# MoodLight: Exploring Personal and Social Implications of Ambient Display of Biosensor Data

**Jaime Snyder°, Mark Matthews°, Jacqueline Chien°, Pamara F. Chang*, Emily Sun°, Saeed Abdullah°, Geri Gay°***
Cornell University
°Information Science Department
*Department of Communication
{js2829, mark.matthews, jtc229, pfc46, es765, sma249, gkg1} @cornell.edu

**ABSTRACT**
MoodLight is an interactive ambient lighting system that responds to biosensor input related to an individual's current level of arousal. Changes in levels of arousal correspond to fluctuations in the color of light provided by the system, altering the immediate environment in ways intimately related to the user's private internal state. We use this intervention to explore personal and social implications of the ambient display of biosensor data. This study provides greater understanding of the ways in which the representations of personal informatics, with a focus on ambient feedback, influence our perceptions of ourselves and those around us.

**Author Keywords**
Personal informatics; self-discovery; biofeedback; stress management; light; color; ambient display.

**ACM Classification Keywords**
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

## INTRODUCTION

> "To *reveal* is to allow to be known what has heretofore been hidden (a passive act)…and to *disclose* is to act, to make known an occurrence that has been under consideration but, for valid reasons, has been kept under wraps" [22, p. 238].

We are now several years into an era of biosensor research in the field of human computer interaction [cf. 19]. The devices for gathering micro-metric data about even the smallest fluctuations in our biological forms are shrinking in size, becoming more reliable and are increasingly and seamlessly integrated into our environments.

Much of the research in this area has been motivated by a desire to reveal more about ourselves and to provide users with tools to cultivate an increased sense of self-awareness. For example, Affective Health [10; 31] is a bio-sensing tool designed to support stress management by helping people to track trends associated with the response the body has to day-to-day activities and environments. Like similar systems [e.g., 5; 26], Affective Health uses a combination of skin conductance, heart rate and accelerometer sensors to collect data that are displayed on a user's mobile phone in real-time. The designers of this system have explained that "by finding patterns in their own behavior, users can start [to figure] out both what stresses them and how to cope" [31, p. 48].

Extending from this and similar work, we created Moodlight, an interactive ambient lighting system that responds to an individual's physiological markers of arousal. We were interested in learning more about the mechanics of self-awareness provided by real-time display of an individual's biosensor data, particularly in social contexts. We wanted to investigate how the representation of self that is offered by these systems interacts with and influences an individual's own sense of wellbeing. Biosensor systems for self-awareness carry the benefits of ubiquitous and automatic data collection but also embody real risks associated with removing control from users [16; 19]. These systems challenge the ways we have traditionally thought about the process of self-discovery [33] and intentionality of self-disclosure [21].

## MOTIVATION

The motivation for MoodLight grew out of two focus group sessions and a series of conversations with clinicians who provide mental health counseling to college students, a population particularly susceptible to stress [9; 34]. For these mental health practitioners, working with students to cultivate successful stress management skills typically involves assessing stress levels, encouraging non-judgmental self-awareness through talk therapy, teaching


*CSCW '15,* March 14-18, 2015, Vancouver, BC, Canada.

http://dx.doi.org/10.1145/2675133.2675191

traditional relaxation tools such as deep breathing and, in particular, mindfulness meditation, a stress management technique which places an emphasis on developing a detached awareness of momentary cognitive and emotional experience. Research in psychology has shown that cultivating a sense of non-judgmental mindfulness or awareness of present-moment experience can produce substantial improvements in wellbeing, especially for people suffering from pain and distress [1; 4].

The counselors reported that many students find it extremely challenging to practice relaxation techniques, like mindfulness meditation, both at home and in the clinic. One counselor explained: *"Students can self-experiment with some of the therapeutic exercises but I don't feel that they actually reflect on these experiments, It would be nice to have a way to help them reflect, [to] provide convincing evidence [that it works]."*

Another therapist mentioned the benefits of supporting self-discovery in social contexts by making feelings and emotions "more concrete," visually representing them not only to the individual but also to others in a group session, thereby helping session members validate and acknowledge the feelings of others. She anticipated that a visual display might be particularly helpful for students who lacked or were in the process of developing a vocabulary for their emotions. A third clinician commented that the visual representation of an internal state could provide the opportunity for students to reflect on and accept even negative emotions (their own or others) without judgment, shutting down or denying their existence, thereby supporting healthy self-discovery in the future.

With input from these clinicians, a design probe was deployed to observe MoodLight being used by college students singly and in pairs. During the study we spoke with the students about the experience of seeing their internal, affective state represented in an ambient display. The practical goal of the study was to explore the possibility of using MoodLight in clinical and home settings to cultivate mindfulness, provide a novel outlet for self-discovery, and enhance stress management interventions by supporting social engagement. Our more formative goal was to use this domain to look more reflectively at the process of self-represention through the use of biosensor data and the ways in which this influences our perceptions of ourselves and those around us.

