a powerful mechanism for ER. Therefore, the design challenge is not merely to hide the swarm, but to provide visibility management that allows users to toggle between discreet privacy and expressive modes.

Additionally, although many participants described their swarm creations as comforting, some also raised concerns about emotional substitution and dependency. Assigning names, personalities, or caregiving roles to robots can lead to emotional over-attachment to the swarm. Prior work on SARs notes risks of emotional over-attachment and dependency [108], particularly among individuals experiencing loneliness or vulnerability [57]. Multi-agent collectives may diffuse attachment to a single entity, yet our results show that users still project personality, social roles, and emotional expectations onto the swarm, creating potential for avoidance-based coping or substitution for human contact. Designers must consider how to support emotional engagement without the risk of fostering unhealthy dependency or displacing human relationships [48].

6.2.2 Tension between Agency and Control. Our findings highlight a conflict between the swarm's collective agency as a social entity and its predictable utility as a controllable material. On one hand, the efficacy of the swarm often relies on its perceived aliveness. Research suggests that proactive, autonomous behaviors in SARs are essential for building trust and perceived social presence, which are prerequisites for effective companionship [39, 57]. Unlike single-agent SARs, participants did not just value the "mind" of a single robot, but the "collective mood" expressed through the swarm's spatial configuration and synchronized movement. For instance, in the Greeting Swarm interaction pattern, the emotional validation comes from the swarm's active, decentralized decision to swerve toward the user. This emergent agency where the collective appears to possess a shared purpose, is what transforms a group of machines into a responsive social presence. If the system is perceived as merely mechanical, it risks losing the capacity to provide validatory social support. However, this agency becomes a liability when users seek grounding and stability [55, 72]. In contexts of high anxiety, the unpredictability of an autonomous agent can feel overwhelming [12]. For many participants, the swarm's value shifted from a social group to a dynamic material or a living tool that should be entirely subservient to their physical needs, such as acting as a stable haptic anchor or a rhythmic breathing guide. Here, the swarm's autonomous social jitter or independent pathfinding felt intrusive rather than comforting.

Future designs might address this by implementing sliding autonomy [33], allowing users to toggle the swarm between a passive "artifact mode" for immediate stress relief and an active "social mode" for long-term emotional engagement.

6.2.3 Complexity of Personalization. Our study revealed highly individual and contextual preferences for swarm size, behavioral intensity, and emotional framing. The inherent ambiguity of swarm behavior invites users to project their own interpretations onto the system. Unlike human-like agents, swarms lack familiar affective cues such as facial expressions, relying instead on motion parameters [53, 55]. This openness led participants to assign highly divergent capabilities, personalities, and emotional roles to the robots. As a result, personalization emerged not merely as a preference for adjustable parameters, but as a deeply idiosyncratic process of meaning-making, where each participant has unique individual and contextual preferences of the swarm [45, 60]. Designing for personalization at both the behavioral and symbolic levels introduces significant complexity, particularly when each robot might be assigned a unique role or identity. Thus, designers must negotiate a delicate balance: preserving the interpretive openness that makes swarm interfaces expressive and personally meaningful, while ensuring sufficient emotional legibility and behavioral consistency to prevent misinterpretation and support reliable ER across diverse users.

Furthermore, our findings suggest that personalization is shaped by factors beyond mere aesthetic preference, including user background and emotion types. We observed qualitative trends indicating that participants with STEM backgrounds (e.g., Robotics, Engineering) tended to design functional artifacts focused on mechanism and control (e.g., medical tools), whereas those from Humanities backgrounds often crafted narrative-driven social agents (e.g., siblings, characters). Even age appeared to play a role; our oldest participant (53) designed a static, nature-inspired ambient swarm, contrasting with the dynamic, gamified interactions favored by younger users. This implies that effective swarm ER systems may need to adapt not just to the user's personality, but to their demographic profile and the specific type of emotion being regulated, shifting from a "pet" during loneliness to a "tool" during stress.

6.3 Limitations and Future Work

While this study provides initial insights into the design space of swarm user interfaces for ER, several limitations must be acknowledged. First, the findings reflect users' imagined experiences rather than long-term interactions in everyday contexts. Many of the proposed behaviors assumed levels of affective responsiveness, environmental awareness, and coordination that exceed what current swarm platforms can support or require extensive development. While participants responded positively to the imagined interactions and articulated meaningful emotional connections, we do not yet know how these behaviors would function in everyday settings, how users might integrate them into their routines, or whether the patterns would sustain engagement over time. Future research should conduct in-situ evaluations that examine swarm-based interventions.

Second, the emotional scenarios elicited in the workshops were skewed toward successful regulation episodes. This was a deliberate choice to avoid emotional distress during co-creation but may have limited the range of strategies explored. The use of *situation selection* strategy and *didactic* delivery mechanism was less frequently represented in participants' designs. Future studies could examine how swarm systems might support these alternative strategies, especially in contexts where users are not yet motivated or able to engage directly with their emotions.

Last, the physical materials provided in the workshops, specifically the white cubic clay casings and the miniature scale of the Toio robots, may have introduced both morphological and scalar biases. While the cubic choice was grounded in the form factor of the robots used for enactment, it likely influenced participants to conceptualize swarm agents as rigid, modular blocks rather than organic entities. The small size limits the swarm's ability to provide substantial physical comfort (e.g., hugging) or distinct social presence, potentially leading users to view them as "toys" rather than "companions." However, we posit that the interaction mechanisms identified are scale-independent and could generalize to larger embodiments, such as swarms of quadrupedal "robot dogs" or humanoid agents. Future research should explore how these interaction patterns translate to human-scale swarms, specifically investigating the trade-offs between emotional impact and perceived safety.

