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DreamCatcher: Exploring How Parents and School-Age Children Can Track and Review Sleep Information Together

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Abstract

Parents and their school-age children can impact one another's sleep. Most sleep-tracking tools, however, are designed for adults and make it difficult for parents and children to track together. To examine how to design a family-centered sleep tracking tool, we designed DreamCatcher. DreamCatcher is an in-home, interactive, shared display that aggregates data from wrist-worn sleep sensors and self-reported mood. We deployed DreamCatcher as a probe to examine the design space of tracking sleep as a family. Ten families participated in the study probe between 15 and 50 days. This study uses a family systems perspective to explore research questions regarding the feasibility of children actively tracking health data alongside their parents and the effects of tracking and sharing on family dynamics. Our results indicate that children can be active tracking contributors and that having parents and children track together encourages turn-taking and working together. However, there were also moments when family members, in particular parents, felt discomfort from sharing their sleep and mood with other family members. Our research contributes to a growing understanding of designing family-centered health-informatics tools to support the combined needs of parents and children.

Keywords

Sleep; health; families; self-tracking; personal informatics; family informatics

1 INTRODUCTION

In families, the health of each member is interconnected [17], especially when it comes to sleep. When school-age children experience poor sleep, it has carryover effects on their parents [58]. However, most sleep-tracking tools are designed for adults [48], and in families the responsibility of tracking and monitoring health typically falls solely on the parents. This practice is difficult to maintain, and parents struggle to find tools that allow them to share and distribute sleep-management activities to other family members. Furthermore, school-age children have also expressed interest in working with their parents to track and review information [46]. This matches childhood development recommendations, as experts recommend teaching healthy skills and habits as children mature and seek independence [7, 29, 39]. We posit there is an opportunity to leverage children's interest in tracking to both help educate children on health and share the burdens of tracking—when appropriate—between parents and children. Our work explores designing a sleep display for parents and their school-age children.

Designing to include both parents and children in health-related activities also aligns with public- and family-health perspectives. Public- and family-health research considers the family unit as a set of individuals that are interconnected and affect each other [8, 41, 42, 54]. From this perspective, family members take on specific functions, depend on each other to perform day-to-day tasks, and overall function as a system comprised of subsystems defined by invisible boundaries [36]. Our work focuses on the task of tracking in families and the boundary that exist between parents and children with respect to tracking. We explore how to move from a rigid tracking boundary (i.e., parents tracking their children's health) to diffused (i.e., children and parents tracking together).

To explore these boundaries, we conducted a technology probe [26] that examined what happens when children and parents have the ability to track health together, using sleep as a case study. For the study probe, we designed and developed DreamCatcher (Figure 1)—a shared tool for family members to track and view sleep information together. DreamCatcher was co-designed with families and consists of an in-home family display that combines: (1) sleep data collected through wrist-worn sleep sensors, (2) self-reported mood data manually reported by both parents and children, and (3) reflection prompts that allow family members to share and reflect on their sleep. The probe study lasted from 15 to 50 days with 10 families consisting of a total of 20 adult parents and 18 children between the ages of 7 and 14. Each family included at least one child experiencing poor sleep, as reported by a parent.

Using the Family Systems Framework [8, 41, 42, 54] for our analysis of interviews and reflections with family members using DreamCatcher, we found: (1) the features of DreamCatcher enabled children to track health data both for themselves and on behalf of their parents, and (2) DreamCatcher affects the tracking boundary between parents and children. Before using DreamCatcher, this boundary was rigid, with tracking and reviewing performed by parents. DreamCatcher demonstrated that the tracking boundary can be become diffuse when parents and children are empowered to track for themselves and others. However, this boundary diffusion can lead to discomfort. In the case of parents, openly sharing with their children was a new experience that challenged the traditional hierarchical boundary that often exists between parents and children. This research therefore contributes to a growing body of work on family-centered health technologies, including: (1) a new artifact in a system that can enable sleep tracking across families; and (2) an empirical understanding of how this system impacts families when deployed in the home. Specifically, we investigate the following research questions:

1. How can a family-centered tool for tracking sleep and mood help school-age children participate in tracking with their parents?
2. How does DreamCatcher impact the tracking boundary between the parent and children subsystems of a family system?

2 RELATED WORK

This section connects our research with prior work on designing for parents and caregivers, on family informatics, and on designing for sleep. Throughout our research, we use the following definition of family: “two or more people who are related biologically, legally, or emotionally and have lived together long enough to exhibit both patterns of interaction and stories that justify and explain these patterns” [42].

2.1 Designing Tracking Tools to Support Parents

Family-centered tracking research has focused primarily on parents as trackers. WAKEY [9], Estrellita [25], Baby Steps [30], ParentGuardian [47], Mobero [53], and work on health promotion in families [49, 50] focus on technologies to help parents track aspects of their children’s lives or to support parent interactions with their children. Other research has explored remotely monitoring children’s health and sharing the information with parents. Toscos et al. [55] examined how a blood glucose meter that automatically collects, tracks, and shares information to parents of children with diabetes can impact family relationships. They found that sharing children’s glucose information with parents can reduce tensions between parents and children. In each of these systems, children’s health is monitored by their parents. Designing for tracking a particular family member lends itself well to situations where there are specific concerns about that family member’s wellbeing. In other situations, such as sleep, there is a need for the entire family’s health to be considered.

2.2 Designing for Family Informatics

A family-centered approach to tracking means that all family members participate in and benefit from tracking. Previous work has explored how stages of personal informatics (e.g., deciding, selection and preparation, collection, integration, reflection, action, lapsing and resuming) [19] can be mapped to families [46]. This work identified opportunities for family members to share the burdens of collecting and to make sense of data across all stages of tracking. However, designing for family informatics requires accounting for the age and capabilities of each family member by adjusting the granularity and modality of tracking and

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how information is presented. Previous research in family informatics has explored designing for the stages of collection, integration, and reflection. Colineau [14, 15] and Kimani [32] have examined the use of online family portals and social networks to support family wellbeing. In these systems, each family member can individually track a health goal and view other family member's goals. The intent was to help family members learn about each other's goals and to encourage family participation. However, family members could only view information, not track for each other.

Eating and nutrition behaviors are another area of health heavily shaped by family. SnackBuddy [52], TableChat [34], and Grimes et al. [23] explored how to support parents and children helping each other choose healthier snacks and meals. This body of work shows that journaling together facilitates support and curiosity, that family members can add context to each other's journaled meals, and that sharing eating records can support awareness and coordination within the family. For physical activity, Spaceship Launch is an exercise game where every family member can participate [51]. Its design strives to encourage all family members to take part in more physical activity through family-friendly competition. In another study, parents and children wore fitness trackers to explore how to promote physical activity among families living in neighborhoods that lacked safe spaces and public parks [49]. Though both parents and children wore fitness trackers, the results focused on celebrating parent physical activity while taking into account the lack of public spaces in which families can be physically active. Our research extends such work by exploring the context of sleep.

2.3 Designing Technology for Sleep Health

Designing interactive technologies for improving overall sleep health is of growing interest in the research community [1, 5, 10, 12, 13, 16, 28, 40, 48]. Previous work in human-computer interaction has focused on design opportunities for sleep, identified that people struggle to manually track sleep, and provided guidance on how to design lower-barrier sleep tracking technologies [10]. SleepTight applied the lessons of that research and found that leveraging widgets in mobile phones can reduce the burdens of manual tracking while still preserving the benefits of manual tracking, such as sleep awareness [12]. Shuteye found that a smartphone's active wallpaper can be leveraged to provide to timely guidance on activities that could impact sleep [5], whereas Lullaby focused on using visualizations from environmental sensors to identify potential disruptors to sleep [28]. BuddyClock found that sharing daily waketimes and bedtimes with a select group of friends can help people feel more connected [31].

