

# **Design of a Multimodal System for Social Emotional Learning in Early Childhood Classrooms**

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*For my cabin friends and family.*



## **Abstract**

As the prevalence of mobile and touch-based devices continues to expand in society, so too does its impact on young children. With educational technologies also on the rise, young children benefit most from those technologies that are designed to be developmentally appropriate, and the development of social and emotional skills, which are key for learning and academic success, are crucial in the early childhood years. Addressing these skills prior to students transitioning to kindergarten is critical, as the extensive support systems available in preschool are often unavailable in kindergarten.

In this thesis, the design of MindfulNest, a robotic multimodal system, is presented, which aims to guide students through (1) identifying their emotions, and (2) applying emotion regulation strategies. While prior work relies on using biofeedback technologies and wearing special equipment, MindfulNest prioritizes independent use of the system for young children (ages 3-5) and provides feedback in non-invasive ways. Reviewing developmentally appropriate technology design for young children, a set of design goals is presented as well as the technical description of the implemented MindfulNest system. The goals and findings from pilots in six early childhood classrooms are also presented.



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# Chapter 1

## Introduction

Benefits of self-regulation at an early age are far-reaching and widely documented. Children who can appropriately regulate emotions have been found to display greater social competence, better social skills, and greater peer popularity [21, 22, 23, 24, 26, 28, 29]. Similarly, emotion regulation skills can affect the quality of student-teacher relationships, which supports the child throughout challenging educational environments and has increasingly been recognized as an important contributor to children’s early school adaptation [8, 29, 43, 44]. Conversely, inefficient emotion regulation physiologically inhibits a child’s use of higher order cognitive processes in the classroom [29]. Denham also states that young children without developmentally appropriate emotional and social competencies participate less in the classroom and are less accepted by classmates and teachers, who in turn provide them with less instruction and positive feedback [19].

According to Denham, teachers associate a child’s readiness to learn and teachability with positive emotional expressiveness and an ability to regulate emotions and behaviors, and they cite emotional-behavioral issues among their top needs for training and technical assistance [12, 19]. Slovák has also highlighted that human-computer interaction (HCI) technology has the potential to address these issues by utilizing the extensive history of peer-reviewed social emotional learning (SEL) programs that have already been deployed to tens of millions of students [53]. The work presented in this thesis centers around the design and implementation of the MindfulNest system and is influenced by the cited potential for addressing SEL needs in the prekindergarten classroom through robotics and HCI technologies.

This thesis aims to address the following question: can we design a robotic multimodal system for prekindergarten classrooms that guides students through (1) identifying their emotions, and (2) applying emotion regulation strategies?

### 1.1 Outline of Work

Chapter two describes the motivations behind the project’s focus on SEL for early childhood and how a set of focus group workshops with teachers had informed the design goals for the MindfulNest system. Chapter three provides a review of related work and background literature, including SEL, tangible user interfaces (TUIs), and technology design for young children.

Based on these related works and background research, a set of design goals for an abstract multimodal system is first presented (Chapter 4), followed by a detailed description of the MindfulNest system and the developed software application (Chapter 5).

The remaining chapters describe three phases of experiments and pilots that took place between Spring 2019 and Spring 2021 as well as a discussion of the results and conclusions drawn from this work.



# Chapter 2

## Motivation

The early childhood years have been identified as a crucial period for the development of social and emotional skills as well as important executive functions (e.g. attention, inhibition, working memory), which are key for learning and academic success [19, 29]. In a representative U.S. survey, only 44% of U.S. teachers (from elementary, middle, and high school) indicated that their schools use a school-wide social emotional learning (SEL) program [10, 54]. However, Graziano et al. highlight the importance of addressing social and emotional skills prior to students transitioning to kindergarten, as the extensive support systems that are available in preschool are often unavailable in kindergarten [29]. Furthermore, kindergarten presents novel demands of learning new academic and interpersonal skills, and these goals must be accomplished under decreased supervision due to increased class size and increased emphasis on autonomy [11].

After interviewing SEL researchers and developers in educational psychology, Slovák et al. identified key challenges where technology could be of use, such as (1) extending the scaffolding for learners beyond SEL lessons in the classroom and (2) facilitating a wider community of support for learning skills by involving teachers as well as parents and caregivers (many SEL efforts fail because long-term, coordinated plans and school-home partnerships are not developed) [52, 53]. The key focus of most social and emotional skills is to learn how to appropriately react, even in situations of high emotion and stress. Therefore, learning must first happen on a procedural basis (i.e. as a sequence of actions that one performs in pursuit of a particular objective [33]), followed by a transfer out of the classroom into everyday contexts. However, when skills are to be transferred beyond classroom lessons, learners can no longer take advantage of the direct scaffolding provided by teachers and lesson structures. Instead, learners must reinforce and apply skills on their own. This includes identifying “teachable moments” when the newly-learned social and emotional skills could be applicable, as well as giving themselves space to reflect on and learn from the experience afterwards. This reflection might be difficult for situations outside of SEL lessons, in which the teachable moment is wrapped up in activities that prevent immediate reflection.

## 2.1 Prior Work in Education and Early Childhood

Since 2006, the CREATE Lab at Carnegie Mellon University has worked on implementing education technologies in preK-12 classrooms. Its earliest educational robotics program, Arts & Bots, was developed in response to a drop in enrollment by women in engineering and computing degree programs [16]. The Arts & Bots program engaged students in engineering and programming tasks through collaborative projects which were integrated in classes with adaptable curriculum to empower students to create robotic diagrams aligned with class content. One of the goals of the program was to give students opportunities to form positive attitudes early on in their education about their ability to create technology. Ten years later, evaluation of the results from Arts & Bots led to the development of a new robotics kit for in-school use with elementary-age students. Focusing on sensors and input/output systems, Flutter Links (Figure 2.1) was created to support systems thinking in students, where relationships (“links”) could be assigned between inputs (sensors) and outputs (LEDs, servos, buzzers) [31]. The software, which ran on mobile devices, communicated over Bluetooth with a microcontroller to assign the links between inputs and outputs on the microcontroller. The Flutter Links system was then used to pilot a digital manipulative for elementary mathematics classes [15], which led to the development of two novel tangible user interface (TUI) devices. One of the key lessons learned from these math pilots was the apparent trade-off between flexibility and concreteness in TUIs [63]. This also informed decisions on the tangible interfaces that were implemented for the MindfulNest system and how they evolved across pilots, which are described later in this thesis.

Message from Me is another education technology developed by the CREATE Lab in 2009, which focuses on students’ social development by facilitating conversations between them and the adults in their lives. Through the use of pictures and recorded audio messages, Message from Me assists students in communicating their daily activities and learning experiences as they sometimes struggle to communicate what they did “at school” to others [2]. Developed prior to the prevalence of mobile devices, the first piloted prototype of the system was an embedded system designed as a transparent kiosk, including a set of light-up buttons, a microphone, a digital camera, and an LCD screen (Figure 2.2). The system has since transformed to run as a mobile application on either iOS or Android tablet devices (Figure 2.3).

Originally, our prior work around sensors and input/output systems was the driving factor for exploring new work in preK classrooms. However, when trying to design an approach with younger students, we found that teachers would rather have technology that focused on helping students’ social and emotional development [57]. This became the motivation for our designed system, which still leveraged our prior experience with Bluetooth and mobile technologies.

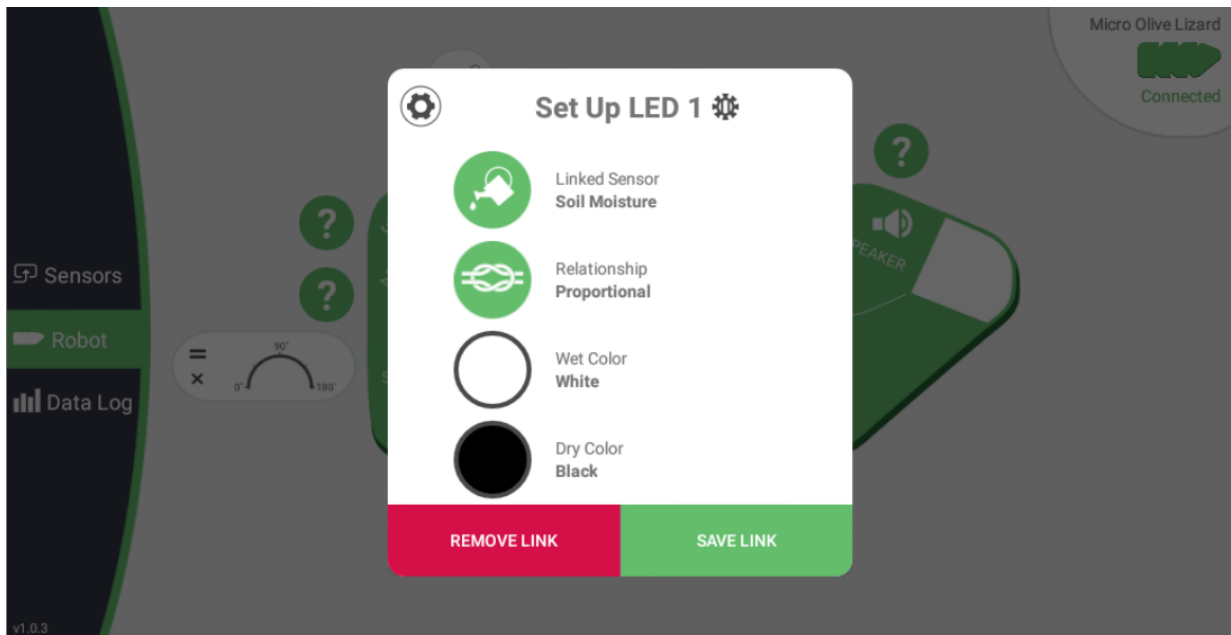


Figure 2.1: Screenshot from the Flutter Links mobile application. Tapping any of the four elements allows the user to configure settings for that attribute of the relationship. In this link, the color of an LED is proportional to the sensor reading from the soil moisture sensor.



