Personal Dream Informatics: A Self-Information Systems Model of Dream Engagement

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ABSTRACT

We present the research area of personal dream informatics: studying the self-information systems that support dream engagement and communication between the dreaming self and the wakeful self. Through a survey study of 281 individuals primarily recruited from an online community dedicated to dreaming, we develop a dream-information systems view of dreaming and dream tracking as a type of self-information system. While dream-information systems are characterized by diverse tracking processes, motivations, and outcomes, they are universally constrained by the ephemeral dreamset—the short period of time between waking up and rapid memory loss of dream experiences. By developing a system dynamics model of dreaming we highlight feedback loops that serve as high leverage points for technology designers, and suggest a variety of design considerations for crafting technology that best supports dream recall, dream tracking, and dreamwork for nightmare relief and personal development.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; **HCI theory, concepts and models**; • **Applied computing → Health informatics**.

KEYWORDS

personal informatics, dreams, dreaming, dreamwork, dream tracking, dream journaling, dream informatics, self-tracking, mental health informatics, quantified self, self-information systems, system dynamics, reddit, survey

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1 INTRODUCTION

Dreaming is a fundamental component of the human experience. The extent to which dream experiences influence waking life, however, varies across cultures and across individuals. For the Ongee, an indigenous group on the island of Little Andaman in India, dreams are a kind of instruction or guide for what to do in waking life. For example, the group may decide to search for berries in a certain area of the forest based on intelligence derived from dreams [72]. Many Native American cultures have even been considered "dream cultures," given their emphasis on dream life even above and beyond waking life [54].

Perspectives on dreaming in Western cultures have been shaped by 20th century psychologists, namely Freud [27] and Jung [45], who saw dreams as an invaluable way to access the subconscious self. Modern-day therapists use the phrase "dreamwork" to describe a variety of therapy strategies that utilize dreams both in informal and formal (clinical) settings [36].

An important purpose of dreamwork is to reduce suffering from nightmares. While true nightmare prevalence is unknown [100], representative surveys of German citizens indicate that roughly 9–14% of the population experience nightmares on at least a monthly basis [79, 80], and 5% on a weekly basis [58]. Nightmare frequency is correlated with measures of well-being [98] and disproportionately affects individuals managing severe mental illnesses such as bipolar disorder, depression, anxiety, and post-traumatic stress disorder (PTSD) [77].

Apart from managing nightmares, dreamwork can be used for more general personal growth and development. Dreams can provide sources for creativity, aid in understanding the self, and help solve problems in waking life [38, 95]. While dream interpretation sessions are common in therapy contexts [46], individuals are also engaging with dreams informally as evidenced by the online communities dedicated to dreaming, such as Reddit's subreddits /r/dreams and /r/luciddreaming, which together have over 500,000 members.

Regardless of intention, if a dream is to be engaged with in waking life, some memory or record of the dream must be persisted beyond the time the dream initially takes place. This is notoriously difficult given the rapid memory loss that occurs after awakening from a dream [75]. For the Ongee, this challenge is overcome through cultural practices: group sleeping arrangements and morning/evening social routines serve to keep dreams in conscious awareness so they can be used for group decision making.

In Western culture, however, there is no clear solution to the challenge of dream memory loss. One known method of improving recall and persisting dream memory long enough for conscious

use is dream tracking [86], the process of creating some record of a dream experience upon waking up. However, clinical literature often treats dream tracking exogenously, noting only that patients "brought dreams into therapy" [39]. While prior work has described personal experiences with dream tracking, such as keeping a clipboard journal next to one's bed [6] or recommending the individual to lie still upon waking to improve recall [20], there is little research on effective dream tracking processes or characterizations of systems that support these processes.

Fortunately, the CHI community is well positioned to fill this knowledge gap. The research area of personal informatics [57] studies technology for self-tracking various kinds of data about the self such as physical activity, nutrition, mood, and sleep [23]. As the only way to access dream experiences is through conscious recollection after the fact, dreams present an interesting challenge for personal informatics and smart journaling [22]. Unable to rely on sensors or experience sampling methodologies, personal informatics systems for dreaming must rely on engaging individuals in the short period of time between the dream occurrence and the rapid dream memory loss that swiftly follows awakening. In addition, dreams contain perhaps every aspect of waking life, and maybe more, creating another challenge of determining what specific components of a dream experience to track.

Building on epistemic grounds that studied self-trackers ("quantified-selfers") more generally [12], we begin to study dream information systems by learning from the "extreme users" of dreaming—those who track their dreams on a regular basis, and/or who participate in communities dedicated to dreaming. Through an app review and survey of $N = 281$ individuals, $n = 115$ who have previously tracked their dreams, we seek to interrogate the following research questions:

RQ1: How can current dream information systems be characterized? What are the components and processes they maintain?

RQ2: What are the outcomes of dream information systems? What are the benefits and downsides of dream tracking? Why are individuals motivated to cultivate and maintain these systems?

RQ3: How can dream information systems be improved? What role(s) could new technology play in improving dream information systems?

Approaching dream tracking with the stage-based [57] and lived-experience [24] models of personal informatics led us to develop a self-information systems model of dream engagement that seeks to understand the entire system that supports the generation of knowledge of dream experiences. We call this the *dream information system*, the study of these systems *dream informatics*, and, interactive systems designed from this study *dream informatics systems* (in line with precedent of personal informatics and personal informatics systems [57]). While respondents noted a diverse set of motivations and benefits from dream tracking, all were constrained by the challenges of communication between the dreaming self and the wakeful self, characterized by rapid memory loss upon waking up [75].

Individuals have experimented with a variety of technical and non-technical methods for facilitating this communication between the selves. The sleep environment, where dreams are recalled, makes using traditional smartphone apps challenging, so individuals turn to analog methods or purely cognitive methods to track their dreams. We synthesize feedback from respondents about ideal dream-tracking systems, and contribute design implications for technology for supporting dream-information systems, along with future directions for personal dream informatics. Lastly, we close with a discussion on community dream informatics and how a self-information systems view might be a productive perspective for other applications within personal informatics.

2 RELATED WORK

2.1 Relevant Dream Theories

While there still remains debate about the nature and function of dreams [30, 42, 71], researchers have made progress using diverse methods ranging from neuroimaging [55], statistical analysis of coded dream reports [18], and survey methods (such as [83]). While dreaming has traditionally been associated with rapid eye movement (REM) sleep stages, sleeping mentation can occur in all stages of sleep [69]. However, the nature of this mentation varies based on sleep stage [8].

Dreams are hypothesized to be important for memory consolidation [89], simulation of potential threats [94], and building useful mental schemata [37]. Freud is noted for suggesting that dreams contain "day residue," content related to the particular experiences of an individual during the preceding day [27], which has been generalized into the "experiential incorporation hypothesis"—the idea that dreams contain reflections of our waking experiences [19, 87].

Perhaps most motivating for the conscious use of dreams is the *continuity hypothesis* [4], which suggests that dreams "enact and dramatize" the same concerns of waking thought [19]. This suggests that dreams can be a valuable source for learning about oneself, as the same self generates both waking thoughts and dreams. Indeed, statistical differences in dream reports seem to be indicative of qualitative differences between individuals' psychology [32].

2.2 Use of Dreams in Therapy

Psychologists have conducted applied research in the use of dreams in therapy, including the development of various protocols for improving outcomes with dreams [37]. A randomized survey of Florida Psychological Association members found that 83% of respondents utilize dreamwork in their practice at least occasionally [46], while another study found that therapists work primarily with a Fruedian or Jungian theoretical basis [82]. Dreamwork in therapy aligns with the cognitive–experiential model synthesized by Clara Hill [37], which views dreams as having a psychological origin, motivating dream tracking and interpretation.

Nightmare disorder is listed in the DSM-5, for cases in which nightmares cause "clinically significant distress or impairment in… important areas of functioning" [29], and this disorder affects 4% of the population [90]. Nightmares interrupt sleep, lead to difficulty falling asleep, cause anxiety during waking hours, and even increase the risk of suicide attempts [29]. Treatments for nightmare disorder include lucid dream therapies [28], image rehearsal therapies [52, 53], and psychiatric medications [90].