Research has primarily focused on designing for adults self-tracking their own sleep. However, Cherenshchykova et al. explored the design space for family-centered sleep tools for families. Their formative work consisted of home-based interviews with 10 families with children in the age range of 3 to 7 years old [10]. They found there is an opportunity for technology to support waketime and bedtime family rituals, encouraging children's independence and comfort. In the commercial space, there are a few tools to help parents with newborns track and understand their baby's sleep patterns (e.g., Huckleberry[1]). Our research contributes to this space by exploring a family-focused sleep display where both parents and young children can view and interact with the information.

3 DREAMCATCHER DESIGN PROCESS

In this section, we describe our iterative design process that led to the final version of DreamCatcher. We built DreamCatcher based on: (1) reanalyzing data collected from 10 interviews and 3 co-design sessions from prior formative research [46], and (2) new data collected from five feedback sessions on high fidelity prototypes with parent-child dyads that participated in first study.

3.1 Design Insights from Formative Research

In our formative work, we found that parents and children wanted a visual representation of sleep that included all family members. However, the sleep representation of the family also needed to avoid one-to-one comparisons, as parents and children need different amounts of sleep. Parents and children also wanted to connect hours slept with their mood by reporting their mood after waking up, as they understood that hours slept does not fully describe sleep quality. In the participatory design sessions, researchers and children explored representing each family member with a horizontal bar corresponding to hours slept (Figure 2, left). Children found this confusing because they thought it implied a direct comparison between family members. However, it provided a starting point for gathering children's thoughts about what information they want to view and interact with. Children then expressed and sketched ideas for representing information about hours slept and mood together with nighttime imagery (e.g., moons, stars, a night background). As also shown in Figure 2 (left), children drew images of mood emojis next to the bars, moons, and stars.

Another co-design session with paper prototyping explored other ways to represent sleep while: (1) avoiding comparison between family members, (2) connecting mood to hours slept, and (3) using a calendar to select a specific date. In this iteration, the co-design exercise led to sleep being represented as a ring that is shaded based on hours slept and mood represented as an emoji beside the ring (Figure 2, right). Children in the co-design sessions also described wanting to leave messages about the information they were viewing. We used this insight to incorporate audio-based reflection prompts in DreamCatcher (described further in Section 4.3).

3.2 Insights from Prototypes Feedback Sessions

We created two high-fidelity mockups based on the takeaways from the interviews and participatory design work. From the interviews, we learned that the sleep representation needed to: include all family members, be easy for family members to review each other's information, support entering information on behalf of one another, and avoid direct comparison. From participatory design sessions with children, we learned that representations needed to: avoid direct comparison, include night imagery, and support children in making sense of information both on their own and with their parents.

[1] https://huckleberrycare.com

The first view we presented was the *Family Daily View*. This view represented sleep and mood for all family members for one day (Figure 4a). The second view was the *Family Weekly View,* which represented sleep and mood for all family members for one week (Figure 4b). In both family views, the ring represents hours slept. If a family member did not reach their target hours, the ring is incomplete (see Mom in Figure 4). We added a night-themed background including a crescent moon in the middle that fills as more information is added for each family member.

Based on insights from formative work, we designed *DreamCatcher* so that any family member can either self-report their own mood or report mood on behalf of another family member. To enter mood, a person touched a circle corresponding to a family member. Every family member's circle had the text: *How did you feel this morning*? Touching the circle would open a modal window with 8 moods to select from. Each mood is represented by emojis with text descriptors. The person would select one of the moods and the window would close. The circle with the text prompt then transforms into a ring representing hours slept with the selected mood appearing inside the ring. Figure 3 shows the eight mood options (rested, sleepy, nightmare, happy, ok, hungry, painful, upset).

In feedback sessions with parent-child dyads, we walked through paper printouts of prototypes to determine whether family members, in particular children, could make sense of sleep information and enter mood. Children in the sessions were able to select mood, navigate between the daily view and weekly view, and answer questions about the sleep and mood represented in the images. Parents and children requested to update how the daily mood question was phrased as well as the description of the moods.

Parents requested two additional views—a daily view and a weekly view—for a single family member to learn about waketime and bedtime patterns and the amount of restlessness through the night. These requests were motivated by questions healthcare providers ask parents when trying to make sense of what could be causing children to sleep poorly. We therefore created two additional prototype views: single daily view (Figure 4c) and single weekly view (Figure 4d). For single views, we used bars to represent bedtime, waketime, and degree of restlessness. The Single Daily View includes the sleep ring with the mood inside and a bar to show hours slept with bedtime and waketime information. The Single Weekly View includes the same sleep bar as the single daily view—one for each day of the week—and makes it possible to quickly view consistency or inconsistency in bedtime and waketime.

After reviewing these prototypes, parents and children expressed that the order in which mood and sleep are shown is important and that viewing sleep first and then reporting mood would bias their mood answer. The next section describes how we addressed this in DreamCatcher's final design.

4 FINAL DESIGN OF DREAMCATCHER

Based on the ideas and designs generated from formative work, co-design sessions, and feedback sessions, we iterated on the design of DreamCatcher to create its final design and build a working, deployable artifact suitable for a technology probe. This section describes the final version of DreamCatcher and how it was implemented using sleep data from Fitbits worn by each family member and a touchscreen tablet displayed on a family kiosk.

4.1 Sleep Views in DreamCatcher

The final version of DreamCatcher supports four views. Two of the views represent sleep and mood for the entire family: *Family Daily View* (Figure 1) and *Family Weekly View* (Figure 5a). The other two views consist of viewing a single family member's sleep and mood: *Single Daily View* (Figure 5b) and *Single Weekly View* (Figure 5c). We represented overnight restlessness by using the two categories of movement Fitbit can discern: restlessness and movement. To access one of the single views, a person must select a particular family member from the family views.

4.2 Reflection Prompts in DreamCatcher

We kept the same mechanism to report mood used during the prototyping sessions, but updated the available moods based on feedback. The final mood options were: happy, ok, had a nightmare, rested, in pain, sleepy, and tired. We also updated the text that appears in the circle at the beginning of the day. In the final version, the text stated: *How did you sleep*?

To address the concern raised by participants in the feedback sessions on the order of sleep and mood, mood must be reported first and then the previous night's sleep information appears. Mood can be reported only once a day, for the current day, and cannot be reported retroactively. If mood is not reported within 24 hours, the ring is automatically filled with hours slept with an empty interior. In total, family members have three ways to interact with DreamCatcher: (1) exploring the various views, (2) tapping to self-report mood or to report mood on behalf of another family member, and (3) recording audio answers to reflection prompts, described next.

4.3 Reflection Prompts in DreamCatcher

Children in our design sessions reported wanting to leave audio messages, which we therefore incorporated into the design. Family members can leave an audio reflection in two ways. First, family members can at any time tap the microphone icon on the top right and start recording an audio message. Second, a reflection prompt appears when DreamCatcher detects frequent tapping after more than 10 minutes of idleness. This interaction-driven prompt appears up to four times per day. The family member can chose to ignore the prompt, answer the prompt, or request a different prompt. After a prompt is answered, no other prompts appear the rest of the day. The prompts appear on the upper right corner and persist until the stop button is tapped. Figure 5 shows these prompts.

We used two frameworks to generate a list of prompts that focus on learning about sleep, supporting family communication, and encouraging conversations that can capture working together or possible tensions. The first framework comes from education research, which provides guidelines for how to phrase questions with the goal of reflection through the lens of learning by doing [23] and experimental learning [33]. The second framework comes from research on privacy management and information disclosure between family members [44].