7 Conclusion

This work explores how swarm user interfaces may support ER by engaging participants in speculative, hands-on design of emotionally supportive systems. Our contributions are threefold: (1) an empirical account of how users conceptualize swarm interfaces for personal ER needs; (2) a conceptual synthesis of contexts, swarm framings, and interaction mechanisms; and (3) a set of reusable interaction patterns grounded in theoretical models of emotion regulation. Collectively, these findings illustrate how swarm systems can transcend expressive novelty to function as emotionally resonant, context-sensitive companions. Moving forward, swarm interfaces offer a path toward ER support that is ambient, distributed, and deeply relational. Future systems that embrace the playful and performative nature of swarms may better reflect the complexity of human emotional experience, offering novel avenues for care and connection. We envision a future where these collectives participate actively in the ER ecology, transforming regulation from a solitary task into a shared, embodied process.

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References

[1] Sara Ali, Faisal Mehmood, Darren Dancey, Yasar Ayaz, Muhammad Jawad Khan, Noman Naseer, Rita De Cassia Amadeu, Haleema Sadia, and Raheel Nawaz. 2019. An adaptive multi-robot therapy for improving joint attention and imitation of ASD children. *IEEE Access* 7 (2019), 81808–81825. doi:10.1109/ACCESS.2019.2923678

[2] Sara Ali, Faisal Mehmood, Muhammad Jawad Khan, Yasar Ayaz, Umer Asgher, Haleema Sadia, Ernest Edifor, and Raheel Nawaz. 2020. A preliminary study on effectiveness of a standardized multi-robot therapy for improvement in collaborative multi-human interaction of children with ASD. *IEEE Access* 8 (2020), 109466–109474. doi:10.1109/ACCESS.2020.3001365

[3] Asam Almohamed, Jinglan Zhang, and Dhaval Vyas. 2020. Magic Machines for Refugees. In *Proceedings of the 3rd ACM SIGCAS Conference on Computing and Sustainable Societies (COMPASS '20)*. Association for Computing Machinery, New York, NY, USA, 76–86. doi:10.1145/3378393.3402256

[4] Miguel Bruns Alonso, David V. Keyson, and Caroline C. M. Hummels. 2008. Squeeze, rock, and roll; can tangible interaction with affective products support stress reduction?. In *Proceedings of the 2nd International Conference on Tangible and Embedded Interaction (TEI '08)*. Association for Computing Machinery, New York, NY, USA, 105–108. doi:10.1145/1347390.1347413

[5] Patrícia Alves-Oliveira, Maria Luce Lupetti, Michal Luria, Diana Löffler, Mafalda Gamboa, Lea Albaugh, Waki Kamino, Anastasia K. Ostrowski, David Puljiz, Pedro Reynolds-Cuéllar, Marcus Scheunemann, Michael Suguitan, and Dan Lockton. 2021. Collection of metaphors for human-robot interaction. In *Designing Interactive Systems Conference 2021*. ACM, Virtual Event USA, 1366–1379. doi:10.1145/3461778.3462060

[6] Kristina Andersen. 2013. Making magic machines. In *10th European Academy of Design Conference*. doi:10.13140/2.1.1280.1285

[7] Kristina Andersen. 2017. *Making magic machines*. Ph. D. Dissertation. KTH Royal Institute of Technology. https://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-214017

[8] Kristina Andersen and Ron Wakkary. 2019. The magic machine workshops: making personal design knowledge. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. doi:10.1145/3290605.3300342

[9] James Auger. 2013. Speculative design: crafting the speculation. *Digital Creativity* 24, 1 (March 2013), 11–35. doi:10.1080/14626268.2013.767276

[10] Annalena Nora Baecker, Denise Y. Geiskkovitch, Adriana Lorena González, and James E. Young. 2020. Emotional support domestic robots for healthy older adults: conversational prototypes to help with loneliness. In *Companion of the 2020 ACM/IEEE International Conference on Human-robot Interaction.* ACM, Cambridge United Kingdom, 122–124. doi:10.1145/3371382.3378279

[11] Avik Basu, Jason Duvall, and Rachel Kaplan. 2019. Attention Restoration Theory: Exploring the Role of Soft Fascination and Mental Bandwidth. *Environment and Behavior* 51, 9-10 (Nov. 2019), 1055–1081. doi:10.1177/0013916518774400

[12] Jenay M. Beer, Arthur D. Fisk, and Wendy A. Rogers. 2014. Toward a framework for levels of robot autonomy in human-robot interaction. *Journal of human-robot interaction* 3, 2 (July 2014), 74–99. doi:10.5898/JHRI.3.2.Beer

[13] Mark Blythe, Kristina Andersen, Rachel Clarke, and Peter Wright. 2016. Anti-solutionist strategies: seriously silly design fiction. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16).* Association for Computing Machinery, New York, NY, USA, 4968–4978. doi:10.1145/2858036.2858482

[14] Kirsten E Bray, Christina Harrington, Andrea G Parker, N'Deye Diakhate, and Jennifer Roberts. 2022. Radical futures: supporting community-led design engagements through an afrofuturist speculative design toolkit. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22).* Association for Computing Machinery, New York, NY, USA, 1–13. doi:10.1145/3491102.3501945

[15] Emily A. Butler and Ashley K. Randall. 2013. Emotional Coregulation in Close Relationships. *Emotion Review* 5, 2 (April 2013), 202–210. doi:10.1177/1754073912451630

[16] Andy Clark. 2013. Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behavioral and Brain Sciences* 36, 3 (June 2013), 181–204. doi:10.1017/S0140525X12000477

[17] Sawyer Collins, Kenna Baugus Henkel, Zachary Henkel, Casey C. Bennett, Cedomir Stanojevic, Jennifer A. Piatt, Cindy L. Bethel, and Selma Sabanović. 2024. "an emotional support animal, without the animal": design guidelines for a social robot to address symptoms of depression. In *Proceedings of the 2024 ACM/IEEE International Conference on Human-robot Interaction.* ACM, Boulder CO USA, 147–156. doi:10.1145/3610977.3634988

[18] Jean Costa, François Guimbretière, Malte F. Jung, and Tanzeem Choudhury. 2019. BoostMeUp: improving cognitive performance in the moment by unobtrusively regulating emotions with a smartwatch. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 3, 2 (June 2019), 40:1–40:23. doi:10.1145/3328911

[19] Minh Duc Dang, Samira Pulatova, and Lawrence H Kim. 2025. User-Defined Co-Speech Gesture Design with Swarm Robots. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems (CHI '25).* Association for Computing Machinery, New York, NY, USA, 1–15. doi:10.1145/3706598.3714147