## RELATED WORK

### Technology for mindfulness

A variety of intervention techniques have been used to encourage self-awareness including mindfulness meditation [13], breathing exercises, progressive muscle relaxation [25], and acceptance and commitment therapy [30]. Many people, however, find mindful practices such as meditation difficult to learn and apply in daily life [4]. Also, many traditional approaches to self-awareness are practiced in isolation, making it challenging to support the stress management process through positive social engagement.

One prominent example of technology-based interventions to support self-reflection and relaxation is biofeedback [33]. This technique involves using sensor technologies to measure and represent changes in typically automatic biological signals like heart rate, skin conductance and brain activity in order to learn how to voluntarily control them. Biofeedback research in the domain of human computer interaction typically involves designing systems that combine one or more of these detection techniques in order to provide users with an enhanced ability to track their own behaviors and activities. For example, Microsoft Research's Food and Mood project [5] deploys biofeedback in the service of intervention and behavior change. Users wear sensors embedded in their clothing in order to track behaviors and affective states associated with emotional eating so that they can curb undesirable habits. The Affective Health project mentioned above uses a similar set of biometric collection points with the goal of empowering users with the ability to interpret and find their own meaning in the signals as a reflective practice.

Biofeedback and similar affective systems are often screen-based, providing sensor output via a digital graphical display. Some systems present feedback through traditional data visualizations while others use visual metaphors. For example, AffectAura measures head position, posture, voice activity, electrodermal activity (EDA), and GPS to provide participants with an interactive visualization of the user's predicted affective state [26].The team involved in designing and developing the Affective Health system have explored more lyrical expressions of the temporal aspect of biosensor data through displays based on layers and spirals [36].

As the devices for collecting and displaying biosensor data become more refined, attention is shifting to the position of these systems within social contexts. Although not yet a standard component of collaborative work interfaces, there is great potential for biosensor feedback to be used as a means for cultivating co-presence and awareness, especially in distributed contexts. For example, mood sharing applications like MobiMood [6] and the MoodJam project [27] encourage awareness of the emotion climate or collective mood of a shared space.

### Self-revelation and automated disclosure

We chose an ambient output for our system in order to explore both the personal and social impacts of representations of self generated from biosensor data. Based on ubiquitous computing investigations of the mechanics of automated disclosure [21; 32], we anticipated that there would be interesting tensions between the passive and automatic process of *self-revelation* provided by the sensing device and traditional practices of *self-disclosure* that are typically characterized by intentionality. In particular, we found through the process of designing the MoodLight system that our own understanding of the nature of these practices of revelation and disclosure were challenged.

Self-revelation refers to the passive and often inadvertent act of exposing something about yourself in a tacit manner [11; 22]. For example, we reveal clues about personality, preferences and disposition through body language, the arrangement of our personal spaces, and even through the silences in our speech patterns. Levenson [22] describes the process of self-revelation in social situations as inevitable, inadvertent and continuous. The practice of recognizing and interpreting the unconscious self-revelations of others is poetically referred to by Levenson as "exquisite attention" [22, p. 239]. In this sense, biosensor tools offer us a means to cast "exquisite attention" on ourselves, enabling us to notice subtle and unattended details that signal internal states of being.

On the other hand, self disclosure traditionally refers to "an interaction between at least two individuals where one intends to deliberately divulge something personal to another" [12, p. 411]. In spite of cultural and social taboos against sharing personally sensitive information, psychology research indicates that self-disclosure, especially to friends and family members, can play an important role in constructing relationships and coping with stressful or traumatic events [cf. 12]. Greene et al. [12] posit that nondisclosure, especially in stressful situations such as being informed of a serious illness, correlates to psychological inhibition, suppression of cognitive processing and other physical symptoms of anxiety. Not only do mindfulness practices help us to mitigate stress by encouraging non-judgmental self-awareness of negative feelings, but they can also lead to the intentional expression these emotions to others [1; 4].

Recent research looking at computer-mediated interactions has shown that the perceived anonymity offered by online environments can affect our disclosure practices, often encouraging more spontaneous sharing of personal details [17; 35]. While users largely remain in control of self-disclosure decisions on social media sites through the voluntary nature of posts, with sensor-based systems that can passively and continuously track personal information there are risks associated with *automated disclosure* [cf. 21; 32]. Managing disclosure in daily life "is an intuitive, situated social process" [21, p. 2] while managing disclosure in ubiquitous computing is complicated by the seamlessness with which these systems strive to operate. Lederer et al. looked at ways to support intentional disclosure in ubiquitous systems, particularly where the data may be disclosed automatically [20; 21]. They identified a tension between the risk of unintentional revelation of personal information and the burden of having users provide permission for the release of each piece of information about themselves to which the system has access.

Our study was designed to probe representations of self through biosensor data by focusing on the blurred line between inevitably inadvertent self-revelation and the mechanics of automated disclosure. When users make the explicit choice to use sensing technology, this can be seen as intentional acquiescence to automated disclosure (especially when the system is embedded in a social context). However, in many current systems, users quickly lose control of those data points as their personal information is fed into a complex system [16]. What might have begun as an act of intentional disclosure becomes an experience of passive self-revelation [22, p. 240]. Understanding this shift should be of particular concern to researchers in the CSCW community who envision exploiting affective and bio-sensing technologies in the service of establishing and maintaining trust, cohesion and coordination in distributed teams.