We wrote the prompts to: (1) encourage exploration and reflection on the four views included in DreamCatcher, and (2) to cover different family arrangements. For example, there are prompts that a parent-child dyad could answer together, prompts only for children, and prompts only for parents. Table 1 shows the full list of the prompts, including the recommendation we provided for who should answer the prompt.

4.3 DreamCatcher's System Implementation

We built DreamCatcher as a mobile web app designed for a touchscreen tablet interface. The app is implemented using Angular with data stored using CouchDB—a non-relational database that stores data in a collection of JSON documents. We installed DreamCatcher on Samsung Android tablets and packaged the tablet as a standing display kiosk for ease of use. Figure 6 shows all the components needed to deploy DreamCatcher. Because sleep is difficult to report manually [11] and because developing a custom sleep sensor is beyond the scope of our research questions, we decided to capture sleep through a commercially wearable sensing device. For this deployment, every family member wore a Fitbit Flex.[2] The data from the Fitbit was synced via Bluetooth to Fitbit's platform, and our study server queried the data from Fitbit's platform.

There are two ways to sync Fitbit data. The first is to pair one device to Fitbit's mobile app. However, Fitbit's mobile app can pair to only a single device. For our deployment, this would mean every family member wearing a Fitbit would need to have a compatible mobile device (e.g., a family of four would need four Fitbits and four mobile devices with the app installed). A second approach is to have Fitbit's app on a desktop or laptop (i.e., not a mobile device). The desktop version of the app is multi-reader, can read any Fitbit within 20 feet of the desktop, and updates every 15 minutes. We chose the second approach because it is the more practical and cost-effective of the two (e.g., a family of four only needs four Fitbits and a single laptop to sync all four Fitbits). The DreamCatcher web app requests an update from our study server every 15 minutes. The views in DreamCatcher then update if there is new sleep information from the synced Fitbits.

5 STUDY METHODS

We deployed DreamCatcher and evaluated it as a technology probe [26] to examine the feasibility of deploying DreamCatcher in homes and how families used DreamCatcher. This section describes our recruitment process, participants, study protocol, data collected, the framework used to understand the probe in the context of families, and our data analysis approach.

5.1 Recruitment and Participants

We recruited by contacting families from a previous study that had consented to be contacted for future studies, through flyers at schools in the vicinity, and through community

[2]https://www.fitbit.com/home

mailing lists. The flyer requested participation from families with children experiencing poor sleep and had participants contact us for screening. We had three specific inclusion criteria. First, at least one child had to be experiencing poor sleep, as assessed by a parent-completed Children's Sleep-Habits Questionnaire (CSHQ), a validated questionnaire that assesses children's sleep quality [43]. Second, the child experiencing poor sleep needed to be between the age of 7 and 12 years old. We chose this age range because school-aged children are rule-driven, understand right and wrong, and are able to problem-solve. School-age is the ideal developmental period for children to begin sharing responsibility for their health management, collaborate in shared decision-making, and establish lifelong health behaviors [7, 29, 39]. Finally, all participating family member were required to live in the same home.

Twenty-three families expressed interest in participating and ten fulfilled our study's inclusion criteria. All ten families lived in Seattle, WA. Participating families varied in the number of children and in age. Table 2 describes participating families. We compensated families with $100 USD for participating in the entire study, with $25 of the total amount distributed at the end of the first visit and the rest distributed at the end of the study.

Although we strove to recruit a diversity of families, all parents identified as heteronormative and had medium- to high-socioeconomic status. The majority self-identified as white, though we also had families with Filipino-American, Chinese-American, and African-American members. Last, we did not assess for numeracy or health literacy. Our findings may not extend to other families. Future work should examine our questions in families with greater ethnicity representation, non-heteronormative parents, in medium- to low-socioeconomic status families, and assess numeracy and health literacy through a validated questionnaire.

5.2 Study Protocol

Our technology probe consisted of using DreamCatcher for a minimum of 15 days with two visits per family. During the first visit, we consented or assented every participating family member, provided a Fitbit for each family member, and set up DreamCatcher in a central location in the home. While parents completed a demographics survey, we taught the children how to use DreamCatcher. After children were comfortable using DreamCatcher, children were encouraged to teach their parents how to use DreamCatcher. Focusing on children first allows them to get comfortable with the technology and prevents their parents from taking the lead [56]. If parents had questions that children did not feel comfortable answering, the researchers answered for them. Following the tutorial, we conducted a semi-structured interview with all family members. Our questions drew upon literature about the needs of caregivers and care receivers with chronic conditions [4], communication of privacy management [44], and family interviewing methods [2, 18]. Questions covered tensions around sharing sleep information, what knowledge family members have about each other's sleep, family priorities with regards to sleep, and previous experiences with sleep tracking.

Family members were instructed to wear their Fitbit nightly for sleep monitoring and were given the option to also wear it during the day. DreamCatcher's standing display was placed in a central location in the family's home, such as in the kitchen, the living room, or a shared bathroom. Each participating family member was encouraged to self-report mood or to report mood on behalf of another member and to answer the reflective prompts. At the end of the study, researchers conducted a second visit that involved collecting the equipment and conducting a second semi-structured interview. For this interview, parents and children were interviewed separately. Separate interviews allowed for parents and children to express themselves without pressure from others [27, 45]. We drew upon the same body of literature from the first interview but focused on what family members learned and the impact of sharing sleep and mood between family members.

5.3 Data Collection

The study probe consisted of a 15-day deployment, but some families asked to use DreamCatcher for as long as 50 days. We collected five sources of data: (1) semi-structured interviews conducted at the beginning and end of study; (2) answers to DreamCatcher's reflection prompts; (3) logs that captured interactions with DreamCatcher any time a person tapped a sleep view, answered a prompt, or reported mood; (4) who was interacting with the system, as optionally self-reported to the system any time a stream of taps was detected, and (5) sleep data collected via Fitbit. For the interview at the beginning of the study, the average length was 24.9 minutes; the shortest lasted 14 minutes and longest lasted 32.3 minutes. For the interview at the end of the study, the average interview lasted 37.3 minutes, the shortest lasted 19.7 minutes, and the longest was 56.4 minutes. The remaining four data sources were collected for all family members in each family for the duration of the study.

5.4 Data Analysis

5.4.1 Framework to Guide Analysis: Family Systems Framework—To examine the impact of using DreamCatcher, we needed a framework that characterizes how family members in a family unit interact with each other. We used the Family Systems Framework [54], which considers a family as a set of individuals who are interconnected, have functions (e.g., parent, child, grandparent), and affect each other. When one family member experiences a positive or a negative event, other family members experience it directly or indirectly. Family members with similar functions group themselves into subsystems. Members of the same subsystems work together to complete day-today tasks. The most visible subsystems are based on familial relationships and functions (e.g., parents vs. children) [41, 42]. These subsystems interact with each other to maintain stability and wellbeing. The parents and the children subsystems are not equals, as a power hierarchy exist between the two. In families with young children, parents have more authority than children.

Family interactions and expectations emerge from constant negotiation and interaction between the subsystems and external factors [42]. The family system is constantly evolving and seeks to find a balance between change and stability. When a subsystem experiences a change, other subsystems experience ripple effects [54]. Change is both normal and necessary, with the family system reaching a new equilibrium based on the size of a change. There are invisible demarcations between subsystems, called boundaries [41], which create delineations and define the separateness and autonomy of a subsystem but allow for interactions, ripple effects, and transactions between subsystems. Boundaries are permeable and regulate contact between the subsystems.