In dream rehearsal therapy, an individual is guided by his or her therapist to rewrite the narrative of a troubling nightmare such that it is no longer a nightmare, and then mentally "rehearse" the new dream in waking life for several minutes a day [33]. The intention

behind this therapy is that the improved and revised dream will begin to occur during sleep, instead of the recurring nightmare. This has been shown to result in a reduction of nightmares and improved overall psychological well-being [53]. Lucid dream therapies rely on developing an awareness that one is dreaming within the dream [28, 35].

Individuals engage with dreams beyond a simple desire to reduce the negative effect on their lives. In a therapy context, this engagement takes the form of dream interpretation sessions, which have been shown to both improve understanding of dreams and help relate dream experiences to the rest of waking life [38]. While individuals reported preferring therapist-guided sessions, self-guided sessions also resulted in significant therapeutic gains [36]. Outside of a therapy setting, a recent survey reported that individuals find dreams helpful for identifying unacknowledged problems, general insight into the self, and problem solving in various areas of life [68]. In addition, engaging in lucid dreams for personal growth reasons may be associated with greater life satisfaction and self-esteem [49].

2.3 Dream Recall, Tracking, and Sharing

A necessary, but perhaps understudied, aspect of dreamwork in both formal (therapist-led) and informal (self-guided) settings is that of dream tracking. In order to work with dreams in the waking world, some memory or record of the dream must be maintained. Dream recall, as measured via self-report, has been surveyed in multiple populations. Dream recall frequency appears to be stable in an individual across time (measured over a five-year period) [83], may be correlated with mental well-being [84], and is reported differently in retrospective vs. in-the-moment logbook reports [1, 2]. The relationship between dream recall and dream tracking is seemingly reciprocal [86]. A shared finding across multiple studies is that of the "logbook effect," which is that dream tracking generally improves dream recall [1, 78].[1] Dream recall may therefore be both a precursor for, and an ability improved by, dream tracking.

Dream tracking itself, however, is a relatively unexplored area of study. A recent study of 739 individuals found dream tracking ("journaling") to be a stable trait, but only undertaken regularly (at least once a month) by 2.7% of those surveyed (the sample was not representative) [86]. The same study notes that individuals often lose motivation for dream tracking after one week and that studying the motivational factors of dream trackers would be interesting, namely "why do they put such effort into recording dreams?" [86]. Part of our research seeks to answer that very question.

We do know that technology (broadly construed) is a component of dream tracking. Recording dreams using different technologies—for example, a voice recorder versus pen and paper—results in qualitatively different dream records. (The former has more words and details, the latter is more compressed and connected [10].) A cross-sectional survey indicates that about 5% of the general population engages in dream tracking in a given month [81], but the effectiveness, tracking methods used, and motivational patterns of these individuals is as-yet unexplored [86].

Dream sharing, as a social practice, is better documented. Dream sharing is generally undertaken due to reported feelings (real or aspirational) of trust and closeness to those with whom the dreams are shared [43], and may be triggered by dreams with increased levels of emotional intensity [15]. Dream sharing can increase levels of empathy towards the sharing dreamer [5], perhaps due to the closeness necessary to disclose vulnerable or taboo dream content [43]. Dreams are most commonly shared to partners (79%), followed by friends (43%), relatives (40%), colleagues (22%), kids (17%), and therapists (3%) [67].

Through dream sharing, dreams become a subject for collective sense-making, both between trusted contacts and within anonymous online communities. In the Reddit subreddit /r/dreams, it is common for individuals to post dream reports for the purpose of yielding additional perspectives about the meaning of the dream. In this case, social media technology is mediating, and therefore shaping, the collective sense-making process. This suggests another avenue for study within dream informatics: how can technology best support social interaction involving dreams? This is another question we explore through our qualitative survey, which largely draws on the population of the subreddit, which is a convenient source for research participants from specific communities [88].

2.4 Technology for Supporting Dream Tracking

The study of technology for dream tracking is nearly non-existent. A design study for sleep tracking technology noted that individuals desired a feature for recording dreams[11], but dream logging is presented as a simple, self-evident feature [48]. We suggest otherwise: that dream tracking is a poorly understood and nuanced process, lightly evidenced by differences in attributes of dream reports recorded via voice recorder versus written text [85]. The closest related areas within computing research are dream engineering and smart journaling.

Dream engineering addresses the sleeping body as an interface to (and means of manipulating) the dream experience [8, 9, 31]. In line with this perspective are devices designed to incubate specific dream content [31] or to induce lucidity [63]. Dream tracking has not been studied under the scope of dream engineering.

Perhaps the closest related area of study within HCI is that of smart journaling [22] and other "technologies of memory" [96]. These technologies seek to help individuals in "lifelogging" experiences such that they can create detailed records of their life and reflect back upon these records. Smart journaling emphasizes flexibility [3] and capturing narratives alongside objective data [40]. This kind of journaling is often done for the sake of journaling itself (the "experience of writing") [22].

Unlike the "documentary informatics" [21] of waking life experiences, dream experiences do not provide the dreamer with objective sources of media to curate into a cohesive narrative, nor can dream experience data be collected autonomously with sensors like smart journals do [22]. Rather, the individual must consciously recall the dream and create a record of the experience upon awakening. While some question the validity and accuracy of dream reports [97], they remain the only source of bringing dream experiences into waking life.[2]

[1] This can be considered a type of *reactivity effect*, where the act of measuring changes the thing being measured, and often in a desired direction [25, 61].

[2] This may change, as recent lucid dream studies have evidenced two way communication in and out of a dream (lucid dreamers were read math problems and signaled answers back via eye movements [50]).

In this study, we seek to turn the lens of personal informatics on the experience of dreaming and dream tracking, with the goal of learning how technology might support dream engagement. We pull from stage-based models ([24, 57] of personal informatics to explore barriers and motivations to dream tracking. Our epistemological approach draws from previous studies of *quantified selfers*, seeking to better understand the "extreme users" [12] and the tools they build and use. In our case, we look to understand all kinds of dream trackers, but specifically pay attention to those who are most actively engaged in dream tracking.

3 METHODS

3.1 Survey Design

To shed light on the three research questions, our primary methodology was a qualitative survey. In drafting the survey, we relied on wording from the US Census for most demographic questions, and we collected age, occupation category, gender, and ZIP code (as a proxy for geographic location). ZIP code was not used in the analysis due to the uneven respondent density across the reporting ZIP codes. We also collected basic information about dreaming, such as the respondents' attitudes towards dreams (ATD) [38], dream recall frequency (DRF) [99], dream tracking frequency, and most recent dream (MRD) reports (similar to that described by Domhoff [18]). These questions enabled us to segment the population by level of dream engagement and dream tracking.

For **RQ1 (characterizing dream information systems)**, we sought descriptions of systems and processes for dream tracking, including the environments in which they operate. As such, we asked questions about the environment of both recall and sleep, including sleep hygiene (with questions derived from the sleep hygiene index [60]), the location of dream recall, which tracking tools and processes were used, processes for sense-making dream journals, and how dreams were communicated to others.

For **RQ2 (outcomes and motivational factors for dream information systems)**, we sought individuals' perspectives on dreaming and dream tracking. We asked individuals why they started and continue to track dreams, the benefits of dream tracking, negative aspects and challenges of tracking, and motivations for sharing dreams with others.

For **RQ3 (desired improvements and technology implications)**, we asked individuals what they would like to improve about their dream-tracking process, what features they would like in a dream-tracking application, and their current perspective on technologies for dream tracking.

The complete survey text can be found in the supplementary material [3]. The survey logic was designed such that individuals were only prompted with relevant questions. For example, questions asking for details about dream-tracking processes would not be asked to an individual who has never engaged in dream-tracking. The survey took roughly 5 to 20 minutes to complete, depending on the particular survey flow followed. Lastly, the survey contained proactive measures to assist with data integrity. All respondents had to fill out a reCaptcha before taking the survey, and were subjected to an attention check (screener) question [73] that we used to help detect and discard responses generated by robots and inattentive respondents.