Figure 2.2: Students sending a message using the Message from Me Kiosk. This picture was taken at the first pilot at the Carnegie Mellon University's Children's School in 2009.



Figure 2.3: The Message from Me iPad application being used in the classroom.



# Chapter 3

## Background & Related Work

Emotional self-regulation in children facilitates positive interactions with their teachers and peers and is a key aspect relating to children’s school readiness and achievement [60]. Razza et al. [46] have shown that mindfulness-based programs that include simple breathing and yoga poses can be effective in enhancing self-regulation among preschool children. Although these interventions were guided by an instructor, interactive systems may also provide feedback for children to learn strategies to self-regulate and calm their emotions.

This chapter focuses on the relevant literature for the design of a multimodal system, as stated in the first chapter. Background on social emotional learning (SEL) and technology interventions with children are presented, followed by a discussion of design practices and frameworks that include young children and educators. The research and work cited in this chapter is used to inform the design goals of the MindfulNest system, which are discussed in the next chapter.

### 3.1 Social Emotional Learning

There are varying levels of support that children in the classroom will need for any given learning standard, and SEL is no exception. Social and emotional development begins in children as young as 2 years old [20]. Although there exist many prekindergarten programs with SEL as part of their curriculum [10, 41, 54], high-quality implementation can be challenging because of a lack of financial resources, time for implementing into curriculum, and pre-service training for educators [9].

There exist several frameworks for addressing SEL in education settings. A commonly-used framework is defined by the Collaborative for Academic, Social, and Emotional Learning (CASEL) and identifies five core competencies for social and emotional learning: self-awareness, self-management, social awareness, relationship skills, and responsible decision making [41]. In another approach developed at the Yale Center for Emotional Intelligence, RULER outlines five skills for students: *recognizing* emotions in their thoughts and body, *understanding* the causes and consequences of their emotions, *labeling* emotions, *expressing* emotions with different people across contexts, and *regulating* emotions with helpful strategies [9]. When implementing SEL programs or approaches in the early childhood classroom, a review by the U.S. Department of Education Institute of Education Sciences identifies three critical classroom factors that

are associated with SEL in students: classroom climate, instructional strategies, and social and emotional competence of the educators [41].

For the Phase 3 pilots of the project, students were assessed using a scale for measuring social and emotional development. The Preschool Behavioral and Emotional Rating Scale (PreBERS) is a standardized, norm-referenced instrument that assesses the emotional and behavioral strengths of preschool children [25]. Composed of 42 items rated on a four point scale, the PreBERS assesses four areas of a preschooler’s social emotional strengths: emotional regulation, school readiness, social confidence, and family involvement. Whereas other psychometrically sound instruments exist for assessment of young children, the PreBERS focuses on the assessment of strengths and competencies as recommended by The Working Group on Developmental Assessment [25]. This is preferred over other instruments since assessment practices that primarily determine deficits may limit the range and types of information collected and may also unduly emphasize negative aspects of a child’s behavior or functioning at the expense of the positive [25].

## **3.2 SEL Using Technology and Biofeedback**

Sadka and Antle reviewed literature between 2009 and 2019 and identified several opportunities and challenges in technologies designed to address emotion regulation [48]. Emotion regulation training technologies have the opportunity to offer constructive in-the-moment support during everyday stressful situations, sensing behavioral signs associated with emotion regulation in non-invasive ways and providing feedback. They also enable high levels of customization between individuals, although implementations of this were scarce in the reviewed literature. One of the challenges mentioned was the ability for technologies to accurately infer emotional affect or state from sensor data alone. Most technologies also struggled to balance the need to create an engaging experience while also providing moments of reflection for individuals. Providing opportunities for reflection are important because they enable users to understand abstract concepts that are related to their social emotional learning [32].

Similarly, SEL design challenges have been discussed by Slovák et al [54]. One of these challenges is in embedding the learning and reinforcement processes into everyday life. This can be accomplished by identifying teachable moments within everyday interactions, scaffolding reinforcement and learning in these situations, promoting reflective skills, and supporting the transfer of skills through practicing in different contexts.

Prior work has shown that active calming techniques (i.e. facilitated by interaction with users or guiding them through a sequence of actions) are more effective than passive ones. One example of this is ChillFish, a breath-controlled biofeedback game designed to calm children while having their blood drawn [55, 56]. The game runs on an Android tablet and is controlled by a breath sensor embedded in a tangible controller, shaped like a fish. While some biofeedback applications require users to wear special equipment, ChillFish was specifically designed to avoid this, as this might be difficult for children, especially in stressful situations. This aligns with research by Slovák and Fitzpatrick, who state that the key focus of most social and emotional skills is to be able to react appropriately even when learners are overwhelmed with emotions [53].



### **3.3 Tangible User Interfaces**

Although children as young as 2 years old can interact with digital media through touch-based devices [7], these technologies are commonly designed for adult users and are not always suitable for young children. Grounded in theories of embodied cognition, embodied child-computer interaction is built on the theory that young children learn primarily through their physical, sensory, and perceptual interactions with the world and that abstract thought can be enabled through movement [4, 5]. Whereas a graphical user interface (GUI) exists only in the digital world, tangible user interfaces (TUIs) can give physical form to digital information.

By offering the physicality of interaction through graspable or embodied mechanisms, TUIs have been used to support spatial learning in children and have been shown in multiple developmental studies to directly relate to school readiness [7]. One example of TUIs for children are digital math manipulatives, which have been used to support mathematical learning in young children [47, 63]. There is evidence to suggest that TUIs can also be used to facilitate social and emotional learning in children, such as through storytelling [7, 59] and self-regulation [39, 40].

Although work has suggested that abstract thought might be grounded in and built on top of sensory-motor systems [5], there is little empirical work to support the claim that TUIs enhance learning in general, and there is a lack of theoretical framework that outlines how different features of TUIs might affect learning outcomes [37, 47].

### **3.4 Technology Design and Young Children**

The National Association for the Education of Young Children (NAEYC) and the Fred Rogers Center state that technology and interactive media are tools that can promote effective learning and development when they are used intentionally [45]. When technology and media use is properly integrated and becomes seamlessly routine, then the focus of the child or educator is on the activity or on the exploration itself and not on the technology or media being used [35, 45, 50].

Screen time, the amount of time that children spend engaged with screens, is a common concern among caregivers and researchers as it has the potential to impact children both positively and negatively. There is evidence that effective uses of media can close the gap between households of differing socioeconomic status and children who struggle with basic content and skills [35]. Digital technologies have also been found to contribute to young children’s operational skills, knowledge, and increased understanding of the world [50]. This is especially true as the ubiquity of technology grows and technical literacy becomes an important skill for future generations.

However, when used excessively, screen-viewing has also been associated with obesity, academic issues, behavioral issues, irregular sleep patterns, and prevalent feelings of sadness and boredom [61]. Children’s use of and exposure to screen time can also lead to depression, fear, nightmares, increases in aggressive and violent behavior, and decreases in executive functioning [50]. Furthermore, in a review of research on screen-viewing among preschool-aged children attending childcare, Vanderloo highlights that the majority of studies that estimate children’s screen time fails to include viewing that occurs in childcare settings [61]. Although it is one of the most common sedentary activities which preschoolers participate in and is often a proxy measure for

sedentary activity, preschoolers appear to engage in somewhat high levels of screen-viewing while in childcare, particularly within home-based facilities, and increased screen-viewing in childcare has been associated with decreased staff education levels [61].