Boundaries range from rigid to diffused—depending on how open (permeable) and closed the boundaries are. An **unhealthy rigid boundary** is when family members are too disengaged to support family functioning, discouraging closeness and support among family members. An **unhealthy diffused boundary** means family members are too enmeshed with one another at the expense of independence and autonomy. When a **healthy boundary** exists, subsystems support each other in completing tasks while maintaining their role, independence, and autonomy. In general, the greater the clarity and distinction between boundaries in a family system, the more effective the family can function to complete day-to-day tasks. With respect to tracking, we define an **unhealthy rigid tracking boundary** when self-tracking occurs but family members do not support each other, and a **healthy diffused boundary** when parents and children are tracking together but autonomy still exists. Our work explores reaching a healthy tracking boundary between parents and children tracking together.

5.4.2 Analysis Methods—Our goal in deploying a technology probe was to understand ways to support parents and children tracking together, and we developed an analysis process to answer our research questions. The Family Systems Framework helped us understand how DreamCatcher can affect families and family dynamics. For the scope of our study, we focused on two subsystems, parents and children, and their tracking boundary. As such, we categorized the data based on the two subsystems. This categorization allowed us to quantitatively and qualitatively compare the use of DreamCatcher between parents and children. We analyzed interaction logs to determine how often parents and children interacted with DreamCatcher. We calculated daily-average use from the three types of interactions logged: viewing, audio reflections, and mood reporting. We used the difference of means test (t-test) to assess the difference between parents and children.

Qualitatively, we analyzed pre- and post-deployment interviews and all audio reflections, which were transcribed by a professional transcription service. The codes captured the effects of sharing sleep and mood between subsystems and the impact on the tracking boundary between the two subsystems. The codes covered who tracked, how DreamCatcher supported or inhibited tracking, and the experience of sharing mood and sleep with family members. Three of the authors analyzed data independently and together took part in comparative analysis [38].

6 RESULTS

Our research questions focused on (1) how to design a tool to support parents and children to track and reflect as a family, and (2) the effects of the tracking boundary that exists between parents and children. We found that children can actively participate in tracking with their parents and that tracking tasks were shared between family members. Being able to distribute tracking between parents and children indicates that the tracking boundary moved from being rigid (e.g., only parents tracking) to diffused (e.g., parents and children tracking).

The results first describe how children tended to interact more with DreamCatcher than their parents. The second and third sections unpack how the tracking boundary became more diffuse and the adaptions that occurred. The last section presents a technological challenge that surfaced during the study from collecting sleep data from multiple devices through a single data reader.

6.1 DreamCatcher Supported Children to Track and Reflect with Their Parents

Across all three types of interactions (i.e., audio, mood, and viewing), families interacted with DreamCatcher at least once per day on 75% of study days. On average, a family member interacted with DreamCatcher 1.2 times per day. Children interacted with DreamCatcher significantly more than their parents: $t(1, 224) = 0.25$, $p < 0.001$. Figure 7 shows heatmaps for every family with respect to the three types of interactions (i.e., from top to bottom: audio, mood reporting, and viewing). The y-axis represents day in study. The x-axis represents the number of days for each family member, and each column represents a family member.

Of the three types of interactions, families used the mood-reporting more than the other two types of interaction combined. On average, families logged mood 0.73 times per day. Children used this feature significantly more often than their parents: $t(1224) = 0.25$, $p < 0.001$. Children logged mood 0.77 per day and parents logged mood 0.70 times per day.

During family post-study interviews, parents reflected on how children wanted to enter mood themselves:

> **F6 Mother:** [S]he wanted to be the one to answer it…. [S]he would move my hand away and say: ‘Let me do it.’

Furthermore, children not only reported their own moods; they also reported parent moods.

> **F8 Mother:** Well, usually it was one of the girls reporting for everyone … There would be these calls throughout the house, like, ‘Mom! How are you feeling?’ ‘I'm happy! And then she'd be like, ‘Dad! Dad! How are you feeling?’ ‘Well, ah, rested.’

Families used audio reflections the least in only 10% of study days. Although children tended to use audio reflections more, there were not statistical differences between parents and children $t(1228) = 0.04$, $p < 0.13$. Parents and children left messages to capture disagreements and moments of surprise. For example, children left audio messages if they disagreed with the number of hours DreamCatcher displayed and reported it was fun to leave messages. However, parents stated they were too nervous to leave messages or just did not relate to the prompts.

DreamCatcher shows that tracking and reviewing can be done by both parents and children. In the next two sections, we describe how children being able to track and review changed the tracking boundary between parents and children.

6.2 DreamCatcher Encouraged Healthy Diffused Boundaries

During our pre-study interview, all parents wanted to learn about the relationship between their children's sleep and their own. Five of the ten families reported they had previously kept sleep diaries for their children, but had struggled to gather the data. One of the ten families, F6, had previously tried having all family members use Fitbits to track sleep.

> **F6 Mother:** … [We] went to a sleep clinic recently, and they want us to track sleep stats. That's why we started her [daughter] on the Fitbit so we actually kind of need that data to report back to them … and we've only kind of half done it.

However, F6's family members struggled to use that information to learn about each other's sleep. F6's child did not have access to the child's sleep data, only the parents viewed the data.

At the end of the study, parents and children reflected on how they took part in tracking, reviewed, and reported mood on behalf of each other which did not affect family functioning. DreamCatcher enabled the tracking boundary to go from a rigid tracking boundary to a healthy diffused tracking boundary:

> **F5 Mother:** [T]hey [children] would look at my sleep, and most of the time they would see sleepy or tired, and every time they saw that they would be like 'Oh mommy are you okay?' They realized it …

Children also reflected on how they were learning about their own and their parents' sleep:

> **F9 Daughter1 (12 yo):** I don't normally ask my parents, but I was like whoa, I didn't realize, like five hours [of sleep]?

Furthermore, before using DreamCatcher, parents asked about their sleep every day, which frustrated the children.

> **F4 Mother:** I asked her every day how did she sleep.

> **F4 Daughter (10 yo):** I do not like to answer that question.

DreamCatcher's automatic capture of sleep data and children self-reporting of their mood provided parents an opportunity to review the information and follow-up with their children as needed.

> **F6 Mother:** … I think it actually was helpful just to have [Daughter] documenting her mood. Because [we] don't always ask, and she doesn't always tell [us] either […] Some days she would mark in pain, and I would be like, "Oh, you're in pain? I didn't know that you're in pain."

Children appreciated being able to self-report through DreamCatcher and share information with others without having an explicit conversation. Family F4's daughter wanted to use DreamCatcher to share information with her parents as well as with healthcare providers:

> **F4 Daughter (10 yo):** …. If I could pull it [DreamCatcher] up on my phone and be: 'There, this is how I've been sleeping' … that way I don't have to talk … It's overwhelming and tiring. They're all up in your face. With this I don't have to talk.

The information shown also created opportunities for parents and children to reflect together.

Children and parents could ask questions based on the information available through DreamCatcher and avoid sounding judgmental. In an audio reflection by Family F3, the mother and her son reflected on connecting the child's sleep with his bed-wetting struggles:

> **F3 Mother:** [Son] has been sleeping [well]. [Father] hasn't been sleeping. What do you think?

> **F3 Son (7 yo):** I have been sleeping and wetting my bed for two days.

Providing all family members an opportunity to track data allowed the tracking boundary to move from rigid to diffuse. DreamCatcher created a healthy boundary balance for families to support each other in completing the tasks, and maintain independence and autonomy [7, 29, 39]. Designing to reach a healthy balanced boundary aligns with the family systems theory and has the potential to empower and enageg families and avoid tracking fatigue track long-term [21, 46].