[3]Note that not all survey items are analyzed in this paper; the survey is part of a larger line of research inquiry.

3.2 Survey Recruitment

As one of the primary goals of the study was to map the current practices of dream tracking, our population of interest was those who have recorded their dreams before. To reach this targeted population, we recruited heavily from online communities dedicated to dreaming (a general recruitment strategy suggested by [88]), particularly the Reddit subreddits /r/dreams and /r/luciddreaming. In order to compare trackers and non-trackers, we left the survey open to any individual over age 18 from anywhere in the world. To broaden recruiting to members of the general population, we utilized various Slack channels, Twitter, Facebook, and email to advertise the survey study. Respondents were prompted to select how they found the survey so that we could segment the population, if needed. Two $100 gift cards were raffled to provide incentive for respondents who successfully completed the survey. The design of our survey and procedures for participant recruitment were reviewed and approved by the Institutional Review Board at the University of Colorado Boulder.

3.3 Survey Data Analysis

Before analysis, data was cleaned to remove duplicate submissions and obvious bot-generated responses (based on the attention-check question and examination of open-ended responses). We segmented the population into those who have previously conducted dream tracking, and those who haven't. Quantitative summary statistics (demographics, sleep hygiene index, and attitudes towards dreams) were computed using Python and Pandas. Open-ended qualitative questions were coded in MaxQDA following an iterative open inductive coding process [13] conducted by the first author and reviewed and iterated upon in consultation with the other authors.

3.4 Dream Tracking App Review

Despite a lack of presence in the computing literature, technology designed for dream tracking does exist. As we could not find any suitable review of current off-the-shelf dream tracking systems, we briefly conducted our own in order to assess the extent to which respondent feedback aligned with currently available technology. Our review involved a search for the most written about and reviewed applications in the Apple app store and Google Play Store. The six most popular iOS apps were chosen for a content analysis. Two of these were iOS specific, and therefore we added three popular Android-only apps to the analysis to avoid introducing a platform bias. We downloaded and reviewed the features of each application using a custom checklist of application features. A full report with screenshots is available in the supplemental material, and a summary table is presented in the results.

One particular application, Dreamboard, contained many reviews suggesting a loss of dream data when the application went offline. To highlight the importance of privacy and data protection for dream reports (which is a non-traditional kind of personal information), we scraped 394 Dreamboard reviews from the Apple app store and hand-coded each review with a label if it mentioned lack of access to dream data. A scatterplot of the review ratings

across time, colored based on data loss annotation, is presented in the results.

3.5 Cross-Cutting Data Analysis

In seeking to characterize dream information systems, different components of the system were identified from the survey responses. These components helped inform a high-level pictorial diagram of dream information systems which helps to represent key elements of the dream information system design space. This model was further elaborated by constructing a stock-and-flow diagram using causal loop modeling, drawing from the field of system dynamics [91]. The causal structure of the model was developed in an iterative process of synthesizing survey results describing benefits and downsides of dream tracking alongside findings from the dream and sleep science literature. Both models were informally discussed with a licensed psychologist having experience practicing and researching dreamwork in a therapeutic context.

4 RESULTS

In this section, we briefly present the demographics of our respondents, as well as a summary of responses to the open-ended questions. As many of the questions in the survey were not required, or not asked based on the particular survey flow, the number of respondents varies for each question. Fractions of respondents are shown based on those who answered the particular question. The total number of respondents, after removing duplicate submissions and bots, was $N = 281$.

4.1 Respondent Demographics and Basic Dreaming Info

First, we characterize the participants who responded to our survey. Respondents self-reported finding our survey through Reddit (67%), Email (7%), Twitter (8%), Word of Mouth (8%), and other (10%) (N=265). Respondents hailed from the United States (75%), the United Kingdom (3%), Canada (3%), Germany (2%) and, in much smaller numbers, 30 other countries (17%) (N=263). The reported gender distribution of the sample is female (55%), male (39%), and other or unspecified (6%) (N=265). The age distribution of respondents is 18–24 years old (42%), 25–34 years old (36%), 35–44 years old (11%), older than 45 (6%), and unspecified (5%) (N=265). The reported race/origin is White (65%), Hispanic (7%), Black (3%), Asian (8%), other (8%), and multiracial (9%) (N=265). Reported occupations include: students (37%), work for a non-profit (13%), work for a for-profit (25%), unemployed (8%), self-employed (11%), and other (6%) (N=254). 41% of respondents reported having tracked their dreams in the past. Among those, there was a wide distribution of age of first dream recorded, as shown in Figure 1. Figure 2, highlights how dream trackers vary in their frequency of tracking.

4.2 Characterizing Existing Dream Information Systems

4.2.1 Sleep and Dream Environment. Dream information systems are coupled to individuals' sleeping (and therefore dreaming) environments. Our survey results highlight a diversity of sleep hygiene behaviors, and a diversity of conditions in which individuals sleep

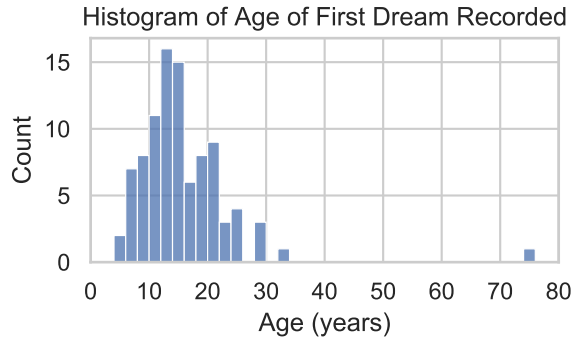

Figure 1: Individuals begin dream tracking at different ages.

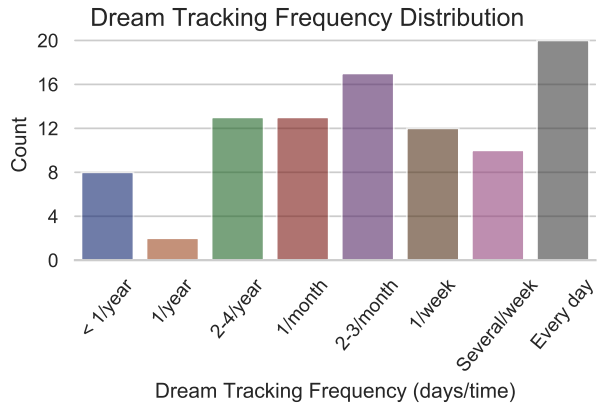

Figure 2: Some individuals track dreams more frequently than others.

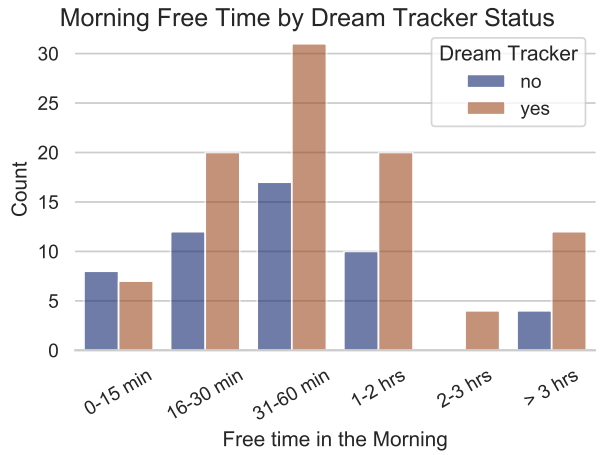

Figure 3: Many dream trackers have significant free time in the morning.

and dream. As seen in Figure 3, respondents have varying amounts of free time in the morning during which they can recall and record their dream experiences. Some have almost no time to engage with and record their dreams; others have hours. It is noteworthy that many dream-tracking respondents reported having a significant amount of morning free time.

The type of alarm used also varied. 67% of 150 reporting respondents wake up naturally without a signal or via sunlight. 65% reported using alarms on their phone, and 7% reported utilizing a standalone alarm clock. 27% of individuals reported being awoken by a pet or another person in the morning.[4]

Dream recall largely occurs in bed or in the bedroom (76% of 158 respondents), with fewer recalling elsewhere in the house (6%), while travelling (2%), at work (1%), or elsewhere (1%)[5]. This is no surprise given the rapid dream memory loss that dream tracking must handle.