One of the reasons for this discrepancy on the impacts of screen time is that it fails to distinguish between beneficial and harmful uses of media and technology. The effectiveness of any education medium depends on the quality of its content and how it supplements instruction [14, 35, 45]. For example, Guernsey describes the three C's framework, which reflects on the Content (How does it support engagement or exploration?), the Context (How seamlessly does it integrate into natural play?), and the individual Child (How can we consider the individual needs, abilities, and interests of the child?) [30]. Not all screens are created equal, and as the scope of digital technology has expanded over time, each unique screen demands its own criteria for best usage.

In general, screen time can be classified as either *active* or *passive*. Active screen time involves cognitively or physically engaging in screen-based activities [58]. Similarly, *interactive media* refers to digital and analog materials designed to facilitate active and creative use by young children and to encourage social engagement with other children and adults [45]. This aligns with the NAEYC statement that effective uses of technology and media are active, hands-on, engaging, and empowering [45]. Non-interactive media such as television programs, videos, and streaming media, unless used in ways that promote active engagement and interactions, can lead to passive viewing and over-exposure to screen time for young children; they cannot effectively substitute for interactive and engaging uses of digital media or for interactions with adults and other children [45].

Furthermore, the combined use of media with active engagement along with face-to-face instruction has the potential for learning benefits greater than the sum of its parts. A pair of studies found that media-based classroom instruction combined with professional development for teachers led to substantial progress in early reading skills for children and closed the achievement gap between children with low-income backgrounds and their middle-income peers on standard measures of literacy development [35]. In another analysis from a set of Australian studies of Internet searching within early childhood settings, it was demonstrated how adults and children could make use of verbal, non-verbal, and embodied actions to produce shared understandings of YouTube videos watched in the classroom, as a thoroughly interactive classroom event [18].

Early studies on technology use in classrooms have also identified barriers to the effective use of technology, such as teacher attitudes, quality professional development, access to technology, and cost [27]. Since studies have shown that ongoing teacher training fosters positive attitudes of technology and meaningful technology use by teachers in the classroom [13], the successful deployment of educational technologies should provide access to technology as well as ample professional development, ideally at no cost to educators. Lyons and Tredwell also outline a five-step process to support using technology in early childhood classrooms: (1) assess technology knowledge of young children, (2) develop technology rules with young children, (3) apply professional judgment and program policy, (4) implement technology into curriculum, and (5) collect data for decision making [36].

Technology design for young children benefits from knowledge of evidence-based practices and learning standards that should be supported. For example, the preschool learning standard 16.1 PK.A states that students should be able to “distinguish between emotions and identify

socially accepted ways to express them” [1]. In a systematic review of SEL research by the U.S. Department of Education Institute of Education Sciences, three common characteristics were found in effective SEL programs: (1) use of a combination of techniques that are skills focused and environment focused, (2) use of a program that is sequenced, active, focused, and explicit (four core “SAFE” practices), and (3) provision of training and technical assistance for teachers [42].

### **3.5 Participatory Design**

When designing a new technology, it is important to get input from everyone that will be impacted by the technology. One helpful method for including end users as designers of technology is participatory design. Also known as co-design, participatory design is a process that attempts to actively involve all stakeholders in the design process, such that designers strive to learn the real needs of users, and users strive to articulate their desired aims and learn the appropriate technological means to obtain them [51].

Activities that support the making of things are at the core of the participatory design process. For the work that this thesis focuses on, there were two distinct approaches that were implemented: generative tools and participatory prototyping [51, 57]. The first participatory design session focused on brainstorming, where generative tools provided ambiguity to non-designers in order to encourage expression of unspoken and latent needs, aspirations, and dreams. The next two sessions were paper prototyping and digital prototyping. Using mock-ups and other low fidelity models, participatory prototyping presupposes that you have already identified the object of the design. This form of iterative prototyping can be viewed as growing early conceptual designs into mature products and testing whether the designs should be further pursued or need to be modified [49].

For our participatory design focus groups, we intentionally decided to recruit teachers and exclude children as co-designers. Although there have been recent calls in research for the inclusion of children in the design process as stakeholders of technologies [7, 38], other researchers have pointed to a lack of participatory design methods customized for children younger than 4 years of age, since they are less able to read, write, verbalize their thoughts, and concentrate on tasks easily [7]. Also, teachers are the ideal end user, due to the educational intent of the tool as well as their experience with a variety of student backgrounds.



# Chapter 4

## Design Goals

Following three focus group sessions that incorporated a participatory design process [57], a tangible interaction system for guiding students through emotion regulation strategies was proposed by the researchers and teachers. Referred to as MindfulNest, the system's name was derived from aspects of the proposed system which incorporate mindfulness techniques (such as controlled breathing and awareness of the body) and the “nested” space in the classroom that could be dedicated for using the system. Based on the research presented in earlier chapters, we hypothesize that a tangible interaction system could be an effective and developmentally appropriate tool for students in the classroom to engage in identifying their emotions and applying emotion regulation strategies.

The following goals were synthesized to guide the design of the MindfulNest system. These design goals also serve as helpful guidelines in the design of robotic multimodal systems for SEL in preK classrooms in general.

1. **Prioritize interactive screen time over non-interactive screen time.** The National Association for the Education of Young Children (NAEYC) defines interactive screen time as when children are engaged in an activity using screens which facilitates active and creative use by young children and encourages social engagement with other children and adults [45]. As prior research has suggested, prioritizing interactive screen time will maximize the benefits while minimizing the risks of students engaging in excessive, passive screen time [35, 45, 58].
2. **Prioritize focus on the child while shifting focus away from the screen.** Technology and interactive media can enhance early childhood practice when the use of technology becomes routine and transparent, i.e. when the focus is on the activity or exploration itself and not on the technology or media that is being used [35, 45, 50].
3. **Leverage multiple modes of interaction.** Examples of these modes of interaction include the use of a tablet-based touch screen, audio prompts, video, and tangible user interfaces (TUIs), which offer a natural and immediate form of interaction that is accessible to learners [5]. This is supported by the theory that children in their early years learn primarily through their physical, sensory, and perceptual interactions with the world [4, 5].
4. **Provide flexibility for limitations across preK classrooms.** Limitations often exist in preK classrooms when implementing technologies. Some examples of this are access to

power outlets, access to Internet, and other competing wireless traffic (Bluetooth) in the classroom or building. There are also limitations to consider with respect to the technical literacy of teachers and caregivers. In other words, the system should be intuitive enough for teachers to easily troubleshoot any issues (such as Bluetooth connection issues or devices that need charged).

5. **Maximize unmediated use across preK classrooms.** It is important that the system can be used independently by the students. This involves making the system as simple and intuitive as possible for the range of student ages that will interact with the system (from 3 to 5 years old) as well as making it accessible even when learners are overwhelmed with emotions [53]. Another important method for skill acquisition in the classroom is through teacher modeling. Therefore, the system should be designed so that the teacher may model its use to students (individually) and the rest of the classroom (as a large group).
6. **Provide support for educators through professional development.** Ideally, teachers should also be provided with adequate training for introducing the system into their classroom. As mentioned previously, a common barrier for the implementation of technologies and SEL programs in classrooms is a lack of training for educators [9, 13, 27, 42]. Prior work in early childhood classrooms has also demonstrated the benefits of providing training to educators through professional development when implementing new technologies in their classrooms [2].

# Chapter 5

## MindfulNest Technical Design

The MindfulNest system consists of a set of tangible user interfaces (TUIs), a software application running on a tablet, and a stand (Figure 5.1). Its implementation in preK classrooms for a variety of target age groups (3 to 5 years old) imposed several constraints and influenced the design choices, which are described in the next section.

### 5.1 Interaction Design

All components of the MindfulNest system are designed to fit within the stand (see Figure 5.1). This constitutes a “station” for the MindfulNest system and facilitates ease of setup in the preK classroom for the teachers. All devices (TUIs and tablet) can be easily charged within the station by USB chargers in the stand. The charging feature is provided by plugging into a wall outlet. Though a portable charger implementation is theoretically feasible in the system, devices are usually charged overnight and do not need to be charging while actively implemented in the classroom. Containing all MindfulNest parts within the stand also assists in distinguishing multiple sets from one another. In this way, it is simple for a teacher to switch out one station with another if necessary or to provide multiple stations in the classroom simultaneously.



(a) Phase 1 Pilots (2019)



(b) Phase 2 Pilots (2019-2020)



(c) Phase 3 Pilots (2021)

Figure 5.1: Iterations of the MindfulNest station across three phases of piloting.