6.3 DreamCatcher Exposed Rigid Boundaries

Parents were concerned about sharing potenitally sensitive information (e.g., mood) that may exacerbate their child's anxiety. A prior study by Grimes et al. [23] found that parents were concerned about sharing their child's diet information would result in increased worry for their child. Parents in our study also expressed concern about sharing mood and sleep may result in unnecessar worry for their child.

> **F2 Mother:** Just the fact that she's just like, 'mom did this thing' … I'm like, 'I am the mom, you are the child. You don't need to worry about this.' She'll be like, 'I have to worry about this.'

Many families adapted to the changes in boundaries of DreamCatcher. Although sharing some information was uncomfortable, families reported that sharing this information provided opportunities of shared accountability and awareness:

> **F9 Father:** Just a good way to get everybody engaged.

> **F9 Mother:** We're all living here together, so whether you want to or not, you still have to deal with it as a family.

Other families found it more difficult to adapt to the changes in sharing and awareness. In these families, one or more family members worked to maintain their rigid boundaries and hierarchy. For example, in family F6, the father completely stopped tracking:

> **F6 Father:** I don't think it would be good to see my sleep… [O]ften times more information is [not good] […] Because then she [Daughter] would know exactly how much I slept […] So I decided then, I'm not sure if it's a good idea.

Family F6's daughter noticed that when she self-reported, she never saw her father's information. She mis-attributed this to being about when she filled out her data:

> **F6 Daughter (7 yo):** The only thing that surprised me is that every single morning I always filled mine out before my dad and so I never actually got to see his.

This example also shows how family members may disagree about benefits of shared tracking and awareness. Consequently, the design of tracking tools should support one family member's disengagement from tracking while avoiding disruptions for the rest of the family. Because DreamCatcher provided the flexibility for family members to self-track and track on behalf of others, families could continue tracking even when some family members discontinued tracking.

6.4 Technological Challenges Encountered in Capturing Sleep across a Family

Each participant wore a Fitbit and the data was synced asynchronously through the Fitbit app on a laptop. This app could read multiple Fitbits in the vicinity. However, we experienced missing data with this approach. We share our challenges to inform researchers and designers of tracking platforms.

Our system failed to collect 26% of person-days of data, but there was significant cross-family variation. Family F9 had 5.6% of its sleep data missing, while Family F8 had 59.5% of its data missing. Figure 8 shows a heatmap of the sleep data that synced. Sleep data for children is represented as dark green and missing as light green, while sleep data for parents is represented as dark red and missing is represented as light red.

Some participants installed the Fitbit app on their mobile devices and paired their Fitbits directly to the mobile app. Though we do not have quantitative data to demonstrate improvement of data syncing, participants described syncing improvements after pairing their Fitbits to a mobile app. The challenges with syncing show that moving from a single-user design space to the family space requires reconsidering the underlying assumptions of wearable sensors.

7 DISCUSSION

This work demonstrates opportunities for collaborative tracking in families. In contrast to parent-focused designs that rely on parents tracking and lack opportunities for children to actively participate, family-centered tracking allows parents and children to engage together in tracking. A parent-focused approach is necessary in many situations, such as tracking newborns and toddlers. But as children mature, the parent-focused approach runs the risk of creating siloes in tracking, creating unequal burdens of tracking, and disempowering children who are otherwise capable. A downside of siloed tracking is that even if multiple family members are tracking, family members will not have the ability to understand how they affect each other, creating rigid boundaries that hinder family members in helping each other. This section reflects on lessons from this probe study.

7.1 Family-Centered Health Technology can be Leveraged to Teach Healthy Habits

Our research demonstrates that tracking interfaces designed with cognitive and developmental skills in mind can support childrening in actively tracking alongside their parents. Enabling children to actively self-track opens opportunities to use tracking and data to scaffold children's individual and family-shared health-management practices. In our study, children used the audio prompts more often than their parents. Higher use of audio prompts by children confirms previous work on children using audio interfaces [57]. Future work should explore how to improve the design of prompts to help children record and report health information.

Previous work has found that building skills and expectations around healthy habits (e.g., as with risky online behavior) before the teenage years (i.e., when children may be seeking more autonomy) may help establish better habits and be more successful in maintaining family relationships [22]. Support for shared and collaborative health-management skills during the school-age years could be a valuable way to establish healthy habits, thereby helping these skills become part of a foundation for a healthy life [59].

7.2 Family-Centered Health Representations Need to Consider Tensions and Privacy

Consistent with prior literature [19, 46], family members would sometimes lapse or entirely stop tracking. Families face challenges in finding a healthy balance between rigid and completely diffused boundaries. This means family members constantly negotiate connectedness and help each other with supporting autonomy and privacy. Disclosing sleep information can support awareness and problem-solving, such as helping family members develop consistent sleep routines (e.g., wind-down time windows, bedtime routines). However, these disclosures also can create and exacerbate privacy challenges, thereby leading to tensions [46].

We were able to avoid some of the privacy tensions described in previous work [46, 55] by focusing on patterns that matter for healthy sleep (e.g., consistency, sleep amount relative to goal). The family views in DreamCatcher represent sleep as a ring—a design choice that reduced concerns about sharing too many details about sleep habits with other family members. In the individual views, the focus was on hours slept and consistency of bedtime and waketime. These views did provide approximate bed- and wakeup- times, which helped parents by supporting specific conversations about sleep with their children. Children, who were all school-age, felt comfortable sharing this information. Future work needs to explore how to design family-centered technology for families with teenagers, as this age tends to be more sensitive to privacy concerns [37]. Future work should also consider potential differences in families with specific or mixed parenting styles [6, 20]. Parenting styles, such as authoritarian approach or authoritative approach, differ in how they perceive different levels of information sharing within the family [22].

7.3 Health Sensing Platforms Should Continue to Explore Multi-readers

The DreamCatcher technology probe also revealed technical and practical hurdles associated with having multiple family members sync data from wearable sensors. DreamCatcher's interface could have done more to communicate sync status to families by showing the last sync time. But the issue of syncing multiple Fitbits in one household highlights how technological design decisions inhibit successful family-centered technologies.

Most commercial health-sensing devices are designed to pair a single person to a specific account. This account is paired to a personal mobile phone with an app that only reads data from the specified account. This technological decision is useful in the single-user design space. However, not every person has a compatible mobile phone. In a family of four, every family member tracking would need a Fitbit (which costs around $100) and a personal device compatible with Fitbit's mobile application (which costs at least $200 as of 2020). Additionally, some families delay providing a smartphone for their children until they are older (e.g., the Wait-Until-8th campaign[3]). As health-sensing capabilities increase, future work should also explore less costly approaches to integrating and aggregating from multiple devices.

Moving from a single-user design space to the family space calls for re-considering underlying technological assumptions. Underlying technologies could associate multiple sensing devices to multiple phones. For example, a child's device and a parent's device could both be associated with and managed by the parent's phone. Facebook Messenger Kids[4] and Niantic Kids[5] (which makes location-based games such as Pokémon GO and Harry Potter Wizards Unite) are both examples of technologies where children's accounts can be managed by parents and also comply with children's privacy laws, such as COPPA[6] in the U.S. Tools and platforms will also need to consider how to support flexibility for families in all additional stages of data management.