These results help to illustrate the universal and divergent characteristics of dream information systems. Nearly all are situated within the bedroom and in the bed, due to dream memory loss shortly upon awakening. However, individuals have different levels of "free time" in the morning, with which they could engage in dream tracking, and have varying waking prompts/experiences.

4.2.2 Tools and Processes Used for Dream Tracking. 94 respondents reported significant diversity in dream-tracking methods, both across and within individuals. Similar to findings about the quantified self community [12], dream trackers experimented with multiple methods of tracking, and changed methods over time. 31% of 94 respondents reported using more than one method for dream tracking. For example, individuals used multiple methods to account for different environments in which the dream was recalled ("I write them down … sometimes on my PC when I suddenly remember a particularly interesting dream at work" R33), or as they experimented and discovered what worked best for them. For example:

> I have used multiple methods. I used to write down my dreams verbatim the moment I woke up. I eventually moved onto audio recordings on my phone because writing was tiresome upon waking up. I moved from audio recordings onto just trying to make mental notes and that works, but poorly and many dreams slip. I now write very short hand bullet points of events and feelings in a notepad physical or on my phone instead of full transcriptions and this is sufficient to reconstruct the dream later as necessary. (R134)

The most common method for dream tracking is the use of a physical notebook, journal, or diary (51%). The second most common method for dream tracking was using a generic notes app on the smartphone (34%), such as Apple Notes or Google Keep. Other methods include general tracking on a computer with Google Docs or another rich text editor (10%).

Social practices were also a commonly cited method of tracking. 9% of respondents noted their tracking involved speaking to other individuals ("I openly talk about them nearly every day with friends and family" R142), and another 5% mentioned sharing dreams to social media (a common practice in the /r/dreams subreddit).

Multiple respondents (5%) noted that they did some kind of mental tracking without using any physical record. One respondent noted the use of the method of Loci, an ancient technique that encodes information in visual "memory palaces." This same technique has been used to help individuals suffering from depression remember self-affirming memories [16].

4.2.3 Processes for Analysis and Reflection on Dreams. 39 respondents reported various methods for analyzing dream experiences, including external interpretation, interpreting independently following traditional practices ("Dialectical Analysis derived from Platonic and Buddhist experiences" R134), and general cognitive or self-reflective methods. One respondent described their method as: "a big thought-soup about my life and all my experiences and the deep web of thought and emotion and memory that connects everything to everything" (R131).

It's important to note that only 4 people reported using explicit quantitative analysis ("counting the number of dreams, the number of lucid dreams" R57), and when they did it was largely goal-oriented, for example: "I look at my frequency of nightmares during a given week and then try to understand why they occurred. Maybe I was super stressed for uni exams etc." (R153).

Another common method was utilizing dream dictionaries to aid in interpretation of dreams (23% of 39 respondents). But the overarching theme across responses was that dream analysis, or "dream work," was largely personal, and can occur entirely cognitively, or perhaps socially, without any sort of auxiliary technology. Unfortunately, respondent R165 was not alone in being "unsure how to describe that [dream analysis processes] by text." The cognitive component of reflecting on and working with dreams appears to be difficult to put into words.

4.3 Motivations and System Outcomes

4.3.1 Reasons for Dream Tracking. 96 individuals expressed a variety of reasons for starting dream tracking. The most commonly cited reason (33% of 96 respondents) stems from having vivid dream experiences, either along the lines of having "persistently funky dreams that I wanted to remember and/or understand" (R26) or when dreams were affecting waking life, such as being "vivid and too negative not to pay attention to" (R232). Other commonly cited reasons included to learn to lucid dream (19%), to better remember dreams (16%), and to better understand oneself (16%). Respondents described a natural intrigue leading to tracking, which may not necessarily be tied to a nameable purpose, for example: "I'm not quite sure [why I started tracking dreams] to be honest. I think I started to feel that sometimes there were moments, visions, feelings, inspirations and insights from my dreams that I didn't want to lose to time" (R78).

To some, dream experiences may be seen as "the MOST interesting events I was experiencing" (R61) or "more exciting than reality" (R194), and dream tracking is a way for individuals to retain stronger memories of these valued experiences: "When I read the dream entry the images appear in my head again and I can remember it almost exactly as it happened" (R113)

[4]Individuals could report more than one alarm-style, so percentages sum to over 100%.
[5]The remaining respondents reported recalling dreams generally "at home."

In addition, dream experiences provide material for creative endeavours. Respondents reported dreams provided inspiration for drawing, painting, and "a lot of original material for creative writing prompts" (R110).

Some seek to change their dreams to reduce the trouble they might cause, e.g., "I wanted to learn to control dreams, so that I have more happy dreams" (R162). Respondents report dream tracking immediately helps with sleep ("writing down nightmares allows me to calm down enough to fall back asleep" R146) as well as helping unpleasant dreams or nightmares the following day: "Normally I wake up with pretty bad feelings after a nightmare and can take up to a whole day to emotionally recover. Going through the dream over and over again and telling it to people I know and trust helps me with feeling better" (R162).

The common desire to *lucid dream* resonates with the intentions of Tibetan Dream Yoga, which seeks to extend mindfulness and meta-awareness to all aspects of cognition, including those occurring while asleep [47]. Dream tracking supports lucid dreaming through a focus of attention: "By keeping a log of my dreams and remembering as much as I can about their contents I am able to become aware of when I am in a dream" (R176).

Lucidity can help individuals change dreams for the better [28, 35], as well as provide an environment for improving particular skills [26] ("spend my time while sleeping doing things like practicing piano or chess or problem solving" R31), or solving practical problems ("I work in engineering and often find solutions to puzzling topics during my early morning dreams" R172).

Others, still, expressed a desire to learn from their dreams:

> I had noticed patterns in my dreams. I also wanted to see if interpretation of those dreams would give me some insight into my sub-consciousness, leading to answers or solutions to problems I face. (R174)

> I have learned so much about my unconscious self. I generally struggle to acknowledge what's bothering me, and dreams provide a unique window into my unconscious. (R64)

We observed a diversity of reasons that individuals engage in dream tracking. All reasons, however, rely on improving the memories of dream experiences or improving dream recall. A simple charge for dream informatics is starting to emerge: helping people to remember their dreams. Now we turn to the challenges of dream tracking that were identified by survey respondents.

4.3.2 Challenges and Barriers to Dream Tracking. 97 respondents shared a handful of common perspectives about challenges and downsides of dream tracking. Individuals reported similar barriers that are present in other self-tracking domains, such as the struggle of building the habit of tracking. 18% of individuals said that dream tracking was time consuming and, moreover, time consuming during very inconvenient periods (i.e., interrupting sleep):

> Sometimes I am interested in what my dreams can tell me. Other times I think that I would not have any time for my waking life if I considered all of my dreams. (R28)

> About half of the dreams I am able to write down I am woken by in the middle of the night, so I'm extremely tired but force myself to stay awake to write down a dream and it might take like 20-39 minutes and it's 3am and I'm dying to go back to sleep. (R129)

This challenge can be compounded due to the sleep-interrupting light emitted by the smartphones that participants reported using to record dreams ("the light of my device bothered me if i had woken up in the middle of the dream" R33).

The most commonly reported challenge of dream tracking (23% of respondents) was the difficulty in remembering dreams upon awakening ("The more you think about it the more it seems to slip away from you." R174). Individuals also noted how dream memory fades quickly ("Recording them immediately when I wake. I often wait a bit and forget parts of my dreams" R172). Individuals also expressed frustration at the difficulty of capturing dream experiences, such as:

> It's really really difficult to put my dreams into writing in the detail that I remember them, with all the colors and the feelings and the way things occurred. "All of a sudden I was in this blue house" doesn't actually convey how the dream transitioned or how I remember it, but there's no other way I can describe it sometimes. (R164)

Another respondent described a similar challenge of "articulating non physical and inter dimensional experiences through language" (R63). This challenge of "articulating experiences through language" is also relevant in the subsequent section reporting the diversity of dream-tracking methods employed.