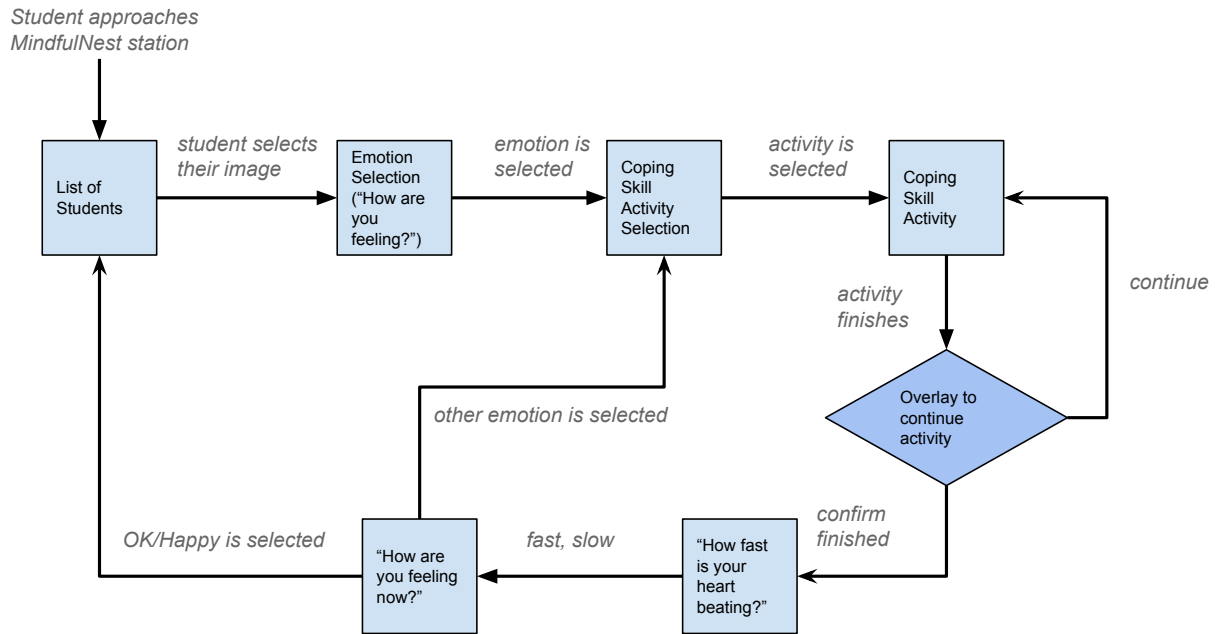


Figure 5.2: Intended app flow for a student session.

The tablet application was designed for a student to identify any emotion that they might be feeling at the moment and to choose an activity to engage in, followed by a brief reflection after completing the activity. This intended interaction is referred to as a “session” and is outlined in the app flow diagram (Figure 5.2). The interaction was designed for students to begin a session by selecting their picture from a list of students in the classroom, and the picture displays in the top-right corner of the screen for the remainder of the session. This first step is important for two main reasons. One reason is that it helps the student identify when another session is still active (for example, if Student A walks away from the station before completing the session and Student B approaches the station to begin a new session, the picture of Student A will still display in the top-right of the screen). This is intended to encourage the student to go back and select their own picture before continuing their interaction. Another reason is that this also allows the system to associate the session with a particular student, and the details of the session can be reviewed by a teacher at a later time.

After selecting themselves from the list, the student is presented with the prompt “How are you feeling?” and a list of cartoon expressions that represent emotions (Figure 5.5). After selecting an emotion, the application responds with a positive affirmation (such as “it’s nice to feel happy” or “it’s ok to feel sad sometimes”) and presents a list of activities for the student to engage in. When the chosen activity finishes, the application then asks the student to reflect back on how they are feeling, first by asking them how fast their heart is beating and then by having them reevaluate their emotional state.

Activities on the tablet application were designed to incorporate emotion regulation strategies so they could be practiced by the students (Table 5.1). There have been efforts in the past to measure the effects of various coping models. For example, Ayers et al. developed a four-factor



<b>Emotion Regulation Skill</b>	<b>Reason for Inclusion</b>	<b>MindfulNest Activities</b>
Deep breathing	Deep breathing can be used as a calming technique in many situations, however young children often struggle with this skill without guidance.	Flower Breathing
Distracting actions through controlled gross motor movement [6]	Guiding attention to one singular point of focus, slow and intentional movements support students as they try to distract themselves from the source of stress.	Wand, Stretching
Channeling Frustration [6]	As a physical release of emotions, this skill gives students a socially acceptable channel with which they can cope [22].	Squeeze, Cuddle
Channeling Extra Energy [6]	Another skill used as a physical release of emotions, this gives students a socially acceptable outlet to channel their extra energy.	Dance, Jumping Jacks
Distracting Actions Through Physical Comfort [6]	Students can make themselves feel better through distracting themselves from their emotions with physical comfort, such as hugging a soft toy.	Cuddle, Cuddle a Toy
Emotional Support [22][6]	The student talks about how they are feeling with a peer or an adult in order to work through their emotions.	Invite a Friend, Talk With Your Teacher

Table 5.1: Emotion regulation skills and the MindfulNest activities designed to support practice with each skill.

model of children’s coping strategies (active, distraction, avoidance, and support-seeking) [6]. Relative to this model, MindfulNest focuses on distraction and support-seeking strategies but may also indirectly serve as an avoidance strategy when use of the system implies leaving the stressful situation. Active strategies are not explored as they are much more context specific (for example, directing cognitive effort to find meaning in a stressful situation or to think about a situation in a more positive way).

## 5.2 System Architecture

Three TUIs were created for the MindfulNest station: the flower, the wand, and the squeezer. The flower has a ring of tri-color LEDs along with a sound sensor and a button. The wand has an inertial measurement unit (IMU), a tri-color LED on one end that is diffused by a white covering, and a button at the center. The squeezer itself acts as a giant button which detects whether or not it is being pressed. All of the TUIs also have an on-off switch for powering the device and a single LED which indicates the power and Bluetooth status (green indicates powered on, blue indicates an active Bluetooth connection is established). In Phase 1 pilots, a wrist band tangible

was included in the prototype but was later removed because we found that it did not impact student engagement with its related coping skill activities.

Amazon Fire tablets were used for the MindfulNest stations. Although iPads are more common in preK classrooms, several factors made the Amazon Fire tablets preferable to use in our testing. The primary factor was the cost of iPad devices, which are significantly more expensive than Amazon Fire tablets. Since we were providing equipment for the pilots rather than relying on what the classrooms might have, it made sense to utilize cheaper devices. Furthermore, our prior work also focused on development using Amazon Fire tablets, and we had several devices that could be utilized for the MindfulNest pilots. This also provided the affordance of having multiple devices that could be swapped out between development and deployments in the field. This prior work also provided opportunities to re-use earlier code with MindfulNest, including frameworks developed for Bluetooth communication and software design patterns for Android applications. There is also a significant barrier to entry for developers when engaging in iPad development, since it requires access to a MacOS system and an Apple developer license. Our team wanted to provide opportunities for inexperienced developers to collaborate on the project with us, and the tools for Android development are much more accessible, regardless of the developer's preferred operating system. In general, there are also better debug tools available for Android that are in open (rather than proprietary) formats which provided developers with more verbose event logging and data backups. Despite all of this, it is worth noting that the choice between Android and iOS platforms has no impact on the theoretical functionality of the system; any technical implementation that can be achieved within one platform would also be possible with the other, with respect to the technical requirements of the MindfulNest system.

### **5.3 Software Application**

The MindfulNest tablet app was developed as a software application for Android using the Android SDK (Standard Development Kit) and written in the Java programming language. The application can be split into two sections: the student section and the teacher section. The student section is the portion of the app that is intended for student interaction and includes the “session” app flow (Figure 5.2). The primary reasons behind having a teacher section in the app are for managing classrooms and students as well as reviewing usage statistics for each student. From previous experience with Message from Me, we wanted to provide a way for teachers to manage settings directly from the tablet app itself, as opposed to accessing this from an on-line account. Usage statistics were also a feature that teachers expressed interest in during the participatory design focus groups [57].

For the student section of the app, several modifications had to be implemented to improve the students' independent use of the system. One of these modifications came from observing students interacting with the tablet screen, where “click” events were triggered from the application screen even when the student did not intentionally click on an interface asset. It was common for students to click rapidly and repetitively on the screen, and sometimes this would trigger a click event before the screen finished transitioning from one page to another. To mitigate this, a delay was implemented to avoid registering click events for the first 1000 milliseconds of the page being displayed.

<b>Activity Name</b>	<b>Interaction Type</b>	<b>Activity Description</b>
Flower Breathing	Tangible	The app first prompts the student to press the button on the flower tangible. It then guides the student through controlled breathing with the prompts “smell the flower” (breathe in) and “blow on the flower” (breathe out) three times. As the student blows on the flower, a ring of LEDs illuminates at the center of the flower.
Wand	Tangible	The app guides the student to slowly move the wand tangible to make music play. The LED on the wand tangible will turn red when it moves too quickly and green when it moves slower. Students can then change the LED color by pressing the button on the wand tangible.
Squeeze	Tangible	As the student squeezes the squeezer tangible, a hot air balloon animates on the tablet screen, floating higher in the air.
Cuddle	Tangible	This activity was created as a replacement of the Squeeze activity, with the squeezer tangible placed inside of a sheep plush toy. The app displays a sheep and prompts the student to “hug the sheep to make the hearts appear”.
Stretching	Dynamic	The app plays a video guiding the student through a stretch. There are four different stretching activities presented: Rock and Twist, Wave and Hug, Swing and Bend, and Spread and Curl.
Jumping Jacks	Dynamic	The app plays a video guiding the student through doing jumping jacks.
Dance	Static	The student is asked to make up a dance to show how they feel, as music plays from the tablet.
Cuddle Toy	Static	The app suggests the student finds a toy to cuddle until they feel better.
Invite Friend	Static	The student is encouraged to invite a friend to play with them.
Talk With Your Teacher	Static	The student is encouraged to talk to their teacher about how they feel.