7.4 Family Health Tracking Tools Need to Account for Complex Family Dynamics

Finally, we note there are many additional challenges in designing for complex family dynamics that our study did not examine. Technology designs and platforms built upon family sensing will also need to support potential changes in family structures (e.g., parental separations, new partners, adoptions, fostering) and their implications for data collection and control. In case of personal health records, when children turn a certain age (e.g., 18, but as young as 13 in some U.S. states), they have the right to own their electronic health records and to not share them with parents[7]. Similarly, sensing platforms will need to support transitioning ownership of a child's account from the parent to the now-adult child. Finally, families in our study, at least in what was revealed to us, were a part of a collegial family relationship. Family-centered health tracking should also consider what might happen when trust in a family is broken or there are adversarial or potentially abusive situations where technology might be used as a form of unauthorized surveillance or in forms of "digital abuse" [35]. Children in temporary care situations, such as foster care, also have particular privacy needs that need to be addressed [3]. Revisiting privacy controls and access regularly could be one way of mitigating some of these concerns. In addition, co-designing activities with both children and families consisting of multiple, diverse family makeups can help identify these issues early in the design process.

[3]https://www.waituntil8th.org/
[4]https://messengerkids.com
[5]https://parents.nianticlabs.com/
[6]https://www.ftc.gov/enforcement/rules/rulemaking-regulatory-reform-proceedings/childrens-online-privacy-protection-rule
[7]https://www.hhs.gov/hipaa/for-individuals/index.html

8 CONCLUSION

This paper demonstrates opportunities for including children in family-centered tracking technologies. It contributes: (1) an empirical understanding of how to design family-centered tracking tools that support parents and children, and (2) a novel technological artifact for family-based sleep and mood tracking in the home. We explored designing a tool that supports parents and children in tracking and reflecting on sleep and mood. From the health perspective, we focused on family sleep due to its overall importance in family health, the relationship between children's and parent sleep, and because it is an interesting case study for exploring privacy issues. From a technological perspective, we focused on family sleep because most sleep tracking platforms focus on a single adult user. Our exploration centers on the iterative design process, development, and deployment of a family-centered, sleep-tracking system, called DreamCatcher.

Our results show that children can participate in tracking along with their parents. Children reported mood on behalf of themselves and others, interacted with the sleep views more than parents, and left audio messages as much as their parents. Providing the means for parents and children to track together affects family tracking dynamics. Tracking technology generally supports a parent tracking a child – which fits into the boundary that exists of parents taking care of children. DreamCatcher distributed tracking across all family members, which changed the traditional role of a parent being the sole tracker to children self-reporting, reporting on behalf of their parents, and viewing information for all family members through one representation. Our work shows that even if one family members discontinued to track, the design of DreamCatcher allowed for the rest of the family to continue tracking. Future work should apply the insights and address the challenges presented in this study. Continuing research in the design of family tracking technologies has the potential to support family-focused technological behavioral intervention to improve sleep quality.

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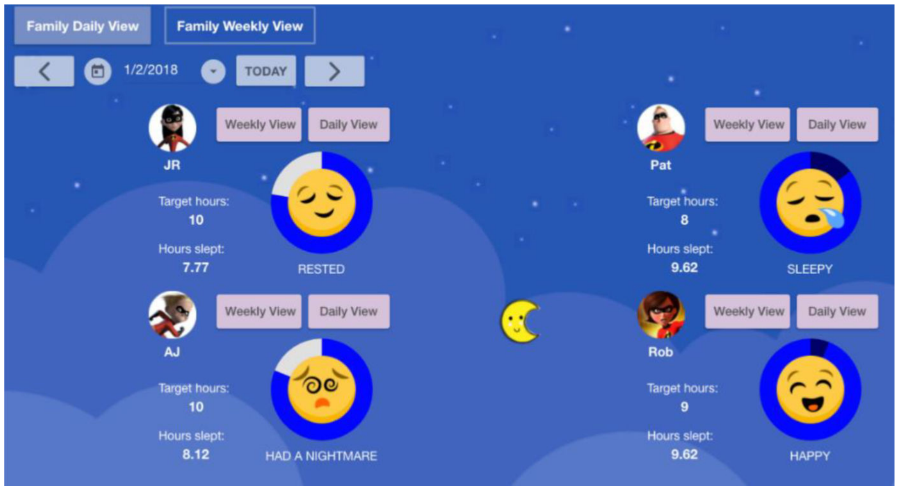

Figure 1.
The main home screen of DreamCatcher that was displayed on a tablet kiosk in a central location in the home. The sleep of each member of the family is represented as a blue ring. Inside each ring is an emoji chosen by family members to represent that person’s daily mood.

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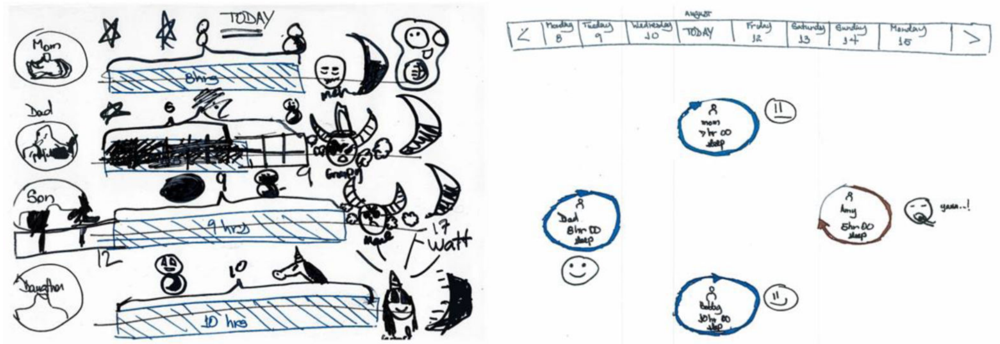

Figure 2.

First (left) and second (right) iterations of co-created paper-prototypes from Participatory Design sessions with children.

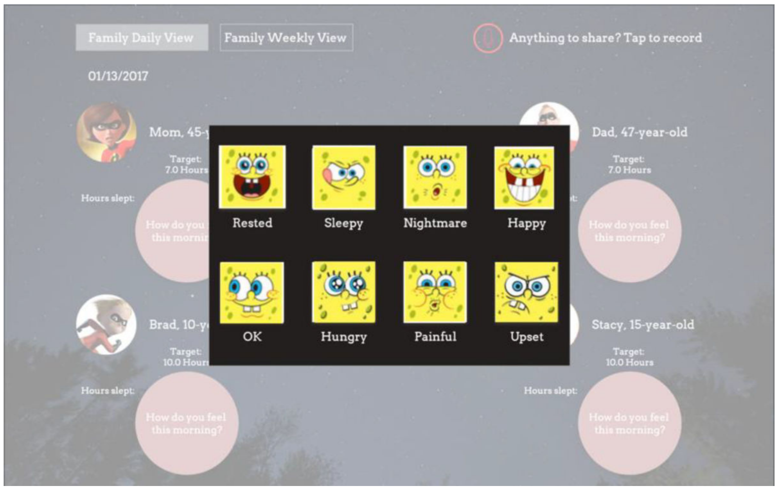

Figure 3.
Prototype mood options for self-report or for reporting on behalf of another family member.