Perhaps the most surprising perspective was that *the experience of dream tracking has the same valence of that of the dreams, themselves.* Tracking negative dreams can be a negative experience, as one respondent noted: "recalling/accidentally reading old nightmares is unpleasant" (R146). This theme, of *keeping negative dreams alive* was the third most-cited challenge (14%) of dream tracking: "That chronic nightmare is bad enough on its own, i don't want to explore it further and see something or image [imagine] something I don't want to" (R137).

Respondents voiced other concerns about negative experiences of the recording process, for example: "sometimes it's a little stressful when I'm writing down a dream and forgetting it as I'm typing" (R60). Individuals also expressed concern about over-analysis of dreams, focusing too much on the dream world instead of reality, and "...find[ing] meaning where there is none" (R130). Individuals also expressed social concerns, such as "waking up my partner who sleeps next to me sometimes" (R69) and that "some people think I'm weird because I post about my dreams on social media" (R5).

Despite the downsides, 80% of respondents (126/158) said they still wanted to engage with their dreams more. As we see next, individuals have a variety of suggestions and ideas about how technology could help mitigate the identified problems.

4.4 Perspectives on Technology for Dream Tracking

40 individuals reported a variety of desired improvements to their current dream tracking processes. Most commonly, individuals wanted to be able to categorize or tag their tracked dreams (23%) and to allow for different types of modalities of dream recording (28%).

Table 1: Dream Tracking Feature Availability by Application

Application	Entry Type			Entry Specifics		Past Dream Entries			Other Features				Platform	
	Voice	Text	Image	Dream Tags	Date	Data Viz	Export	Interpre-tation	Notifi-cations	Dream Sharing	Educational Content	Journal Lock	Android	iOS
Capture-Your Dream Journal		✓	✓	✓	✓	✓	✓	✓			✓			✓
Dreamwall		✓		✓	✓			✓		✓				✓
Dreamboard App		✓		✓	✓	✓							✓	✓
Dream Journal Ultimate		✓		✓	✓		✓		✓	✓			✓	✓
Lucid-Dream Journal	✓	✓		✓	✓	✓			✓		✓		✓	✓
Lucidity	✓	✓		✓	✓		✓	✓			✓	✓	✓	✓
Dream Journal and Lucid Tool		✓		✓	✓	✓			✓			✓	✓	
Dream Dictionary and Dream Journal	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	
Awoken - Lucid Dreaming Tool	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	

Individuals expressed interest in recording drawings, handwritten notes, voice, and video to capture the content of their dreams.

15% of reporting individuals expressed a desire to receive reminders to record in the morning, although one noted a universal challenge of dream tracking: "I think the only way to improve it would be to be woken up slightly and asked what I'm dreaming about. But I'm not sure I could even speak clearly in that state. Sometimes I can't stay awake enough to type them or it looks like gibberish" (R111).

13% of individuals wanted the ability to track other information about their waking life, including physiological and behavioral data that might be relevant to the context in which dreaming occurred ("Adding EEG info, medications taken before sleep, notes about mental state prior to sleep" R106). Others sought general improvements in organization and search capabilities, such as, "If my writing could be digitized so I could run a search through my dreams, that would be perfect" (R64). Individuals also wanted dream-tracking systems to support low-effort dream recall: checklists, large symbols for tapping, and prompts to guide the collection of various meta-data about the dream experience.

4.4.1 Dream Tracking App Review. The results of our content analysis of dream-tracking apps is summarized in Table 1. The majority of dream-tracking apps are effectively note-taking applications, intended for the user to record and save text-based dream narratives. Some apps allowed for the collection of metadata about the dream, such as the date it was dreamt or the emotional state of the dreamer before falling asleep. Some apps included prompts for certain dream aspects, such as dream-level tags to annotate dreams as being nightmares, lucid dreams, or that they contained certain emotions, etc. Some apps provided (manual) interpretation dictionaries, which are explicitly warned against by Hill, as the meaning of dreams are dependent on (i.e., personal to) the dreamer [37]. The last feature noted was the inclusion of educational material about dreaming, and, in particular, strategies for inducing lucid dreams.

70 respondents provided feedback on features they would like to see in a dream tracking application. The following desired features were not found in any current dream-tracking app that we reviewed:

- automated method for extracting specific dream information, like location, character, emotion
- specific prompts for reflection ("asking about… what role they play in your life" R251)
- allow for tracking of physical sensations upon waking up ("did you wake up sweating, laughing, crying, with heart palpitations, with tense muscles, in sleep paralysis, with pain somewhere, etc" R87)
- hand-written narratives understandable by computers (such as via optical character recognition)
- allow for storyboarding of events in the dream
- video recording
- store character details
- facilitate mixing multiple images with text
- built-in sleep tracking
- timeline to "maintain the chronological narrative of the dream" (R134)
- share with those who have similar dreams

Apart from missing features, individuals noted that current apps have less-than-ideal user interfaces: "The additional features not directly connected to note taking are obnoxious but I can't change the app out of fear of losing the stuff I've already written down" R158.

The quote from R158 highlights a recurring theme in that the individuals who track dreams value privacy and the protection of their data. During our app review, we noticed a slew of negative reviews about one app in particular, *DreamBoard* [44]. DreamBoard was taken offline, and based on the reviews, many individuals lost their dream reports. For example, Figure 4 shows a review highlighting the value placed on long-term collection of dream reports.

Figure 5 further highlights the impact that this loss of data had on the user experience. There is a sharp decline in ratings around

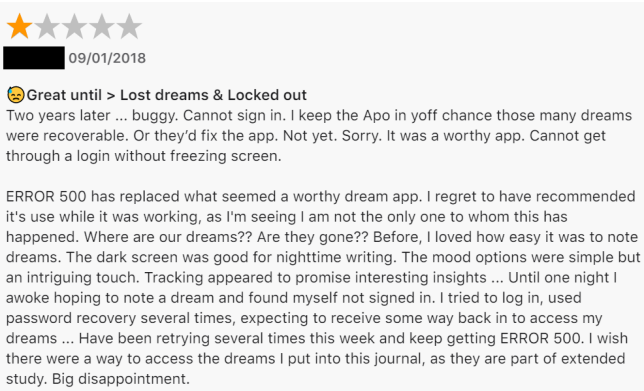

Figure 4: A review from a user of the DreamBoard app, having lost their dream records.

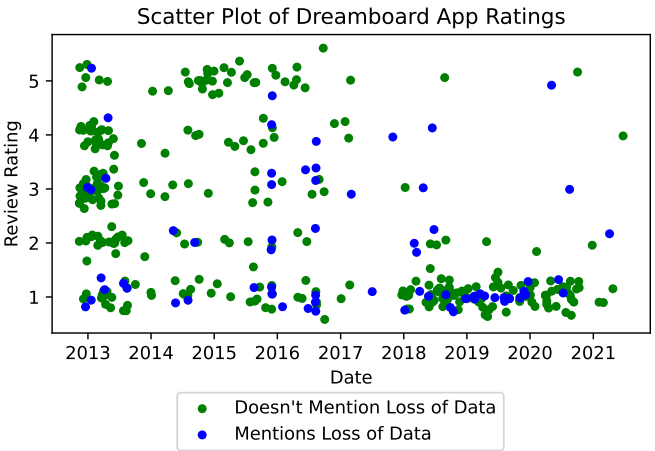

Figure 5: A scatterplot of Dreamboard app reviews over time. Highlighted points indicate reviews that mention loss of access to dream report data (68/394 mention data loss).

2017 when the app seemingly went offline. While dream reports stored in commercial applications are not protected health data, individuals still value them. The irreplaceable nature of dream content necessitates technology designers carefully consider how dream reports are saved, kept private, and persisted for users.