Table 5.2: List of coping skill activities in the MindfulNest system. An activity’s interaction type is determined by whether the activity uses one of the TUIs (“Tangible”) or if it incorporates guidance through animation or video (“Dynamic”). Otherwise, the interaction is considered “Static”.

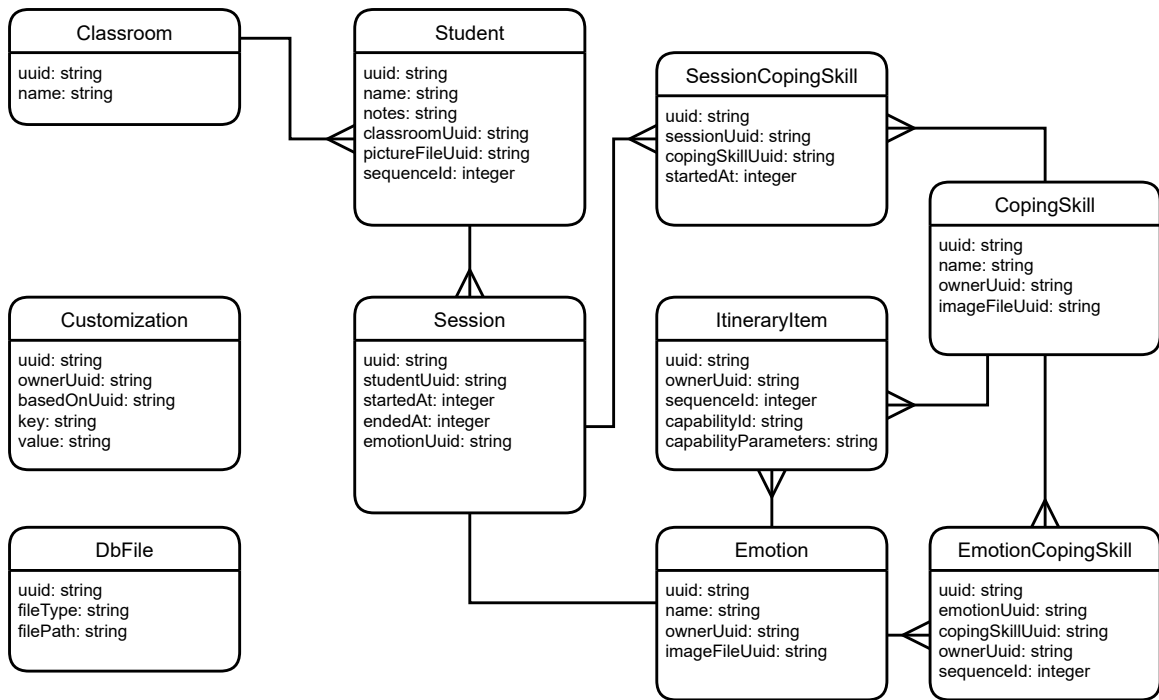


Figure 5.3: Entity-relationship model for the MindfulNest application database.

Another set of modifications were implemented to provide consistency for the intended student flow. Ideally, when a student approaches the MindfulNest station, the tablet should be displaying the page containing the list of students. There are typically two scenarios when this would not happen. One scenario is if another student left the station before they finished their session. To detect this, a timer was implemented for every page in a session. After 3 minutes of inactivity, an overlay is displayed on the screen (Figure 5.6). If no option is selected after 15 seconds, the application ends the session and returns to the list of students. The other scenario is when the application enters into the background of the tablet system. Similarly, when the application detects this event, the application ends the session and returns to the list of students.

### 5.3.1 Application Database

The application database was implemented using the Room persistence library, which provides an abstraction layer over SQLite. See Figure 5.3 for the entity-relationship diagram of the database tables within the application database. The database centers around the Session table, which is associated with a student, an emotion, and several coping skills. The EmotionCopingSkill table handles the mapping between a row in the Emotion table and the available entries in the CopingSkill table.

For a student session, the app flow that is presented in Figure 5.2 is actually determined by the entries in the `ItineraryItem` table, which serve as step-by-step instructions on what to do next in the session. For example, when a session begins, the student is presented with options from the `Emotion` table to choose from. After an emotion is selected, the application then reads values from the `ItineraryItem` table. For the default application build, this leads to the display of coping skills for the student to choose from, and the application similarly reads values from the `ItineraryItem` table based on which value was selected from the `EmotionCopingSkill` table, which maps to a row in the `CopingSkill` table.

### **5.3.2 Customizations and Modularity**

In order to support a variety of classrooms, it was important to avoid “hard-coding” content whenever possible during the development of the application. For example, the application supports displaying a different list of emotions and different coping skill activities, depending on the classroom or the student that is currently selected. This level of customization is achieved by populating the application database on initial installation with rows of “default” values. These rows can then be later modified, or entirely new rows can be created to display teacher-defined emotions and coping skills.

### **5.3.3 Troubleshooting and Version Control**

As multiple stations were implemented in a single classroom and iterative development of the software application occurred throughout the pilots, specific protocols and software features were implemented to identify the versions of software used in the field as well as to diagnose and troubleshoot system issues. Issues with BLE communication between the TUIs and the tablet were common during testing. To help identify this, an icon would appear in the top-right of the screen, if the coping skill activity used a TUI that had a disconnected BLE status (Figure 5.7).

Identifying matching sets of equipment were also a problem when multiple stations were used, since the software applications in the field were configured to connect to specific hardware components (e.g. the tablet from MindfulNest Station A would only connect to the TUI flower from MindfulNest Station A and would not connect to the TUI flower from MindfulNest Station B). This led to the practice of drawing one of 4 unique symbols (moon, heart, smiley, or tree) on all equipment within a matching set. A corresponding symbol would also be displayed in the lower-left corner of the application’s home screen, along with an application version identifier. This version identifier typically mapped to a specific git commit hash or branch in the project’s source code, which proved useful when resolving software and system issues.



Figure 5.4: Screenshots of all implemented coping skill activities.

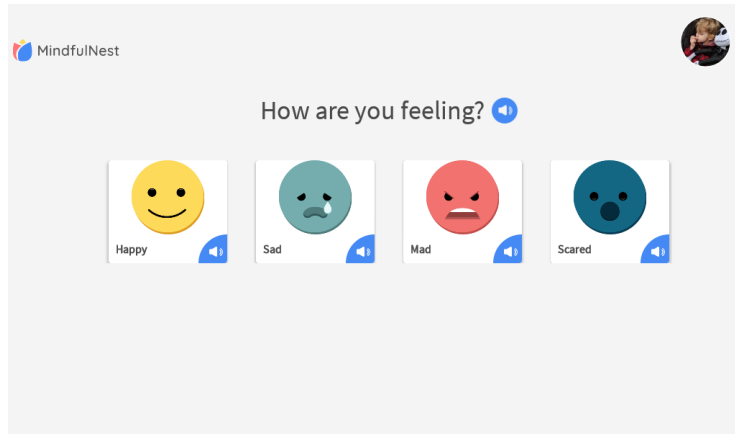


Figure 5.5: The first screen in a student session prompts the student to ask themselves how they are feeling.

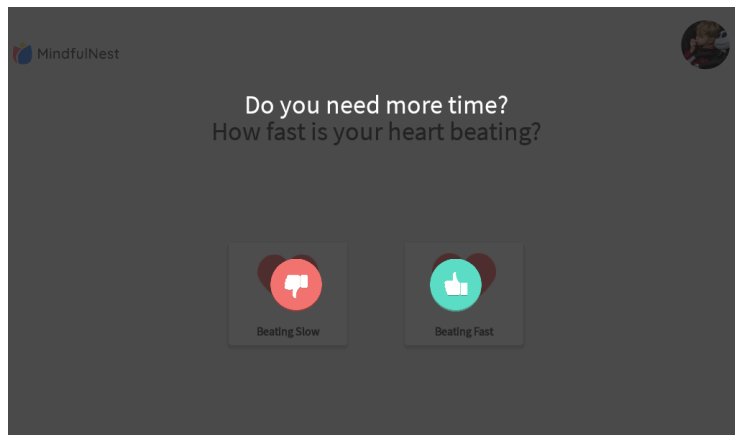


Figure 5.6: An overlay displays on the screen during a student session after remaining inactive for several minutes.