[20] Claudia Daudén Roquet and Corina Sas. 2020. Body Matters: Exploration of the Human Body as a Resource for the Design of Technologies for Meditation. In *Proceedings of the 2020 ACM Designing Interactive Systems Conference (DIS '20).* Association for Computing Machinery, New York, NY, USA, 533–546. doi:10.1145/3357236.3395499

[21] M. Deady, I. Choi, R. A. Calvo, N. Glozier, H. Christensen, and S. B. Harvey. 2017. eHealth interventions for the prevention of depression and anxiety in the general population: a systematic review and meta-analysis. *BMC Psychiatry* 17, 1 (Aug. 2017), 310. doi:10.1186/s12888-017-1473-1

[22] Manon Demange, Hermine Lenoir, Maribel Pino, Inge Cantegreil-Kallen, Anne Sophie Rigaud, and Victoria Cristancho-Lacroix. 2018. Improving well-being in patients with major neurodegenerative disorders: differential efficacy of brief social robot-based intervention for 3 neuropsychiatric profiles. *Clinical Interventions in Aging* 13 (2018), 1303–1311. doi:10.2147/CIA.S152561

[23] Griffin Dietz, Jane L. E, Peter Washington, Lawrence H. Kim, and Sean Follmer. 2017. Human perception of swarm robot motion. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '17).* Association for Computing Machinery, New York, NY, USA, 2520–2527. doi:10.1145/3027063.3053220

[24] Katherine L Dixon-Gordon, Samantha L Bernecker, and Kara Christensen. 2015. Recent innovations in the field of interpersonal emotion regulation. *Current Opinion in Psychology* 3 (June 2015), 36–42. doi:10.1016/j.copsyc.2015.02.001

[25] Michikuni Eguchi, Shigeo Yoshida, Mai Nishimura, and Takefumi Hiraki. 2025. FluidicSwarm: embodiment of swarm robots using fluid behavior imitation. In *ACM SIGGRAPH 2025 Emerging Technologies (SIGGRAPH '25).* Association for Computing Machinery, New York, NY, USA, 1–2. doi:10.1145/3721257.3734028

[26] Charles Fage, Charles Consel, Kattalin Etchegoyhen, Anouck Amestoy, Manuel Bouvard, Cécile Mazon, and Hélène Sauzéon. 2019. An emotion regulation app for school inclusion of children with ASD: design principles and evaluation. *Computers & Education* 131 (April 2019), 1–21. doi:10.1016/j.compedu.2018.12.003

[27] Mehrad Faridan, Marcus Friedel, and Ryo Suzuki. 2022. UltraBots: Large-Area Mid-Air Haptics for VR with Robotically Actuated Ultrasound Transducers. In *Adjunct Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology (UIST '22 Adjunct).* Association for Computing Machinery, New York, NY, USA, 1–3. doi:10.1145/3526114.3561350

[28] D. Feil-Seifer and M.J. Mataric. 2005. Defining socially assistive robotics. In *9th International Conference on Rehabilitation Robotics, 2005. ICORR 2005.* 465–468. doi:10.1109/ICORR.2005.1501143

[29] Jennifer Fereday and Eimear Muir-Cochrane. 2006. Demonstrating rigor using thematic analysis: a hybrid approach of inductive and deductive coding and theme development. *International Journal of Qualitative Methods* 5, 1 (March 2006), 80–92. doi:10.1177/160940690600500107

[30] Jose Maria Garcia-Garcia, María del Mar Cabañero, Victor M. R. Penichet, and María D. Lozano. 2019. EmoTEA: teaching children with autism spectrum disorder to identify and express emotions. In *Proceedings of the XX International Conference on Human Computer Interaction (Interacci&#xf3;n '19).* Association for Computing Machinery, New York, NY, USA, 1–8. doi:10.1145/3335595.3335639

[31] Cally Gatehouse, Matthew Wood, Jo Briggs, James Pickles, and Shaun Lawson. 2018. Troubling vulnerability: designing with LGBT young people's ambivalence towards hate crime reporting. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18).* Association for Computing Machinery, New York, NY, USA, 1–13. doi:10.1145/3173574.3173683

[32] Ioanna Giorgi, Sachini Rajapakse, Marco Palomino, and Giovanni L. Masala. 2025. Older adults' perceptions of robots with differing intelligence in social multi-robot interactions. *J. Hum.-Robot Interact.* 15, 1 (Nov. 2025), 25:1–25:28. doi:10.1145/3769854

[33] M.A. Goodrich and D.R. Olsen. 2003. Seven principles of efficient human robot interaction. In *SMC'03 Conference Proceedings. 2003 IEEE International Conference on Systems, Man and Cybernetics. Conference Theme - System Security and Assurance (Cat. No.03CH37483)*, Vol. 4. 3942–3948 vol.4. doi:10.1109/ICSMC.2003.1244504

[34] Pauline Gourlet, Mathieu Le Goc, and Sean Follmer. 2017. Revisiting turtles and termites: an open-ended interactive physical game with multiple robots. In *Proceedings of the 2017 Conference on Interaction Design and Children (IDC '17).* Association for Computing Machinery, New York, NY, USA, 679–682. doi:10.1145/3078072.3091979

[35] Kasper Grispino, Damian Lyons, and Truong-Huy D. Nguyen. 2020. Evaluating the potential of drone swarms in nonverbal HRI communication. In *2020 IEEE International Conference on Human-machine Systems (ICHMS).* 1–6. doi:10.1109/ICHMS49158.2020.9209467

[36] James J. Gross. 1998. The emerging field of emotion regulation: an integrative review. *Review of General Psychology* 2, 3 (Sept. 1998), 271–299. doi:10.1037/1089-2680.2.3.271

[37] James J. Gross. 2015. Emotion regulation: current status and future prospects. *Psychological Inquiry* 26, 1 (Jan. 2015), 1–26. doi:10.1080/1047840X.2014.940781