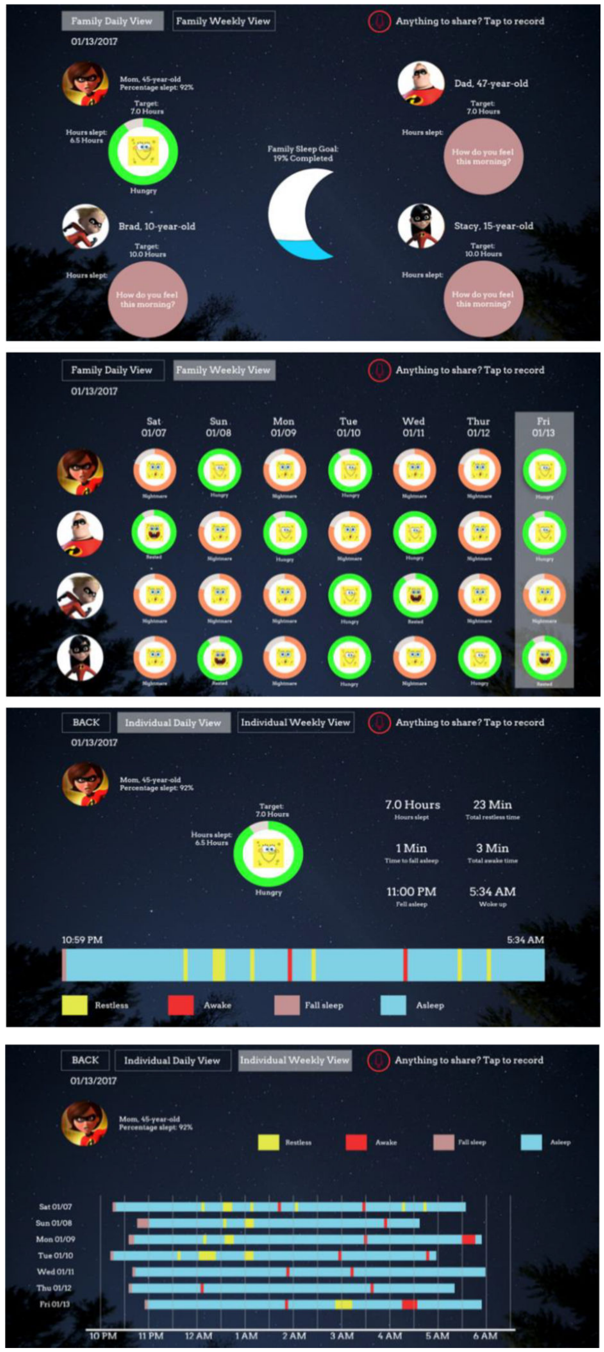

Figure 4.

Four views of DreamCatcher's high-fidelity prototypes used in feedback sessions.

a) *Family Daily View* showing an example of when one family member's sleep and mood is presented but information is missing for the rest of the family. The crescent-shape moon at the center fills in with blue as more sleep and mood information is collected.

b) *Family Weekly View* showing 7 days of data for every member.

c) *Single Daily View* containing one day of data. Sleep is represented as a ring and a bar. The bar contains bedtime, waketime, and movement during the night.

d) *Single Weekly View* showing a 7-day version of the Single Daily View.

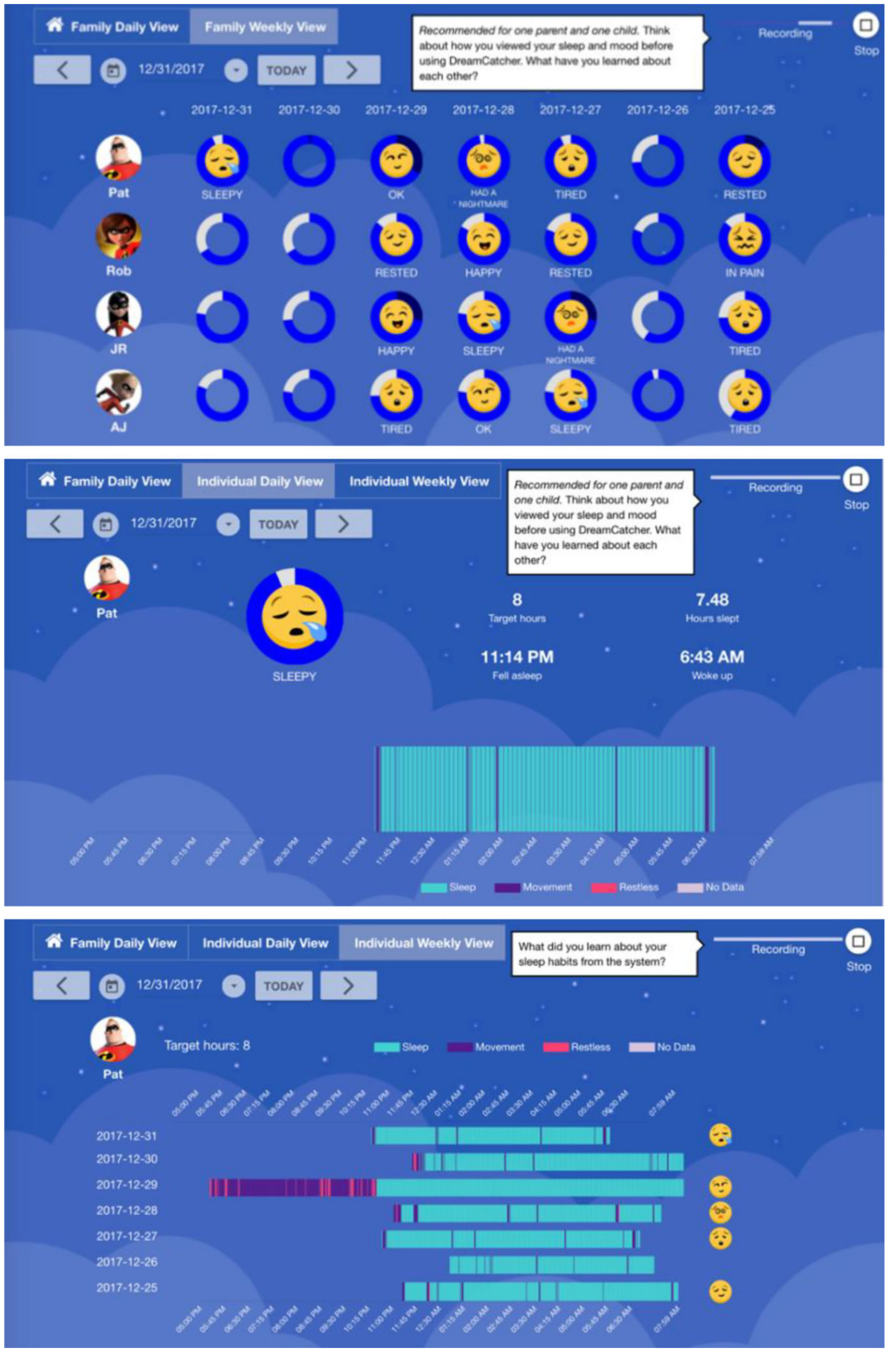

Figure 5.

Screens in the final design of DreamCatcher. Figure 1 also shows the *Family Daily View*. Each example also includes a reflective prompt and an indicator that audio is being recorded.

a) *Family Weekly View* with mood and sleep data. Rings without an emoticon in the middle represent days where mood was not reported.

b) *Individual Daily View* representing sleep as a ring and a bar.

c) *Individual Weekly View* representing sleep with bars.

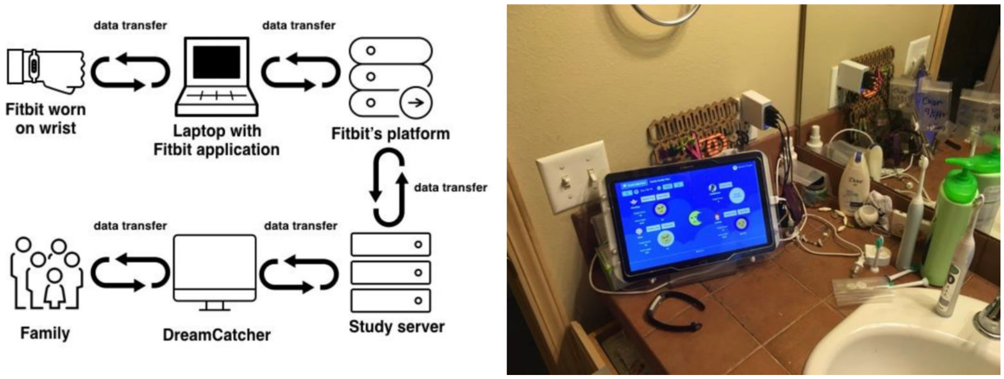

Figure 6.