5 DISCUSSION

5.1 A Self-Information Systems View of Dream Tracking

Based on a holistic synthesis of our survey response corpus, it is clear that existing dream tracking practices cannot be understood solely by studying a particular digital technology. The majority of respondents preferred to use paper-based, handwritten notes for dream tracking, and some relied purely on cognitive methods of memory and engagement. This contrasts with the traditionally technology-centric views of personal informatics, which focus on identifying the barriers in different stages of engaging with self-tracking technology [24, 57]. This dissonance led us to increase the scope of our study beyond solely examining the roles of and designs for technology to include the entire system that maintains processes for dream engagement.

We began to understand dreaming as part of a system for learning about the self—*a self-information system*. Some dream experiences are remembered consciously, while others are forgotten. Dream tracking is a way of persisting memories of the dream experience into the future, facilitating communication between the dreaming self and the wakeful self, a type of technology of memory [64, 96]. Dream experiences are only accessible during the ephemeral *dreamset*, after which rapid memory loss causes the experience to fade from memory [75]. By engaging with dream experiences, dreaming can be a way to better understand and learn about oneself, and is facilitated by what we are calling *dream information systems*.

Survey questions addressing **RQ1 (characterizing dream information systems)** helped to reveal the different components of these systems: a collection of tools, processes, behaviors, and environments that support persisting dream experiences into long term memory. Figure 6 highlights the major components identified of dream information systems: sleep–wake environments, social contacts (close relations, online communities, and therapists), and dream-tracking technologies, all serving to facilitate (or hinder) engagement with dream experiences, including the persistence of memories of dream experiences.

Indeed, it is likely that everyone is embedded in some sort of dream information system; anyone who has any amount of dream recall engages in some level of communication between their dreaming self and their wakeful self. Our present study of dream enthusiasts is therefore focused on those who intentionally cultivate and maintain dream information systems for some conscious purpose. To expand on the model above, we pulled from methods in system dynamics [91], creating a mock-up of a stock and flow model to highlight various feedback loops present in dream information systems, shown in Figure 7.

5.1.1 A Stock and Flow Model of Dreaming. A stock and flow model (Figure 7), using causal loop diagrams, helps to highlight the various feedback loops present in the system. This (non-simulatable) model was developed as a synthesis of the survey respondents and the literature on how dreaming affects an individual. Dreams flow from the source cloud on the far left, into the various stages of dream tracking, and into "sinks" represented by clouds. In this model, all dreams are experienced, and only some are recalled after the experience. While scientists currently debate the function of dreams, dreaming has been shown to help with memory consolidation [89], simulation of threats [94], and to generally support mental health and well-being [41]. Dreaming has these effects regardless of recall or persistent memory of the dream [30], and therefore experienced dreams increase the *effect of dream experience on self*.

While the exact mechanisms of dream generation is under debate [70], longer periods of sleep (*average time asleep*) allow for more dreaming (*dreams per night*). In the model, we draw from our survey results which suggest that dream tracking can interrupt sleep ("More likely to wake up in the middle of the night from a

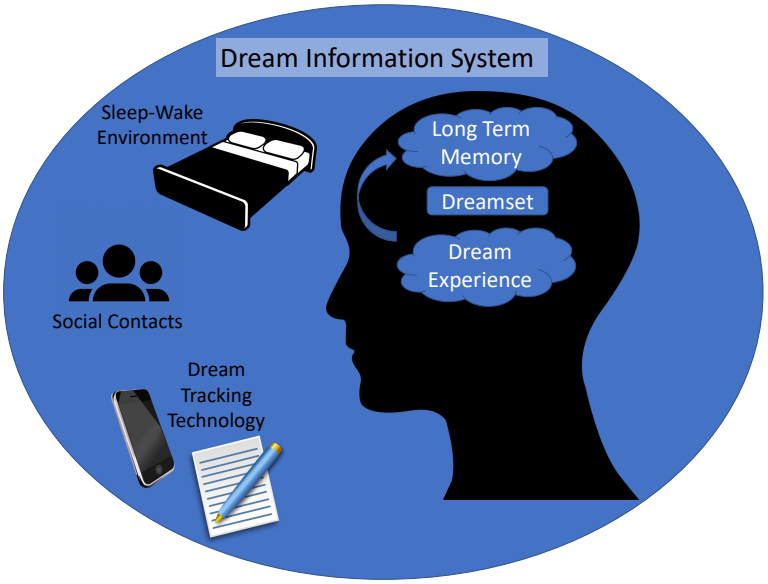

Figure 6: A dream information systems model of dreaming and dream tracking. Dream information systems are constrained by the ephemeral "dreamset," the short period after waking and before dream memory loss. The sleep environment, social contacts, and tracking technology facilitate dream engagement in waking life.

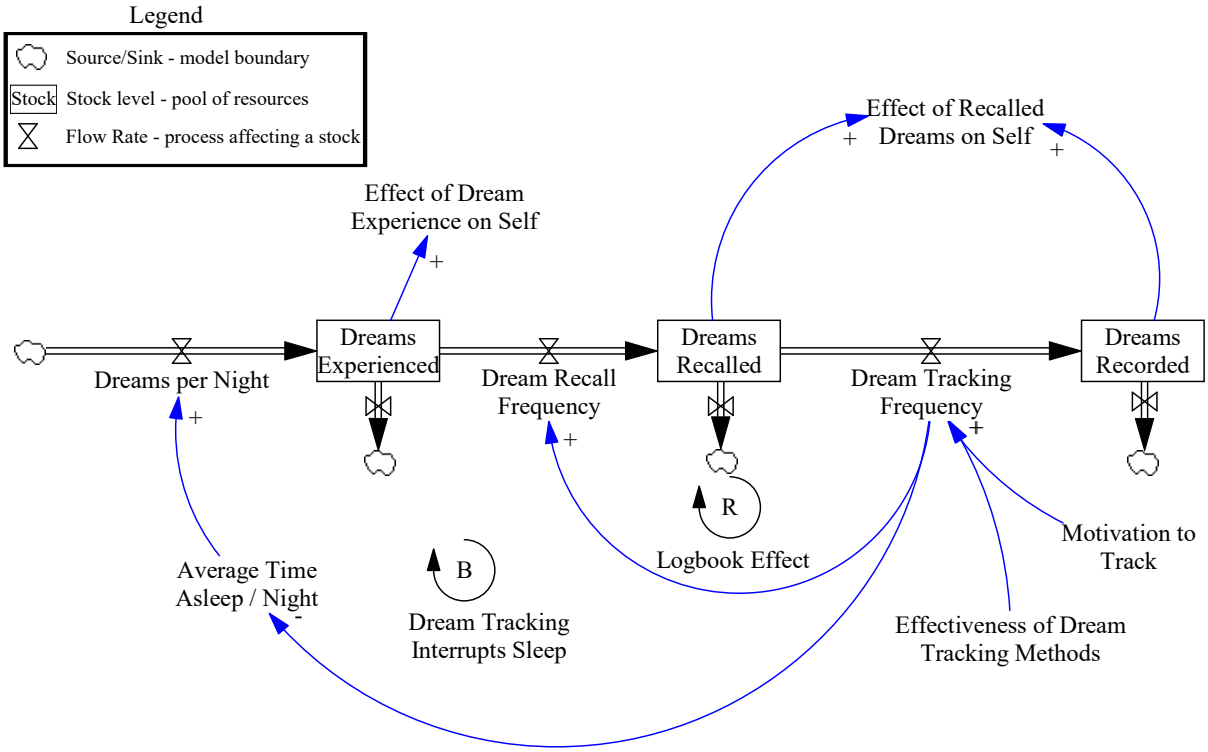

Figure 7: A stock and flow model of dream information systems. Dreams flow from the left source to the right. Dreams are experienced, then potentially recalled and tracked. The Logbook Effect loop serves to reinforce dream recall, mediated by motivation to track and effectiveness of dream tracking methods.

dream. Then you have to write down the dream while you are super sleepy or you will forget it. This can make it harder to go back to sleep." -R93), which may reduce the number of dreams experienced. This relationship is not straightforward, in fact, if interrupting sleep simply delays sleep (a technique recommended to increase REM sleep by LaBerge and Rheingold [56]), then the number of dreams experienced may actually increase. This model simply reflects the downsides of dream tracking suggested by our survey respondents, and assumes a consistent sleep window in which sleep interruptions reduce the time available for dreams to occur.