[38] James J. Gross and Brett Q. Ford. 2024. *Handbook of emotion regulation.* Guilford Publications, New York, UNITED STATES. http://ebookcentral.proquest.com/lib/sfu-ebooks/detail.action?docID=30772785

[39] Imane Guemghar, Paula Pires de Oliveira Padilha, Amal Abdel-Baki, Didier Jutras-Aswad, Jesseca Paquette, and Marie-Pascale Pomey. 2022. Social robot interventions in mental health care and their outcomes, barriers, and facilitators: scoping review. *JMIR Mental Health* 9, 4 (April 2022), e36094. doi:10.2196/36094

[40] Christina Harrington and Tawanna R Dillahunt. 2021. Eliciting tech futures among black young adults: a case study of remote speculative Co-design. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21).* Association for Computing Machinery, New York, NY, USA, 1–15. doi:10.1145/3411764.3445723

[41] Daniel Harrison, Scarlett Rowland, Gavin Wood, Lyndsey Bakewell, Ioannis Petridis, Kiel Long, Konstantina Vasileiou, Julie Barnett, Manuela Barreto, Michael Wilson, Shaun Lawson, and John Vines. 2023. Designing Technology-Mediated Peer Support for Postgraduate Research Students at Risk of Loneliness and Isolation. *ACM Trans. Comput.-Hum. Interact.* 30, 1 (March 2023), 10:1–10:40. doi:10.1145/3534961

[42] Eva Hornecker and Jacob Buur. 2006. Getting a grip on tangible interaction: a framework on physical space and social interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* ACM, Montréal Québec Canada, 437–446. doi:10.1145/1124772.1124838

[43] Lillian Hung, Cindy Liu, Evan Woldum, Andy Au-Yeung, Annette Berndt, Christine Wallsworth, Neil Horne, Mario Gregorio, Jim Mann, and Habib Chaudhury. 2019. The benefits of and barriers to using a social robot PARO in care settings: a scoping review. *BMC Geriatrics* 19, 1 (Dec. 2019), 1–10. doi:10.1186/s12877-019-1244-6

[44] Sosuke Ichihashi, So Kuroki, Mai Nishimura, Kazumi Kasaura, Takefumi Hiraki, Kazutoshi Tanaka, and Shigeo Yoshida. 2024. Swarm body: embodied swarm robots. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems (CHI '24).* Association for Computing Machinery, New York, NY, USA, 1–19. doi:10.1145/3613904.3642870

[45] Bahar Irfan, Aditi Ramachandran, Samuel Spaulding, Dylan F. Glas, Iolanda Leite, and Kheng Lee Koay. 2019. Personalization in long-term human-robot interaction. In *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI).* 685–686. doi:10.1109/HRI.2019.8673076

[46] Katherine Isbister, Peter Cottrell, Alessia Cecchet, Ella Dagan, Nikki Theofanopoulou, Ferran Altarriba Bertran, Aaron J. Horowitz, Nick Mead, Joel B.

Schwartz, and Petr Slovak. 2022. Design (not) lost in translation: a case study of an intimate-space socially assistive "robot" for emotion regulation. *ACM Trans. Comput.-Hum. Interact.* 29, 4 (March 2022), 32:1–32:36. doi:10.1145/3491083

[47] Katherine Isbister, Mike Karlesky, Jonathan Frye, and Rahul Rao. 2012. Scoop! a movement-based math game designed to reduce math anxiety. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems (CHI EA '12)*. Association for Computing Machinery, New York, NY, USA, 1075–1078. doi:10.1145/2212776.2212389

[48] Katarzyna Kabacińska, Tony J. Prescott, and Julie M. Robillard. 2021. Socially assistive robots as mental health interventions for children: a scoping review. *International Journal Of Social Robotics* 13, 5 (Aug. 2021), 919–935. doi:10.1007/s12369-020-00679-0

[49] V. G. Kaburlasos, Ch. Dardani, M. Dimitrova, and A. Amanatiadis. 2018. Multi-robot engagement in special education: a preliminary study in autism. In *2018 IEEE International Conference on Consumer Electronics (ICCE)*. 1–2. doi:10.1109/ICCE.2018.8326267

[50] Hiroki Kaimoto, Kyzyl Monteiro, Mehrad Faridan, Jiatong Li, Samin Farajian, Yasuaki Kakehi, Ken Nakagaki, and Ryo Suzuki. 2022. Sketched reality: sketching Bi-directional interactions between virtual and physical worlds with AR and actuated tangible UI. In *Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology (UIST '22)*. Association for Computing Machinery, New York, NY, USA, 1–12. doi:10.1145/3526113.3545626

[51] Lawrence H. Kim, Veronika Domova, Yuqi Yao, Chien Ming Huang, Sean Follmer, and Pablo E. Paredes. 2022. Robotic presence: the effects of anthropomorphism and robot state on task performance and emotion. *IEEE Robotics and Automation Letters* 7, 3 (July 2022), 7399–7406. doi:10.1109/LRA.2022.3181726

[52] Lawrence H Kim, Veronika Domova, Yuqi Yao, and Parsa Rajabi. 2023. SwarmFidget: exploring programmable actuated fidgeting with swarm robots. In *Proceedings of the 36th Annual ACM Symposium on User Interface Software and Technology (UIST '23)*. Association for Computing Machinery, New York, NY, USA, 1–15. doi:10.1145/3586183.3606746

[53] Lawrence H. Kim and Sean Follmer. 2017. UbiSwarm: ubiquitous robotic interfaces and investigation of abstract motion as a display. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 3 (Sept. 2017), 66:1–66:20. doi:10.1145/3130931

[54] Lawrence H. Kim and Sean Follmer. 2019. SwarmHaptics: haptic display with swarm robots. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. doi:10.1145/3290605.3300918

[55] Andreas Kolling, Phillip Walker, Nilanjan Chakraborty, Katia Sycara, and Michael Lewis. 2016. Human interaction with robot swarms: a survey. *IEEE Transactions on Human-Machine Systems* 46, 1 (Feb. 2016), 9–26. doi:10.1109/THMS.2015.2480801