Left: System overview; Right: DreamCatcher display kiosk shown in a family bathroom.

Figure 7.

Heatmap of interactions for each family. Rows represent the type of interaction (from top to bottom): audio reflection, mood reporting, and views. Each column represents a family, from right to left, Fam 1 represents Family F1 to Fam 10 representing Family10. The x-axis in each family column represents family members and the y-axis represents the day of the study. Dark green bars represent the days on which children interacted, light green represents days children did not interact, dark red represents days parents interacted, and light red represents days parents did not interact.

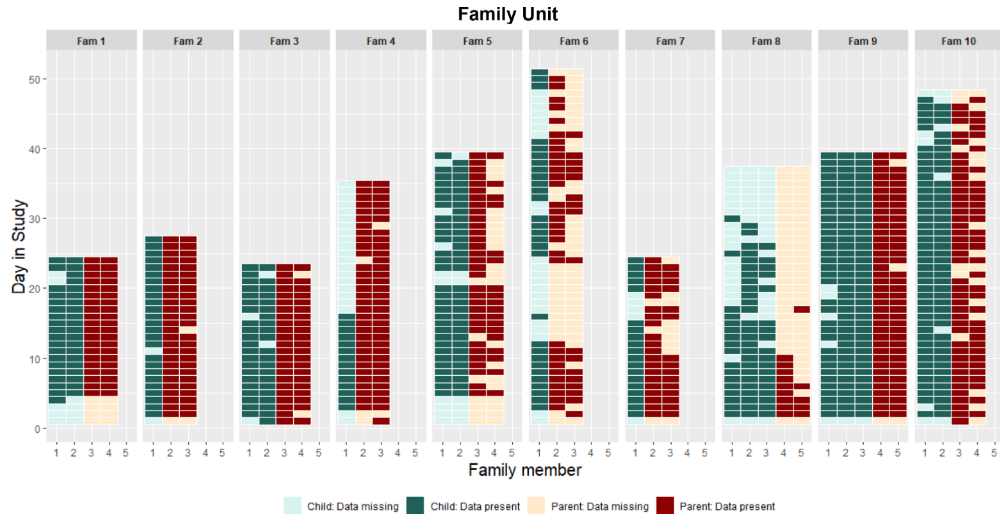

Figure 8.

Heatmap of sleep data captured. Dark green represents days when children interacted, light green represents days children did not interact, dark red represents days parents interacted, and light red represents days parents did not interact.

Table 1.

Reflection Prompts integrated in DreamCatcher.

ID	Prompt	Recommended For
1	What are you learning about your sleep habits?	Child or Parent
2	In what ways do you think you can improve your sleep?	Child or Parent
3	Look at another family member's **Weekly View**. Are they getting enough hours of sleep?	Child or Parent
4	Go to your **Weekly View** page. How is your mood with respect to your sleep?	Child or Parent
5	Go to the **Family Weekly View** page. Are there connections between each other's sleep and mood?	At least two family members responding together
6	Go to your **Weekly View**. How is your mood with respect to your sleep?	Child or Parent
7	What are you learning about how your family sleeps?	At least two family members responding together
8	Go to your child's **Individual Weekly View**. What information is surprising to you? What is expected?	Parents
9	How are you using the information you see?	Parents
10	What are your reactions to viewing every family member's sleep in one's place?	Child or Parent
11	Go to **Family Weekly View**. Talk to each other about what is good about your sleep.	At least one parent and one child
12	How are you using the information DreamCatcher is presenting?	Parents
13	Go to your **Weekly View**. Are you satisfied or dissatisfied with your sleep?	Child or Parent
14	What has surprised you so far?	Child or Parent
15	Go to your **Individual Weekly View**. Looking at the sleep bars. Are you going to sleep at a consistent time? What can you change about your bed time routine?	Child or Parent
16	Go to **Family Weekly View**. Is there a day where the family slept poorly (e.g., where the circles are not full)? If so, what happened?	At least two family members responding together
17	Go to **Family Weekly View**. Is there a day where the family sleep well (e.g., where the circles are mostly full)? If so, what worked?	At least two family members responding together
18	Go to **Family Daily View**. Pick a day where there is information. What are your thoughts on viewing the family in one place?	Child or Parent
20	How many hours are your parents sleeping? What surprised you?	Children
21	What has been surprising about your sleep?	Child or Parent
22	What has been surprising about your children's sleep?	Parents
23	Are each of you going to sleep at a consistent time? If not, what can you do to improve your bedtime?	One parent and one child
24	Are each of you waking up at a consistent time? If not, what can you do to improve your bedtime?	One parent and one child.
25	What is useful about viewing your children's and your sleep in one place?	Parents
26	How do you feel about viewing each other's sleep in one place?	Parents
27	What trends are you seeing about each other's sleep?	Parents
28	What are you learning about your children's sleep?	Parents
29	What are you learning about your spouse's sleep?	Parents
30	What conclusions are you making about your own sleep?	Parents
31	What conclusions are you making about your children's sleep?	Parents
32	Identify and share sleep improvements with your children.	At least one parent and one child
33	How do you feel about sharing your sleep with your family?	Children

ID	Prompt	Recommended For
34	Look at your sleep and tell us what you see. Where do you need help?	Child or Parent
35	Is there a day where most of the family reached their sleep goal? If so, reflect on what led to a good night sleep for the family.	Child or Parent
36	Is there a day where most of the family did not reach their sleep goal? If so, reflect on what you would like to do different.	Child or Parent
37	What are you learning about each other's sleep?	At least two family members responding together
38	What are days that you are proud about your sleep?	Children

Table 2.

Overview of study participants.

Family	Family Member	Age	Gender	Marital Status	Occupation
F1	Father	51–60	Male	Married	registered nurse
	Mother	41–50	Female		physical therapist assistant
	2 Children	11, 14 **			
F2	Father	31–40	Male	Married	game-data analyst
	Mother	31–40	Female		naturopathic physician
	2 Children *	8			
F3	Father	31–40	Male	Married	CEO of tech company
	Mother	31–40	Female		teacher
	2 Children	7, 10			
F4	Father	41–50	Male	Married	Boeing, assembly
	Mother	41–50	Female		stay-at-home mom
	Child	10			
F5	Father	31–40	Male	Married	banking
	Mother	31–40	Female		research consultant
	2 Children	7, 10			
F6	Father	41–50	Male	Married	engineer
	Mother	41–50	Female		stay-at-home mom
	2 Children *	7			
F7	Father	51–60	Male	Married	engineering manager
	Mother	N/A	Female		N/A
	Child	13 ***			
F8	Father	41–50	Male	Married	real-estate broker
	Mother	41–50	Female		office manager bookkeeper
	3 Children	8, 10, 12			
F9	Father	41–50	Male	Married	heavy-equipment operator
	Mother	31–40	Female		elementary instructional coach
	4 Children *	7, 11, 12			
F10	Father	41–50	Male	Married	firefighter, RN
	Mother	41–50	Female		RN
	3 Children *	10, 13			

* One child did not participate because he/she was younger than seven years of age.

** We recruited based on the age of the child who parents self-reported to have poor sleep quality. The second child was older than 12, but we did not want to exclude her from the study.

*** F7 Child turned 13 right after the family started the study.

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