Dream recall enables dreams to have what we are calling an *effect of recalled dreams on self*, meaning that the dreams are engaged with in waking life, consciously, aligned with Hill's view of dreamwork in therapy [37]. Recalled dreams that are not recorded can affect the self simply by remembering the experience itself ("For the next week or so I experienced an incredible feeling of peace and acceptance" R64 or "They leave me feeling uplifted during the day" -R72). Recording dreams enables additional effects on the self, for a variety of reasons such as improved memory ("I can remember the dream later once it's been cemented in my mind by writing it down." R164), bringing an accurate dream report into therapy ("I can tell my therapist about the dreams that bother me the most" -R162), and finding patterns across longer time scales ("I could notice patterns about my dreams" -R31).

Motivation to self-track (part of "deciding" in Epstein's stage-based model [24]) is an important factor in the system. Dream tracking frequency is modulated by both attitudes towards dreams (*motivation to track*) [14, 86] as well as the *effectiveness of dream tracking methods*. As mentioned in the results, individuals reported different outcomes and experiences from using different tracking methods ("moved onto audio recordings because...writing was tiresome upon waking up...moved from audio recordings onto just trying to make mental notes and that works, but poorly, and many dreams slip. Now I write hand bullet points..." -R134). The dream tracking methods therefore impact dream tracking frequency.

This model helps highlight two important feedback loops mentioned by multiple respondents. First the "logbook effect" loop (the **R** in the model, well noted in literature [1, 78]) shows that increasing dream tracking frequency increases dream recall frequency. In fact, this is one of the primary reasons individuals track their dreams: to better engage with vivid dreams (33% of respondents) and remember dreams (16% of respondents). Importantly, this loop is self-reinforcing. As dream tracking increases, more dreams are recalled, increasing the amount of dreams that can be tracked. This highlights an area of opportunity for dream informatics: if the initial hurdle of starting dream tracking can be overcome, the reinforcing "logbook effect" feedback loop will help further increase dream tracking and dream recall without any additional intervention.

The second feedback loop, "dream tracking interrupts sleep" (the **B** in the model), is a balancing feedback loop. One of the most commonly noted challenges of dream tracking was the struggle to record a dream in the middle of sleep. As more dreams are recorded, more sleep is interrupted, reducing the amount of dreams that can be recalled and tracked. This suggests an inherent balance in dream tracking—dream tracking increases dream recall, but also tends to interrupt sleep, reducing the number of dreams that can be recalled. In other words, the overall dream information system serves to balance out growth of recall and tracking via sleep interruptions and a reduction in dreams.

This model presents just one partial view of dream information systems. By further refining the model, it would be possible to run simulations to discover the effect of various dream tracking strategies on an individual's life. Regardless of simulation capability, viewing domains of personal informatics from a perspective of self-information systems can help technology designers and policy makers understand high leverage points for change in a system. Indeed, in our sample model above, we see that improved dream tracking methods have the potential to affect dream tracking frequency, and therefore activate the self-reinforcing "logbook effect" feedback loop. Building technology interventions based on insights from comprehensive system models can help avoid unintended consequences [92], and better understand the role of technology in the larger system. We therefore focus the rest of the discussion on the ways in which technology can affect dream information systems, to help meet the needs of dreamers and dream trackers.

5.2 Technology supporting the ephemeral Dreamset

Across all dream information systems that we studied, we noticed a handful of common characteristics. First, many respondents noted the phenomenon of rapid memory loss upon waking up, in that they could only recall the dream immediately after waking up. We develop the phrase *dreamset* (akin to sunset) to describe this "setting" of the dream experience: the period of time between waking up and when the dream can no longer be recalled. This dreamset represents a crucial window during which accurate dream tracking can occur, and is likely a feature of the hypnopompic state, characterized by reduced mental faculty (the noted grogginess) immediately upon waking up [17].

A primary challenge of dream informatics is to help individuals best utilize the dreamset for desired purposes. It is likely that differences in sleep–wake environments facilitate different dreamset experiences. Our respondents used different methods of waking up, primarily smartphone alarms and waking up naturally. Wake-up tasks have been studied in HCI in the context of task-based alarms [66]. In this context, the goal is to wake up the user through tasks of various difficulty, and "inconvenient interaction" is seen in a positive light, given the ability to push the user into a different cognitive state (namely, a state of wakefulness). An ideal dream-tracking process, on the other hand, is not seeking to change the cognitive state of the tracker, but rather to prevent or delay changes in cognitive state, such that dreams can be recorded to the extent necessary before the dreamset ends. In addition, as individuals may awake and record dreams in the middle of the night, they may want to return to sleep, meaning a full awakening is undesired.

Dream tracking is therefore a process that occurs alongside the dynamic cognitive states of the awakening individual. Individuals described the common problem of "remembering the dreams long enough to write them down" (R158). Some have suggested this is because a dream experience is only stored in short-term memory, and it can take roughly two minutes after awakening before new long-term memories can be stored [93]. If an individual is distracted when awoken (perhaps by a loud alarm), the short-term dream experience can be lost before the long-term memory capabilities of the brain can "wake up" and save the memory. This presents

an inherent tension in dream information systems: recalling more (and more of) dreams requires more interruption of sleep.

This suggests a fruitful area of research for dream informatics: *what strategies can individuals use to maintain a record of dreams (physically, digitally, or mentally) with as little disruption possible to the sleepy cognitive states in which dreams can be accessed?*. Respondents highlight one suggestion: to utilize notifications and prompts for specific dream details. The specific sequence and content of prompts likely affects both the fidelity of the dream record and the cognitive interruption. A system could empirically learn effective prompt orders for each individual user based on randomized experiments, and compare which prompt orderings led to the most detailed or comprehensive dream reports. These experiments could be conducted using a continuous evaluation framework [62], as the system (and its user) experiments with new types and arrangements of prompts.

Technological interventions could also facilitate the process of waking up with an embedded alarm (a desired feature of our respondents). Alarms that are responsive to the sleep cycle ("smart alarms") are currently available in other smartphone apps [11, 48]. Sensing the current phase of an individual's sleep cycle (such as deep sleep, REM sleep, hypnogagia) allows for alarms that are adaptive to the individual's cognitive state. It should be a matter of user preference as to which states the system should wake them up in, as these states may provide various windows into dreaming. For example, the hyponogagic stage is associated with creativity, and others have already developed a prototype glove that is designed to respond to this stage [31]. Moving further, neuroscientists are starting to discover neural correlates that indicate whether or not a dream will be recalled [7, 76]. A dream informatics system could use a wearable electroencephalogram (EEG) device (or some other measurement of brain activity, such as in-ear biosensing [65]), to sense the cognitive state of the user, and react according to the user's self-programmed wishes.

Non-technological lifestyle changes may be an even more fruitful area for intervention to improve dream engagement. One of the largest challenges of dream tracking was how time consuming the process was. This conflicts with the short amount of morning free time that respondents reported. Early work and school start times impose temporal restrictions on the capacity for individuals to engage with their dreams, and policies that allow more flexibility in the morning may result in improved dream engagement.

5.3 Capturing Indescribable Experiences

Setting aside issues of the sleep–wake environment, dream-tracking technologies shape the persistent record of the dream. Dreams are a particularly challenging phenomena to be captured because dream tracking is no less than *experience tracking*: capturing an entire lived experience. Unlike smart journaling, there is no steady stream of objective media and content from which the individual can "curate" [22] a record of the experience. Dreams are additionally difficult to record due to their often-abstract nature, inclusion of unknown strangers, and rich landscapes, among other reasons.

One solution, as hinted at in the survey responses, is to accommodate diverse ways of capturing indescribable experiences. It is clear from our survey data that dream trackers are already piecing together their own homemade dream-tracking systems (31% of respondents reported using more than one method to track their dreams). Some dream trackers, like "quantified selfers"[12], experiment and create systems from assemblages of familiar tools.