[56] Sander L. Koole. 2009. The psychology of emotion regulation: an integrative review. *Cognition and Emotion* 23, 1 (Jan. 2009), 4–41. doi:10.1080/02699930802619031

[57] Theresa Law, Meia Chita-Tegmark, Nicholas Rabb, and Matthias Scheutz. 2022. Examining attachment to robots: benefits, challenges, and alternatives. *ACM Transactions on Human-Robot Interaction* 11, 4 (Dec. 2022), 1–18. doi:10.1145/3526105

[58] Mathieu Le Goc, Lawrence H. Kim, Ali Parsaei, Jean-Daniel Fekete, Pierre Dragicevic, and Sean Follmer. 2016. Zooids: building blocks for swarm user interfaces. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16)*. Association for Computing Machinery, New York, NY, USA, 97–109. doi:10.1145/2984511.2984547

[59] Mathieu Le Goc, Charles Perin, Sean Follmer, Jean-Daniel Fekete, and Pierre Dragicevic. 2019. Dynamic composite data physicalization using wheeled micro-robots. *IEEE Transactions on Visualization and Computer Graphics* 25, 1 (Jan. 2019), 737–747. doi:10.1109/TVCG.2018.2865159

[60] Min Kyung Lee, Jodi Forlizzi, Sara Kiesler, Paul Rybski, John Antanitis, and Sarun Savetsila. 2012. Personalization in HRI: a longitudinal field experiment. In *Proceedings of the seventh annual ACM/IEEE international conference on Human-Robot Interaction (HRI '12)*. Association for Computing Machinery, New York, NY, USA, 319–326. doi:10.1145/2157689.2157804

[61] Merel M. L. Leijse, Levi van Dam, Thimo M. van der Pol, René Breuk, and Arne Popma. 2025. The effects of a smartphone app (feelee) to enhance adolescents' emotion regulation skills in a forensic outpatient setting: protocol for a multiple single-case experimental design. *JMIR Research Protocols* 14, 1 (July 2025), e64756. doi:10.2196/64756

[62] Jingjin Li, Nayeon Kwon, Huong Pham, Ryun Shim, and Gilly Leshed. 2023. Co-designing magic machines for everyday mindfulness with practitioners. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference*. ACM, Pittsburgh PA USA, 1630–1647. doi:10.1145/3563657.3595976

[63] Jiatong Li, Ryo Suzuki, and Ken Nakagaki. 2023. Physica: Interactive Tangible Physics Simulation based on Tabletop Mobile Robots Towards Explorable Physics Education. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference (DIS '23)*. Association for Computing Machinery, New York, NY, USA, 1485–1499. doi:10.1145/3563657.3596037

[64] Rong-Hao Liang, Bin Yu, Mengru Xue, Jun Hu, and Loe M. G. Feijs. 2018. BioFidget: biofeedback for respiration training using an augmented fidget spinner. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, Montreal QC Canada, 1–12. doi:10.1145/3173574.3174187

[65] JunSeo Lim. 2023. Effects of a cognitive-based intervention program using social robot PIO on cognitive function, depression, loneliness, and quality of life of older adults living alone. *Frontiers in Public Health* 11 (Feb. 2023). doi:10.3389/fpubh.2023.1097485

[66] Youn-Kyung Lim, Erik Stolterman, and Josh Tenenberg. 2008. The anatomy of prototypes: prototypes as filters, prototypes as manifestations of design ideas. *ACM Trans. Comput.-hum. Interact.* 15, 2 (July 2008), 7:1–7:27. doi:10.1145/1375761.1375762

[67] Ting-Han Lin, Willa Yunqi Yang, and Ken Nakagaki. 2023. ThrowIO: actuated TUIs that facilitate "throwing and catching" spatial interaction with overhanging mobile wheeled robots. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. ACM, Hamburg Germany, 1–17. doi:10.1145/3544548.3581267

[68] Jiadi Luo, Veronika Domova, and Lawrence H. Kim. 2024. Impact of multi-robot presence and anthropomorphism on human cognition and emotion. *Conference on Human Factors in Computing Systems - Proceedings* (May 2024), 15. doi:10.1145/3613904.3642795/SUPPL_FILE/3613904.3642795-TALK-VIDEO.VTT

[69] Chris Lytridis, Cristina I. Papadopoulou, George A. Papakostas, Vassilis G. Kaburlasos, Vasiliki Aliki Nikopoulou, Maria Dialechti Kerasidou, and Nikolaos Dalivigkas. 2020. Robot-assisted autism spectrum disorder (ASD) interventions: a multi-robot approach. In *2020 International Conference on Software, Telecommunications and Computer Networks (SoftCOM)*. 1–4. doi:10.23919/SoftCOM50211.2020.9238273

[70] Susan Maury, Dianne Vella-Brodrick, Jane Davidson, and Nikki Rickard. 2022. Socio-emotional benefits associated with choir participation for older adults related to both activity characteristics and motivation factors. *Music & Science* 5 (Jan. 2022), 20592043221137759. doi:10.1177/20592043221137759

[71] Kateri McRae and James J. Gross. 2020. Emotion regulation. *Emotion* 20, 1 (Feb. 2020), 1–9. doi:10.1037/emo0000703

[72] James W. Moore. 2016. What is the sense of agency and why does it matter? *Frontiers in Psychology* 7 (Aug. 2016). doi:10.3389/fpsyg.2016.01272

[73] David B. Newman and John B. Nezlek. 2022. The influence of daily events on emotion regulation and well-being in daily life. *Personality and Social Psychology Bulletin* 48, 1 (Jan. 2022), 19–33. doi:10.1177/0146167220980882

[74] Karen Niven. 2017. The four key characteristics of interpersonal emotion regulation. *Current Opinion in Psychology* 17 (Oct. 2017), 89–93. doi:10.1016/j.copsyc.2017.06.015

[75] Heather Ohly, Mathew P. White, Benedict W. Wheeler, Alison Bethel, Obioha C. Ukoumunne, Vasilis Nikolaou, and Ruth Garside. 2016. Attention restoration theory: a systematic review of the attention restoration potential of exposure to natural environments. *Journal of Toxicology and Environmental Health, Part B* 19, 7 (Oct. 2016), 305–343. doi:10.1080/10937404.2016.1196155