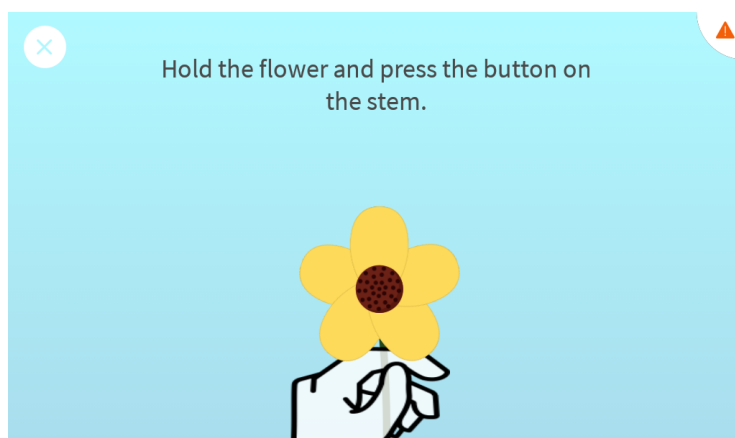


Figure 5.7: Coping skill activities that use one of the TUIs will display a Bluetooth connection indicator in the top-right corner of the screen when a Bluetooth connection is not established.





# Chapter 6

## Experiments & Pilots

The MindfulNest system was tested in 6 different classrooms between January 2019 and May 2021. Based on the research methods used in each classroom and the major changes implemented over this time span, these tests can be separated into three distinct phases: Phase 1 in Spring of 2019, Phase 2 in the 2019-2020 school year, and Phase 3 in Spring of 2021.

For the development of our professional development and educational materials for teachers, we worked closely with Trying Together, an organization in Southwestern Pennsylvania that supports high-quality care and education for young children and our continued partners on the Message from Me project (Section 2.1).

### 6.1 Phase 1 Pilots (Spring 2019)

Following the participatory design of the MindfulNest system, Phase 1 was conducted to perform evaluative research on the early system prototype [49]. Along with evaluating the effectiveness of the system, these short tests provided a way to include children in the design process by observing their interactions with the prototype and their direct conversations with researchers. As part of an iterative process, software changes were made to address any observed issues and to deploy new coping skill activities as they became available.

#### 6.1.1 Methods

Two eight-week long pilots were conducted in two different classrooms. Each pilot occurred sequentially, the first starting in January and the second in March. The first classroom had 9 students (2 boys, 7 girls), one teacher, and one aide. The second classroom had 11 students (4 boys, 7 girls), one teacher, and one aide. Teachers and aides were provided with two MindfulNest sets and participated in three hours of professional development before each pilot began.

At least two researchers observed the classroom for two and a half hours each week. Notes were taken as semi-structured field notes. Interviews with the teachers were conducted one week after each pilot ended.



Figure 6.1: A student using MindfulNest to calm down during Phase 1 pilots.



Figure 6.2: A student uses an activity with the squizzer before feedback from the squizzer tangible was implemented.



Figure 6.3: Teachers modeling the use of the MindfulNest system was most effective for students learning how to use the system. On the left, one of the Phase 1 teachers introduces the MindfulNest system to their classroom in the first week. On the right, another Phase 1 teacher guides a student through navigating the app.

## 6.1.2 Findings

When designing the app flow with teachers, our initial thought was that students would benefit from having specific emotions associated with some of the activities. However, when the prototype app displayed different activities depending on the selected emotion, we found that students would navigate the app to select their preferred activities, regardless of their emotional state. This finding is contrary to previous work around tangibles that shows children’s preference based on their emotional state [17].

The Phase 1 pilots also provided insights on which tangibles to implement in future activities. At this point in testing, the only tangible that communicated its sensor information with the MindfulNest app was the flower. There were activities on the app that prompted the use of the squeezer and wristband tangibles, but we found that students were motivated to do these activities even without feedback from the tangibles (Figure 6.2). However, we did note that students expected the squeezer to be interactive, similar to the flower. Therefore, development on the squeezer tangible continued whereas the wristband was removed from future testing.

Students were able to use MindfulNest independently, even during states of distress or when students were overwhelmed with emotions (Figure 6.1). There were even observed instances of multiple students using MindfulNest together, especially with the more physical activities, such as stretching and jumping jacks. The teachers mentioned that video prompts and teacher modeling were two important factors in guiding students’ successful use of MindfulNest (Figure 6.3).

With respect to classroom integration, both teachers expressed that they were comfortable introducing the technology to their classrooms, citing the intuitiveness of the system and their general familiarity with using technology. At least one of the teachers felt that MindfulNest would have been more effective if it were brought in to the classroom at the beginning of the school year. One of the teachers also commented positively on the iterative improvements that were made to the app and how they addressed issues observed throughout the pilots.

## 6.2 Phase 2 Pilots (2019-2020)



Figure 6.4: The list of all coping skill activities available in the Phase 2 pilots.

For the next phase of testing, our primary goal was to determine how the system could be used across age groups that are common in the prekindergarten classroom (3 to 5 years old) and what changes might improve unmediated use across age groups. At this point, all coping skill activities were implemented and presented in the MindfulNest app (Figure 6.4). With all of the coping skill activities available from the beginning, this round of testing was also used to determine how frequently the activities were being used in the classroom.

### 6.2.1 Methods

A year-long test was run in two different preschool classrooms at the same center, simultaneously. The testing ran from the beginning of the school year in October to the end of the school year in March (22 weeks)<sup>1</sup>. Each classroom had one teacher and one aide and were provided with two MindfulNest sets as well as three hours of professional development. Along with the professional development, teacher materials were provided for six classroom lessons as well as materials to share with parents and caregivers. Across both classrooms, there was a total of 29 students (15 boys, 14 girls) with ages ranging from 3 to 5.

At least one researcher observed each classroom for two and a half hours each week. Observations times were coordinated with the teacher to correspond with times that students were

<sup>1</sup>The school year for the Phase 2 pilots was cut short due to the COVID-19 Pandemic.





Figure 6.5: Two students from the Phase 2 pilots use the Squeeze activity from separate MindfulNest sets to “race” each other through the floating balloon animation.

more likely to use MindfulNest. Notes were taken as semi-structured field notes. Interviews with the teachers were conducted one month after the year-long test was concluded. Additionally, data related to system use was logged by the app, including how long the app was used by each student and the emotions and coping skill activities that were selected.

## 6.2.2 Findings

In order to improve use of MindfulNest across age groups, several changes were made to the app based on observations during the year-long test. A video prompt was added for the post-coping skill activity that prompts students to check how fast their heart is beating. Also supported by the findings from Phase 1 pilots, we found that the visual cues improved student response across all ages. In addition, the Phase 1 observation that students would choose emotions based on the activity they desired was also observed in the Phase 2 pilots, and so in week 13 we made all the activities available for all emotions.

In earlier weeks, some students were observed clicking on the screen randomly without apparent intention, especially the youngest students (age 3). To help encourage more intentional clicking, the click delay (see section 5.3) was implemented in week 16. The student thumbnails in the top-right corner of the screen were also increased in size to help students recognize when they were using the app under a different student’s image.

Another interaction that some students struggled to identify and use properly was scrolling through lists. Several of the app pages contained more items than could be displayed on the screen at once, including the home page with the list of students and the list of coping skill activities to choose from. Younger students had trouble recognizing when they should scroll, whereas this issue was not observed in the older students. To help the younger students better navigate the options relevant for them, some of the options in the lists were moved to the beginning (e.g.

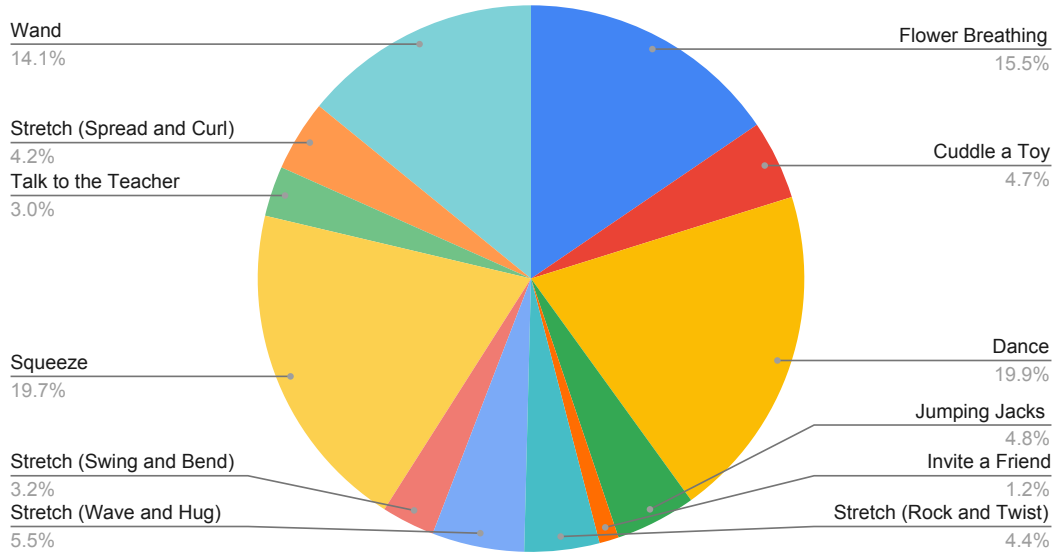


Figure 6.6: Frequency of coping skill activities used during the Phase 2 pilots.

ordering the youngest students to appear first on the home page, and placing the most popular activities at the top of the list).