Indeed, different methods of dream tracking have been shown to produce different outcomes. Voice recording tends to yield a higher word count in dream reports [85] with more visual imagery [10]. Written reports appear to be condensed, perhaps with a slight loss of semantic information, potentially due to a preservation of cognitive resources [10]. Our respondents noted a similar experience, stating:

> I have used multiple methods. I used to write down my dreams verbatim the moment I woke up. I eventually moved onto audio recordings on my phone because writing was tiresome upon waking up... I now write very short hand bullet points of events and feelings... and this is sufficient to reconstruct the dream later as necessary. (R134)

These findings suggest that a flexible dream tracking system should accommodate multi-model dream tracking. Going beyond the basic text entry found in most dream tracking apps, dream tracking systems could include affordances for low effort tracking, such as voice activated voice recording ("Hey Alexa, record my dream"), or by creating a series of large buttons an individual can quickly tap to categorize and capture high-level information about a dream. Given the large number of individuals who still use handwritten notes, the system could also provide a way to scan in handwriting, and use optical character recognition (OCR) to convert the writing into search-able text. The system could also facilitate photos of artwork and drawings, as well as integrating other graphics found online. These different methods for recording dreams may support different "types of remembering" [21] various aspects of dream experiences.

5.4 Supporting Reflection and Dreamwork

Similar to motivations for smart journaling [22], individuals reported that dream tracking is a valuable experience, regardless of future use of the dream record. However, many individuals reported post-hoc usage of dream reports, and these reports are also necessary for different types of dream therapies. In this section, we propose design affordances that could support individuals in dreamwork.

To start, dream informatics could assist individuals in identifying dreams that may be fruitful for dreamwork. This functionality could be based on an organization system for dreams involving tags (a desired feature noted by several of our respondents, and already available in many dream tracking apps noted earlier). For example, individuals could create a tag for "dreams about missing an exam" or dreams that elicit a specific emotion. The system could then provide statistics about the frequency of such recurring dreams, and include the ability to summon-up all past dream reports that share the same tag. This kind of topical search could help dreamers to identify the most frequent or troubling recurring nightmares that would be fruitful for targeted dreamwork. In addition, it could allow for tracking progress in personal development, as individuals could identify variations in the recurring dream which may be correlated

with evolving mental schemata (as suggested by Hill [37]), suggesting progress in a particular facet of life. Current apps (reviewed earlier) that provide search-by-tag features and custom tagging could be manually utilized for this kind of process. Future developments could include automatic differencing of dream reports based on natural language processing technology, highlighting changes automatically to assist in noticing of personal growth.

The current dream tracking applications largely provide a mechanism for storing information about dreams. Some provide additional educational material on dreaming or support for inducing lucid dreams. Four applications included an interpretation feature, but this was limited to boilerplate content found in dream dictionaries. Dream dictionaries have been criticized for supplying definitions of "meaning" based on cultural norms rather than understanding the dreamer and particular dream experience [37]. Dream informatics systems could do more than provide static dream dictionary content to support dreamwork. A dream informatics system could provide the scaffolding prompts and inputs to lead the individual in specific processes for dreamwork traditionally undertaken by an individual in therapy, making these methods more widely accessible. For example, in dream rehearsal therapy, an individual is guided by the therapist to rewrite the nightmare such that it has a better ending. The re-written dream is then mentally rehearsed by the individual, with the intention that the improved and revised dream will begin to occur during sleep, instead of the recurring nightmare [33]. A dream informatics system could provide a series of prompts to guide the user through this process, either informally or with the assistance of a therapist. The system could support a notification schedule to facilitate rehearsing the rewritten dream enough to be effective, and perhaps even learn the best periods of time to suggest dream rehearsal based on changing frequencies of nightmare occurrence.

Survey respondents reported using dream reports to start conversations with close relations, therapists, and with members of online communities. Dream informatics systems could intelligently facilitate this communication, automatically identifying when contacts show up in dreams and prompting the user to connect with those individuals. This facilitates dreaming as a kind of social network – listening to when the subconscious self mentates on a particular individual, and reifying this mentation through contact in the waking world. Dream informatics could also serve to map out networks of dream character occurrences over time, helping provide a novel source of information about one's cognitive social network [51]. Indeed, a study of five individuals' dream reports identified meaningful structure in their dream social networks [34].

5.5 Community Dream Informatics

A dream informatics system could also serve as a platform for researchers to engage with the community of dream trackers. A common concern from many respondents was the risk of accidental loss or disclosure of sensitive personal dream data (a fear realized in the inaccessibility of dreams captured by the Dreamboard app). If a dream informatics system can be built securely and is trusted by the community, then individuals may be willing to anonymously provide data to advance humanity's collective knowledge of dreaming. This kind of sharing-centric approach would extend personal dream informatics into the realm of *community dream informatics*. A community dream informatics platform could then serve as a catalyst for more large-scale, longitudinal studies that have been long called for by those in the dreaming academic community (e.g., [59, 83]).

An important opportunity that community dream informatics might facilitate is the application of machine learning to find connections between dreams and other medical conditions. Linking personal dream health data (perhaps coded by emotional state, nightmare frequency, etc) with physical and mental health records stands to provide a new stream of data about an individual's mind. Machine learning techniques could potentially help to discover if these data streams are predictive of (or predicted by) other serious health conditions. For example, researchers have already started to find connections between nightmare frequency and mental health conditions [77]. One may even find large-scale patterns across individuals, which may shed light on issues that lie in the subconscious mind of a population, such as the growing report of disease-related dreams during the COVID-19 pandemic [74].

5.6 Study Limitations

The study likely suffers from a sample bias because our survey participants were largely recruited through specific Reddit communities. As a result, we focused our analysis and discussion on the qualitative nature of the responses, rather than seeking to draw statistically significant quantitative conclusions. Future work could seek to identify and assess various factors that demonstrably correlate with dream tracking.

In addition, the themes drawn from the results were generated by a single coder (the first author), although vetted and refined in consultation with the other members of the research team. The conclusions are therefore subject to the cognitive vagaries of this individual. Fortunately, the first author is also a long-term dream tracker, so the perspective from which the paper was written is from a member of the target audience the paper seeks to describe.

Finally, this work relied on a single online survey and app review for its data sources. Future work could include in-depth interviews or focus groups to better characterize dream-tracking practices, dream information systems, and the processes that these systems maintain.

6 CONCLUSION

In this work, we explore the self-tracking of dreams from a lens of personal informatics. Through a survey of $N = 281$ dreamers and dream trackers, we characterize dream information systems, a type of self-information system. Dream information systems serve to facilitate engagement with dreams by persisting dream experiences into long term memory, effectively facilitating communication between the dreaming self and wakeful self. Dream information systems vary in their processes and outcomes, but are consistently limited by the cognitive constraints of the ephemeral *dreamset*, the period of time between awakening and the rapid dream memory loss that swiftly ensues. Dream information systems serve to overcome this constraint through dream tracking, social dream sharing practices, and operating in a conducive sleep/wake environment.

Dream informatics is therefore the study of dream information systems and how they can be improved to reach outcomes desired by the individuals embedded in these systems. While large-scale public policy (such as school/work start times) may have a larger influence on dream information systems than any specific technology, dream tracking is one system component that can be easily modified by individuals and technology designers. An analysis of the reported challenges and desired improvements of dream tracking suggests that dream tracking technologies should provide an easy way to gather the most important dream content during the dreamset, and facilitate multi-modal dream recording in order to capture indescribable experiences. While dream tracking is seen as a worthwhile activity by itself, technology can also support the effective use of dream reports, by providing prompts to facilitate clinically validated therapies for working with dreams, such as dream rehearsal therapy.

This novel exploration of dream tracking and the design of dream-tracking technologies provides two high-level messages for members of the HCI community. First, it helps to connect the personal informatics and dreaming academic communities, highlighting the role that HCI can play in personal dream informatics: cultivating dream information systems to suit the needs of dreamers, and more specifically, crafting technologies to improve dream memory. Secondly, a *self-information systems* view of self-tracking can help personal informatics move towards its implicit goal: improving systems for learning about the self.

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