[76] Eri Otaka, Aiko Osawa, Kenji Kato, Yota Obayashi, Shintaro Uehara, Masaki Kamiya, Katsuhiro Mizuno, Shusei Hashide, and Izumi Kondo. 2024. Positive emotional responses to socially assistive robots in people with dementia: pilot study. *JMIR Aging* 7, 1 (April 2024), e52443. doi:10.2196/52443

[77] Maria Panagiotidi, Simon Wilson, and Tony Prescott. 2019. Exploring the potential of the animal-like robot MiRo as a therapeutic tool for children diagnosed with autism. In *Biomimetic and Biohybrid Systems*, Uriel Martinez-Hernandez, Vasiliki Vouloutsi, Anna Mura, Michael Mangan, Minoru Asada, Tony J. Prescott, and Paul F.M.J. Verschure (Eds.). Springer International Publishing, Cham, 351–354. doi:10.1007/978-3-030-24741-6_36

[78] Jonathan Posner, James A. Russell, and Bradley S. Peterson. 2005. The circumplex model of affect: an integrative approach to affective neuroscience, cognitive development, and psychopathology. *Development and psychopathology* 17, 3 (2005), 715–734. doi:10.1017/S0954579405050340

[79] Sara Price, Nadia Bianchi-Berthouze, Carey Jewitt, Nikoleta Yiannoutsou, Katerina Fotopoulou, Svetlana Dajic, Juspreet Virdee, Yixin Zhao, Douglas Atkinson, and Frederik Brudy. 2022. The making of meaning through dyadic haptic affective touch. *ACM Transactions on Computer-Human Interaction* 29, 3 (June 2022), 1–42. doi:10.1145/3490494

[80] Lihui Pu, Wendy Moyle, Cindy Jones, and Michael Todorovic. 2019. The effectiveness of social robots for older adults: a systematic review and meta-analysis of randomized controlled studies. *Gerontologist* 59, 1 (Jan. 2019), e37–e51. doi:10.1093/geront/gny046

[81] Samira Pulatova and Lawrence H Kim. 2024. Co-designing programmable fidgeting experience with swarm robots for adults with ADHD. In *Proceedings of the 26th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '24)*. Association for Computing Machinery, New York, NY, USA, 1–14. doi:10.1145/3663548.3675614

[82] Samira Pulatova, Jiadi Luo, Janghyeon Lee, Veronika Domova, Yuqi Yao, Parsa Rajabi, and Lawrence H Kim. 2023. SwarmFidget: exploring programmable actuated fidgeting with swarm robots. In *Adjunct Proceedings of the 36th Annual ACM Symposium on User Interface Software and Technology (UIST '23 Adjunct)*.

Association for Computing Machinery, New York, NY, USA, 1–4. doi:10.1145/3586182.3615806

[83] Sarah M. Rabbitt, Alan E. Kazdin, and Joanna H. Hong. 2015. Acceptability of robot-assisted therapy for disruptive behavior problems in children. *Archives of Scientific Psychology* 3, 1 (2015), 101–110. doi:10.1037/arc0000017

[84] James A. Russell. 1980. A circumplex model of affect. *Journal of Personality and Social Psychology* 39, 6 (1980), 1161–1178. doi:10.1037/h0077714

[85] Anastasia Ruvimova, Junhyeok Kim, Thomas Fritz, Mark Hancock, and David C. Shepherd. 2020. "transport me away": fostering flow in open offices through virtual reality. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–14. doi:10.1145/3313831.3376724

[86] Ofir Sadka and Alissa Antle. 2022. Interactive Technologies for Emotion Regulation Training: A Scoping Review. *International Journal of Human-Computer Studies* 168 (Dec. 2022), 102906. doi:10.1016/j.ijhcs.2022.102906

[87] Frensen Salim. 2025. Transforming emotional health: smartwatches as catalysts for emotional regulation and self-awareness. In *Proceedings of the Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (CHI EA '25)*. Association for Computing Machinery, New York, NY, USA, 1–7. doi:10.1145/3706599.3720279

[88] Pedro Sanches, Axel Janson, Pavel Karpashevich, Camille Nadal, Chengcheng Qu, Claudia Daudén Roquet, Muhammad Umair, Charles Windlin, Gavin Doherty, Kristina Höök, and Corina Sas. 2019. HCI and Affective Health: Taking stock of a decade of studies and charting future research directions. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–17. doi:10.1145/3290605.3300475

[89] María Santos and Magnus Egerstedt. 2020. From motions to emotions: can the fundamental emotions be expressed in a robot swarm? 13 (June 2020), 751–764. doi:10.48550/arXiv.1903.12118

[90] Douglas Schuler and Aki Namioka (Eds.). 2017. *Participatory design: principles and practices.* CRC Press, Boca Raton. doi:10.1201/9780203744338

[91] Donald A. Schön. 1983. *The reflective practitioner: how professionals think in action.* Basic Books, New York.

[92] Arielle Aj Scoglio, Erin D. Reilly, Jay A. Gorman, and Charles E. Drebing. 2019. Use of Social Robots in Mental Health and Well-Being Research: Systematic Review. *Journal of Medical Internet Research* 21, 7 (July 2019), e13322. doi:10.2196/13322

[93] Nathan Semertzidis, Michaela Vranic-Peters, Josh Andres, Brahmi Dwivedi, Yutika Chandrashekhar Kulwe, Fabio Zambetta, and Florian Floyd Mueller. 2020. Neo-Noumena: Augmenting Emotion Communication. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. doi:10.1145/3313831.3376599

[94] Hashini Senaratne, Kirsten Ellis, Sharon Oviatt, and Glenn Melvin. 2019. Designing efficacious mobile technologies for anxiety self-regulation. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems (CHI EA '19)*. Association for Computing Machinery, New York, NY, USA, 1–6. doi:10.1145/3290607.3312766

[95] Judith Silkenbeumer, Eva-Maria Schiller, Manfred Holodynski, and Joscha Kärtner. 2016. The role of Co-regulation for the development of social-emotional competence. *Journal of Self-Regulation and Regulation* 2 (Dec. 2016), 17–32. doi:10.11588/josar.2016.2.34351