Tangible use in the system was observed with mixed success. Although the youngest students would frequently blow on the flower rapidly to watch it light up and did not follow the pace of the prompt, most students demonstrated an understanding of the flower as a tool and connected the prompts “smell the flower” and “blow on the flower” to their breathing. A transition of the skill away from MindfulNest itself was also observed in multiple instances across age groups, making it one of the most effective activities using tangibles for the transitioning of skills outside of use of MindfulNest. For the wand and squeeze tangibles, younger students struggled to understand the more complex interactions that they presented. The added complexity of having more than one MindfulNest set in the classroom also led to observations of parts of one set being mismatched with parts from another. This inspired the practice of drawing symbols corresponding to equipment within a matching set (section 5.3.3), though only older students were observed troubleshooting by swapping tangibles if they were incorrectly paired to a set.

Observations of the squeezer tangible and its associated activity also prompted several changes. The first change was made to the squeezer hardware itself. The air pressure sensing in the prototype squeezer was unreliable, and students found it frustrating to use. A new version of the squeezer was deployed in week 6, which relied on springs to detect when the tangible was being compressed, acting as a giant button with a binary value (pressed or not pressed) as opposed to a range of sensed air pressure values. For the squeeze activity itself, all students occasionally used the squeezer as a toy and would try to get other students to race them through the activity (Figure 6.5). These observations would later lead to the development of a new activity (Cuddle, Figure 6.7) utilizing the squeezer tangible in the Phase 3 pilots.

Figure 6.6 shows the frequency of coping skill activities used by students across the 22 weeks of testing. Along with our observations in the classrooms and teacher interviews, we found

that the most popular activities were the physical activities, such as Dance, Jumping Jacks, and Stretching (42.0% total), and those that involved one of the system tangibles (Flower Breathing, Wand, and Squeeze, 49.3% total). Coping skill activities where the system could not facilitate guidance to the students directly (e.g. Cuddle a Toy, Invite a Friend, Talk to the Teacher) appear to be the least popular choices.

### 6.3 Phase 3 Pilots (Spring 2021)



Figure 6.7: Screenshots and images of the available activities from the Phase 3 pilots. The second row shows MindfulNest with tangibles (Condition A). The third row shows the system without tangibles (Condition B).

In Phase 3, we wanted to understand the impact that the TUIs had on student engagement with the system as well as evaluate the impacts that the system might have on students’ social emotional development. Originally, we planned to run pilots in several classrooms from the beginning of the school year but struggled to find classrooms available to start in Fall 2020. We eventually recruited teachers from two centers in Spring 2021.

### **6.3.1 Methods**

Two 16-week long pilots were conducted in two different classrooms (Classroom A, Classroom B). Both pilots started in January and ended in May, although school closures during this time caused a one-week delay for Classroom A and a two-week delay for Classroom B. Classroom A had 18 students (7 boys, 11 girls), one teacher, and one aide. Classroom B had 11 students (3 boys, 8 girls), one teacher, and one aide. These counts exclude three students who did not participate for the entire duration of the study.

The Phase 3 pilots were structured as a counterbalanced study, where both classrooms were exposed to two conditions: a MindfulNest set with tangible user interfaces (Condition A) and a MindfulNest set without tangibles (Condition B). Classroom A started with Condition A for the first eight weeks of the pilot, followed by Condition B for the second eight weeks. Similarly, Classroom B was given Condition B, followed by Condition A. The classrooms were each provided with two MindfulNest sets, based on the condition assigned for the eight-week period. Teachers were given two and a half hours of professional development. For the second eight-week period, the sets were swapped between the classrooms, and teachers were provided with an additional five minutes of professional development. Along with the professional development, teacher materials were provided for six classroom lessons as well as materials to share with parents.

During weeks 4, 8, 12, and 16, one researcher would observe each classroom for six hours for each weekday, with the exception that Classroom B was only observed for four hours during weeks 12 and 16. Notes were taken primarily as structured field notes, using an observation form template (Figure 6.10). Video recordings were also taken while researchers observed the classrooms. Teacher interviews were conducted after weeks 8 and 16. Teachers also completed PreBERS assessments for their students immediately before week 1, on week 8, and immediately after week 16. Additionally, data related to system use was logged by the app, including how long the app was used by each student and the emotions and coping skill activities that were selected.

#### **Activities with tangibles and app-only alternatives**

In order to evaluate the impact of the activities with tangibles, alternative activities were created that substituted tangible interactions with app-based interactions and are demonstrated in Figure 6.7. For the Cuddle activity, the app detects swipe gestures over the sheep on the screen, and students are prompted to “pet the sheep to make the hearts appear.” For the Wand activity, students make the music play by clicking and dragging the silhouette of the hand with the wand. The Flower activity simply prompts the student through controlled breathing, where the app animates a flower on the screen to move with the “smell the flower” and “blow on the flower” prompts.

### **6.3.2 Findings**

Although the classrooms were each provided with two MindfulNest sets, both teachers opted to only set up only one of the sets in their classrooms and kept the other set as a backup. Each



teacher offered the MindfulNest set for their students to use as part of a check-in routine when arriving in the classroom during the mornings. They also offered it as an option available for students to use at any time during the day in the classroom. Both teachers found the professional development informational and appreciated the lesson materials that were provided.

Out of the 520 instances where researchers observed the use of MindfulNest in the classroom, there were 442 instances of students approaching the system without teacher suggestion and using it independently. Using data collected from observation forms (Figure 6.10), we calculated the length of time for each instance of MindfulNest use to determine if students spent a significantly greater amount of time engaging with Condition A (i.e. MindfulNest with TUIs) than they did with Condition B. The results (see Table 6.1) indicated that more time was spent under Condition A than Condition B. This also aligns with a comment made during one of the teacher interviews, where the Classroom A teacher stated that they noticed some of the students would rush through using the app during the second eight weeks of the pilot (under Condition B). Researchers also observed some students that would skip checking in with MindfulNest on some of the mornings.

Student Time Spent with MindfulNest (in minutes)		
	Tangibles (Condition A)	App Only (Condition B)
Mean	2.70	1.64
Variance	18.44	2.08
t-Test (one-tail)	$p = 0.000194962$	
t-Test (two-tail)	$p = 0.000389924$	

Table 6.1: Table of results comparing observations of time spent using MindfulNest between the two tested conditions. On average, students spent significantly more time (a minute longer on average) with the TUI MindfulNest system.

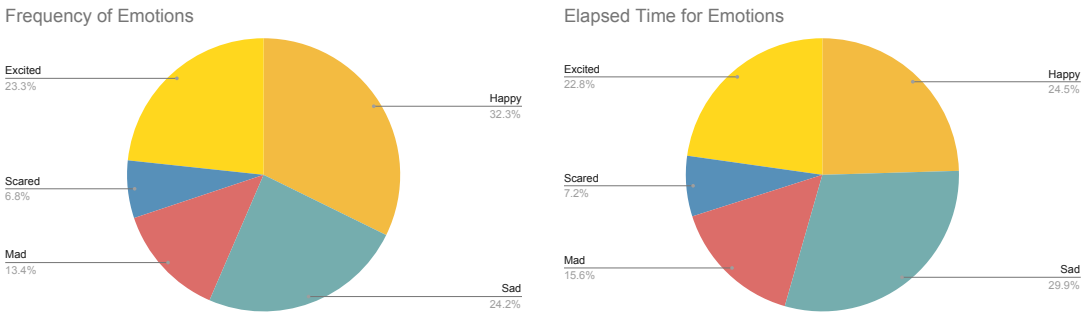


Figure 6.8: Graphs comparing the frequency of emotions selected and the actual time spent in the app for each selected emotion. Although happy was selected most often, students spent the most amount of time with the app when sad was selected.