[96] Petr Slovak, Alissa Antle, Nikki Theofanopoulou, Claudia Daudén Roquet, James Gross, and Katherine Isbister. 2023. Designing for Emotion Regulation Interventions: An Agenda for HCI Theory and Research. *ACM Trans. Comput.-Hum. Interact.* 30, 1 (March 2023), 13:1–13:51. doi:10.1145/3569898

[97] Wally Smith, Greg Wadley, Sarah Webber, Benjamin Tag, Vassilis Kostakos, Peter Koval, and James J. Gross. 2022. Digital emotion regulation in everyday life. In *CHI Conference on Human Factors in Computing Systems (CHI '22)*. ACM, New Orleans LA USA, 1–15. doi:10.1145/3491102.3517573

[98] Pinyao Song, Aparna Hebbani, and Dhaval Vyas. 2025. Exploring Place-Belongingness through Magic Machine Workshops in Refugee Communities. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems (CHI '25)*. Association for Computing Machinery, New York, NY, USA, 1–15. doi:10.1145/3706598.3714246

[99] Sony. 2025. Toio. https://toio.io

[100] David St-Onge, Florent Levillain, Elisabetta Zibetti, and Giovanni Beltrame. 2019. Collective expression: how robotic swarms convey information with group motion. *Paladyn: Journal of Behavioral Robotics* 10 (Jan. 2019), 418 – 435. doi:10.1515/pjbr-2019-0033

[101] Osamu Sugiyama, Kazuhiko Shinozawa, Takaaki Akimoto, and Norihiro Hagita. 2010. Case study of a multi-robot healthcare system: effects of docking and metaphor on persuasion. In *Social Robotics*, Shuzhi Sam Ge, Haizhou Li, John-John Cabibihan, and Yeow Kee Tan (Eds.). Springer, Berlin, Heidelberg, 90–99. doi:10.1007/978-3-642-17248-9_10

[102] Ryo Suzuki, Hooman Hedayati, Clement Zheng, James L. Bohn, Daniel Szafir, Ellen Yi-Luen Do, Mark D. Gross, and Daniel Leithinger. 2020. RoomShift: Room-scale Dynamic Haptics for VR with Furniture-moving Swarm Robots. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. ACM, Honolulu HI USA, 1–11. doi:10.1145/3313831.3376523

[103] Ryo Suzuki, Eyal Ofek, Mike Sinclair, Daniel Leithinger, and Mar Gonzalez-Franco. 2021. HapticBots: Distributed Encountered-type Haptics for VR with Multiple Shape-changing Mobile Robots. In *The 34th Annual ACM Symposium on User Interface Software and Technology*. ACM, Virtual Event USA, 1269–1281. doi:10.1145/3472749.3474821

[104] Ryo Suzuki, Clement Zheng, Yasuaki Kakehi, Tom Yeh, Ellen Yi-Luen Do, Mark D. Gross, and Daniel Leithinger. 2019. ShapeBots: shape-changing swarm robots. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology (UIST '19)*. Association for Computing Machinery, New York, NY, USA, 493–505. doi:10.1145/3332165.3347911

[105] Lorena Sánchez Chamorro, Romain Toebosch, and Carine Lallemand. 2024. Manipulative Design and Older Adults: Co-Creating Magic Machines to Understand Experiences of Online Manipulation. In *Proceedings of the 2024 ACM Designing Interactive Systems Conference (DIS '24)*. Association for Computing Machinery, New York, NY, USA, 668–684. doi:10.1145/3643834.3661513

[106] Amalie Søgaard Neilsen and Rhonda L. Wilson. 2019. Combining e-mental health intervention development with human computer interaction (HCI) design to enhance technology-facilitated recovery for people with depression and/or anxiety conditions: An integrative literature review. *International Journal of Mental Health Nursing* 28, 1 (2019), 22–39. doi:10.1111/inm.12527

[107] Maya Tamir. 2009. What do people want to feel and why?: pleasure and utility in emotion regulation. *Current Directions in Psychological Science* 18, 2 (April 2009), 101–105. doi:10.1111/j.1467-8721.2009.01617.x

[108] Anouk van Maris, Nancy Zook, Praminda Caleb-Solly, Matthew Studley, Alan Winfield, and Sanja Dogramadzi. 2020. Designing ethical social robots—a longitudinal field study with older adults. *Frontiers in Robotics and AI* 7 (Jan. 2020), 1. doi:10.3389/frobt.2020.00001

[109] Daniela Villani, Claudia Carissoli, Stefano Triberti, Antonella Marchetti, Gabriella Gilli, and Giuseppe Riva. 2018. Videogames for Emotion Regulation: A Systematic Review. *Games for Health Journal* 7, 2 (April 2018), 85–99. doi:10.1089/g4h.2017.0108

[110] Preeti Vyas, Unma Mayur Desai, Karin Yamakawa, and Karon Maclean. 2023. A Descriptive Analysis of a Formative Decade of Research in Affective Haptic System Design. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)*. ACM, Hamburg Germany, 1–23. doi:10.1145/3544548.3580735

[111] Kieran Woodward and Eiman Kanjo. 2021. iFidgetCube: tangible fidgeting interfaces (TFIs) to monitor and improve mental wellbeing. *IEEE Sensors Journal* 21, 13 (July 2021), 14300–14307. doi:10.1109/JSEN.2020.3031163

[112] Ruo-Yan Wu, Xin-Heng Li, Yi-Chen Li, Zhi-Hong Ren, Bing-Xiang Yang, Zhen-Tao Liu, Bao-Liang Zhong, and Chen-Ling Liu. 2025. The effect of social robot interventions on anxiety in children in clinical settings: a systematic review and meta-analysis. *Journal of Affective Disorders* 382 (Aug. 2025), 304–315. doi:10.1016/j.jad.2025.04.102

[113] Jiawen Yao. 2024. Info-motion: using the metaphor of plant motion for information communication in shape-changing interface: info-motion. In *Proceedings of the Eighteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '24)*. Association for Computing Machinery, New York, NY, USA, 1–13. doi:10.1145/3623509.3633397

[114] Jamil Zaki and W. Craig Williams. 2013. Interpersonal emotion regulation. *Emotion (washington, D.C.)* 13, 5 (Oct. 2013), 803–810. doi:10.1037/a0033839

[115] Yiwei Zhao, Lawrence H. Kim, Ye Wang, Mathieu Le Goc, and Sean Follmer. 2017. Robotic Assembly of Haptic Proxy Objects for Tangible Interaction and Virtual Reality. In *Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces*. ACM, Brighton United Kingdom, 82–91. doi:10.1145/3132272.3134143

[116] Nianmei Zhou, Steven Devleminck, and Luc Geurts. 2024. Tangible Affect: A Literature Review of Tangible Interactive Systems Addressing Human Core Affect, Emotions and Moods. In *Proceedings of the 2024 ACM Designing Interactive Systems Conference (DIS '24)*. Association for Computing Machinery, New York, NY, USA, 424–440. doi:10.1145/3643834.3661608

[117] Nianmei Zhou, Steven Devleminck, and Lucca Geurts. 2025. Squeeze away the worries: exploring the potential of squeezable interactions for emotion regulation for desk workers. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems*. ACM, Yokohama Japan, 1–20. doi:10.1145/3706598.3713483

[118] Ayberk Özgür, Séverin Lemaignan, Wafa Johal, Maria Beltran, Manon Briod, Léa Pereyre, Francesco Mondada, and Pierre Dillenbourg. 2017. Cellulo: versatile handheld robots for education. In *Proceedings of the 2017 ACM/IEEE International Conference on Human-Robot Interaction (HRI '17)*. Association for Computing Machinery, New York, NY, USA, 119–127. doi:10.1145/2909824.3020247

A Swarm interactions demonstrated during workshops

Table 4 summarizes the example swarm interactions demonstrated during Stage 3 (Swarm Exploration) of the workshops. The interactions were adapted from prior work on swarm-based fidgeting experiences [81].

B Question checklist

Table 5 presents the full question checklist used exclusively by the facilitators during the third workshop phase. It synthesizes elements from ER delivery mechanisms [37], tangible interaction themes [42], and prototype filtering dimensions [66] to guide participants' ideation and design decisions.

C Self-regulation repertoire from the workshops

Participants reported a wide range of self-regulation strategies in their daily lives, most of which aligned with the taxonomy proposed by McRae et al. [71]. They are classified based on the five families of ER strategies in Table 6. Note that there is no situation selection strategy in the baseline due to the prompt used in the workshop. From the baseline self-regulation repertoire, participants' ER goals mostly focused on getting calm or happy instead of anxiety, depression, anger, and boredom.

Table 4: Descriptions and images of swarm robot interactions demonstrated in Stage 3 of workshops, which were based on prior work on swarm robot fidgeting experience (adapted from [81], with permission).

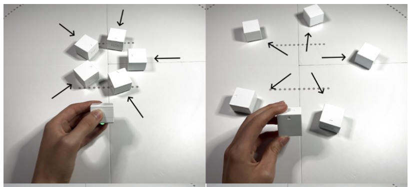
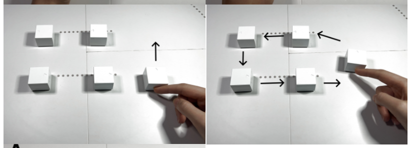
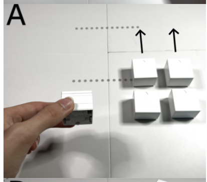
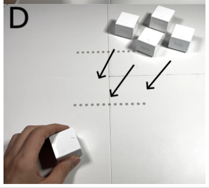
Interaction	Description	Images
Expanding and Contracting Circle	Decrease and increase the radius of a swarm-based circle alternately.	
Conveyor Interaction	If the first robot is displaced from its programmed position, it will go to the end of the line, and the rest of the robots will shift one position forward.	
Remote Interaction (A)	Robots moving forward controlled by the "remote" robot.	
Remote Interaction (D)	Robots moving towards the 'remote' robot.	

Table 5: The facilitator-only question checklist used during the workshop to understand participants' magic machines.

Category	Guiding Questions	Notes/Dimensions
What	Name and Description	–
How	How will they support you?	Didactic vs. Experiential
When	When will they support you?	Offline vs. On-the-spot
Where	Where will you use or place the cubes? How much space will you assign to the cubes?	–
Interaction Type	How might you interact with them? (with hands)	Tangible Manipulation
	Will you use any part of your body besides your hands? Will you move your whole body to interact with the cubes?	Spatial Interaction
	Will your group support multi-users? Does it offer affordances that open up new avenues for explorations?	Embodied Facilitation
	How might they move or behave on their own? Will you use these cubes to express or reflect emotional state?	Expressive Representation
Single Robot Abilities	What are the abilities of your cubes? Can your cubes move, recognize, or think?	–
Swarm Behaviors	Will these cubes cope with certain emotions? If so, why?	–
	What are your inspirations? Did you get inspiration from something that already exists?	–
	How are these patterns triggered?	–
	How many cubes will you use? Why?	–
Decoration	What are your inspirations? Did you get inspiration from something that already exists?	–
	Is any functionality emerging from, or in contrast to, its physical form?	–
	Why did you choose that material?	–

Table 6: Participants’ self-regulation repertoire classified based on strategies in Gross’s ER Process Model [37]).

ER Strategy	Strategies Reported by Participants
Situation Modification	Practice a presentation to feel more confident
Attentional Deployment	Focus on tasks or objects instead of emotions Listen to music Bite their hands to distract themselves Fidget (set goals to achieve while fidgeting) Read books Play games
Cognitive Change	Convince themselves to feel differently Encourage themselves and build self-trust Recall a past success Increase emotional self-awareness
Response Modulation	Call their partner and share their feelings Call their mothers Write about emotions and memories in a diary Play sports until physically exhausted Take deep breaths or control their breathing Drink a glass of water Wash their face Throw or break objects Lie on the floor Go to sleep Cry