Outside of classroom observations, tablet data was also analyzed to determine the frequency of emotions and activities chosen in the app (Figures 6.8 and 6.9). Out of the five emotion

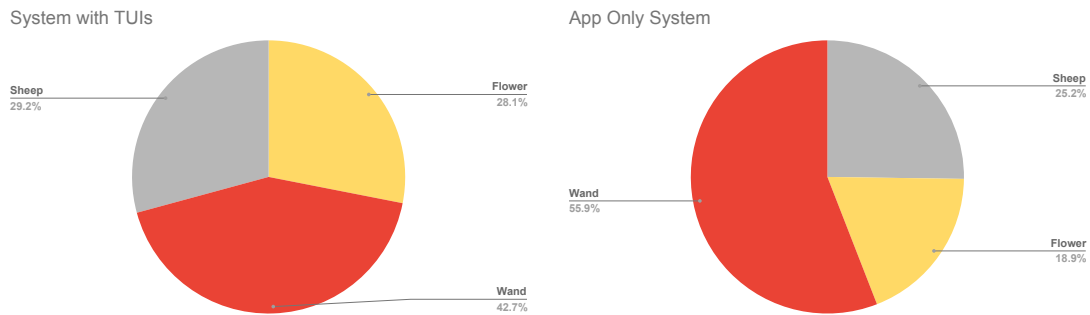


Figure 6.9: Graphs comparing the frequency of coping skills used during Phase 3 pilots.

choices (happy, sad, mad, scared, and excited), students chose “happy” most frequently but spent the most time engaged with the system when “sad” was selected. Furthermore, less time was spent in the app relative to the frequency with which “happy” and “excited” were selected. This seems to suggest that students would spend more time with the app when identifying a difficult or negative emotion, such as “sad”, “mad”, or “scared”. For coping skill activities, the Wand activity was most frequently chosen under both conditions. The Flower activity for Condition B was used the least, which is the only activity under Condition B that does not incorporate any interaction from the student.

Student scores from the PreBERS assessment are presented in Tables 6.2 and 6.3 along with the time spent using MindfulNest, which was collected from the tablet data. Results from the PreBERS assessment appear inconclusive. However, during one of the teacher interviews, one of the teachers acknowledged that some student evaluations may have had lower scores. The teacher attributes this to becoming more aware of some students’ social and emotional development only after MindfulNest was introduced in the classroom. Anecdotally, the teacher expressed that, throughout the pilot, students became more in tune with their feelings and saw a change in how students would deal with situations in the classroom.

When teachers were asked which condition was preferred, the responses were mixed. The teacher from Classroom A stated a preference for the system without tangibles, pointing to how it requires less equipment and teacher maintenance, but acknowledges that the students did miss aspects of the tangible system during the second half of the pilot (e.g. hugging the sheep). By contrast, the Classroom B teacher preferred the tangible system, though they did report that some students struggled in the beginning of the second eight weeks to transition from only using the app to using the system with tangibles. Regardless of the condition, both teachers saw a benefit in using the system as an alternative way to offer emotional support to students. During an interview, one of the teachers reflected on how the system provided this support in their classroom:

“It seems like it helped every day because there was always that one student who was sad, and sometimes as a teacher... you don’t know what to say, but that was always something I could say... ’if you need to calm down just go use the tablet.’ And it did help them.”

**Student:**

**Teacher suggests MN:** Yes | No      **If suggested multiple times, count:**

**Teacher guidance:** Teacher guides student through MN | Child uses Independently

	Interacting with MN*	Calm down	Leave MN
Time			
Notes			

\*Touching the screen, selecting picture, holding tablet, holding manipulative, etc.

**Notes on Observed Emotion:**

**Notes on App Interaction:**

Figure 6.10: Observation form template used by researchers during the Phase 3 pilots.

Classroom A								
Gender	Age	Time spent using MindfulNest (in minutes)	Pre-test			Post-test		
			ER	SR	SC	ER	SR	SC
M	4-5	63.7	0.84	0.84	0.84	0.84	0.91	0.91
M	4-5	125.9	0.37	0.75	0.63	0.5	0.84	0.84
M	4-5	77.4	0.75	0.5	0.5	0.91	0.75	0.75
M	4-5	60.8	0.91	0.75	0.84	0.95	0.91	0.84
M	4-5	77.9	0.95	0.5	0.91	0.84	0.25	0.84
M	4-5	103.7	0.09	0.63	0.75	0.37	0.75	0.84
M	5	66.5	0.91	0.91	0.75	0.95	0.91	0.91
F	4	52.9	0.91	0.84	0.91	0.91	0.84	0.91
F	4	97.4	0.91	0.84	0.91	0.91	0.84	0.91
F	4	164.2	0.84	0.75	0.84	0.84	0.84	0.84
F	4	201.3	0.91	0.63	0.84	0.91	0.75	0.84
F	4	186.1	0.91	0.75	0.25	0.91	0.75	0.63
F	4-5	100.4	0.91	0.63	0.84	0.75	0.63	0.84
F	4-5	57.9	0.91	0.75	0.75	0.91	0.84	0.84
F	4-5	101.5	0.37	0.75	0.84	0.63	0.84	0.84
F	5	138.3	0.91	0.84	0.91	0.91	0.84	0.91
F	5	99.2	0.84	0.84	0.91	0.91	0.84	0.91
F	5	135	0.84	0.84	0.5	0.84	0.75	0.75

Table 6.2: PreBERS assessments completed for each student in Classroom A. The emotional regulation (ER), school readiness (SR), and social confidence (SC) scores are reported as percentile ranks of standard scores. Ages reported as “4-5” indicate that the student was 4 when the pre-test was taken and 5 when the post-test was taken.

Classroom B								
Gender	Age	Time spent using MindfulNest (in minutes)	Pre-test			Post-test		
			ER	SR	SC	ER	SR	SC
M	3	127.7	0.5	0.25	0.25	0.63	0.37	0.37
M	4	44.6	0.75	0.84	0.91	0.63	0.91	0.91
M	4-5	20.6	0.75	0.5	0.75	0.91	0.63	0.84
M	4-5	24.7	0.84	0.84	0.91	0.84	0.91	0.91
F	3	54.2	0.84	0.84	0.91	0.84	0.84	0.91
F	3	56.4	0.5	0.25	0.5	0.5	0.63	0.84
F	3	35.7	0.91	0.75	0.5	0.63	0.63	0.37
F	3	67.6	0.84	0.5	0.5	0.84	0.75	0.5
F	4	29	0.84	0.84	0.84	0.91	0.84	0.91
F	4	32.6	0.91	0.84	0.91	0.91	0.84	0.91
F	5	43.4	0.84	0.75	0.91	0.91	0.84	0.91

Table 6.3: PreBERS assessments completed for each student in Classroom B. The emotional regulation (ER), school readiness (SR), and social confidence (SC) scores are reported as percentile ranks of standard scores. Ages reported as “4-5” indicate that the student was 4 when the pre-test was taken and 5 when the post-test was taken.



# Chapter 7

## Conclusion

MindfulNest is a robotic multimodal system that is designed for early childhood classrooms and guides students through identifying their emotions and applying emotion regulation strategies. Its design was informed by prior work on developmentally appropriate educational technologies for young children, which prioritize interactive media over passive uses of screens while also shifting the focus away from the screen and towards the activities that students are engaged in. The system leverages multiple modes of interaction (e.g. tangible interfaces, audio and video prompts) which also helps maximize its independent use by students as young as 3 years old. Beyond the technology of the system, support is also provided for adults to facilitate a wider community of support for students' social and emotional skills, in the form of teacher professional development as well as educational materials for teachers, parents, and caregivers.

Pilot testing of the MindfulNest system informed our iterative changes to the system for improving student engagement, such as the incorporation of video prompts to better guide students through activities and implementing click delays to encourage more intentional app navigation. Data from the Phase 3 pilots supports the hypothesis that students are more engaged in the MindfulNest system when it includes interactions with tangible user interfaces.

For early childhood teachers, the demand for SEL resources and training is clear [12, 19, 57]. With less than half of U.S. teachers indicating access to school-wide SEL programs [10, 54], it is unclear how teachers can support students' social and emotional development without access to resources or training. At the very least, the presence of a tool in the classroom that is dedicated to SEL provides a space in the classroom for talking about emotions and listening to one another.

### 7.1 Future Work

There is a lot of potential for growth of the MindfulNest system, as it is still in its early stages of development. Testing the system across more centers will ensure more robustness for a wider variety of classrooms and could provide insights on how to improve the technology as well as resources for teachers and caregivers. With the capabilities of customization built into the system (5.3.2), it would be interesting to see how this might be leveraged to provide more personalized learning opportunities for individual students and classrooms. The MindfulNest team is also interested in exploring different types of professional development that target teachers with varying

experience levels, teaching styles, and classroom environments.

As mentioned previously, facilitating a wider community of support for students by engaging with their caregivers and developing school-home partnerships is a key aspect of successful SEL programs. We have seen this in our work with Message from Me, which focuses on fostering school-home partnerships by assisting students in communicating their daily activities in the classroom. Finding ways to leverage this communication to also support the skills being developed with MindfulNest might offer new ways to encourage the transfer of skills, beyond the classroom.



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