### Summary

The capacity for bio-sensing tools to support self-awareness has been the subject of previous work. However, as these tools become more seamlessly embedded in our everyday lives, the data and representations of self that they offer are increasingly integrated into our social landscape. We contribute to this work by viewing representations of self that are offered by bio-sensing systems in terms of not just self-awareness and mindfulness practices, but also within the context of more socially grounded practices of self-revelation and evolving notions of automated disclosure.

## DESIGN OF MOODLIGHT

### Design considerations

The first design consideration we addressed dealt with the recent surge of interest in personal informatics systems driven by low-level biometric and movement sensors [38]. Biofeedback is no longer a specialized therapeutic technique. Readily available sensor-based activity trackers like the Basis wristwatch (http://www.mybasis.com) enable individuals to use high-frequency sampling of low-level outputs in order to see a view of themselves that was previously unavailable. This information provides new opportunities for self-awareness: Do I recognize myself in this micro-level data? We were interested in investigating these representations in the context of self-discovery.

Second, we were sensitive to students' vulnerabilities when it comes to the relationship between avoidance behaviors and technology use [23]. Avoidance behavior, a by-product of stress, refers to any activity a person engages in to avoid facing a source of stress, resulting in a negative impact on everyday life. Examples include gambling, watching television, and playing computer games. According to the American Psychiatric Association's Diagnostic and Statistical Manual of Mental Disorders (DSM-5), newly identified conditions such as Internet addiction could be the result of a strong relationship between technology use and a range of avoidance behaviors. Because of this connection, the design for MoodLight system needed to remove the screen and introduce an element of ambient experience to users.

Third, in order to support social engagement, we designed the system around the notion of playful interaction, with two modes: single play and paired play. It is a passive, ambient display that encodes output as colored light. During single play, the system responds to input from an individual. In the paired play, biometric data from both participants is combined to produce a visible representation of their shared interaction. We did not present a specific goal to participants, but encouraged open-ended exploration of the system.

## System description

The MoodLight system consists of EDA sensors, an android device, a series of commercially available programmable light bulbs produced under the HUE brand by Philips, and a set of desk lamps. Using this technology, it is possible to change the color and/or intensity of the light cast by the bulbs in response to changes in arousal.

### *Measuring arousal*

The Personal Input Pod (PiP), a commercially available sensor used in the MoodLight system, is a novel implementation of standard EDA technology (Figure 1, left). The PiP sensors are about 2cm wide by 3cm long, non-invasive and are held lightly between the participant's thumb and forefinger (Figure 1, left). When the participant makes contact with two separate metal plates on either side of the device, a safe and imperceptible electric charge (13 microamps) is passed through the fingers. The level of conductance is then measured. Readings are taken at regular intervals in order to establish trends of increasing or decreasing arousal for an individual.

EDA sensors can detect changes in an individual's arousal levels via the autonomic nervous system by measuring subtle changes in skin conductivity [8]. The amplitude and rise time of EDA pulses vary between individuals making direct comparisons challenging. The algorithm for assessing changes in individual EDA levels takes this into account by applying Least Means Squares (LMS) on successive windows of data to determine the slope of the EDA curve, and also uses a threshold up/down counter to reject spurious peaks/troughs. An accumulator is used to increment the arousal trend in one direction (stressed) or the other (relaxed). While EDA sensors can detect arousal, or a heightening response to stimuli, they cannot disambiguate whether an individual perceives that sensation of arousal as positive or negative. EDA levels between individuals can vary greatly depending on age, skin type and other factors. For initial testing, the system used a generic profile for interpretation of EDA data.

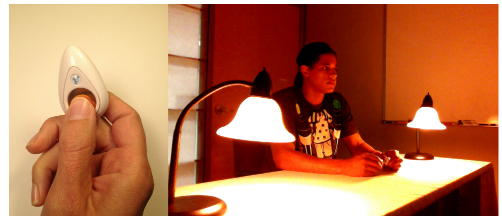

**Figure 1. PiP (left) and setup (right)**

### *Interactive lighting*

MoodLight uses the Philips HUE interactive lighting system hardware and API [29]. The system includes programmable LED light bulbs and a wireless bridge that enables the lights to communicate. Three types of LED, producing a relatively wide range of colors and intensities, define the color profile of the lights. MoodLight has been initially optimized to work within the range of colors available through this system, mapping to ten discrete hues (Figure 2), with transitions moving from magenta-red to blue-violet (discussed below).

**Figure 2. Ten hues representing the MoodLight color range, with red at the top of the circle, moving clockwise to orange, yellow, green, white and blue-violet**

EDA readings are sent via bluetooth to an Android device, which in turn sends a signal to the programmable light bulbs. This information is used to control the hue of ambient lighting conditions in a room, essentially controlling the output of the lights with input representing the participant's current level of arousal.

During use, a participant holds the PiPs between their fingers (Figure 1, left). The EDA sensors pick up increasing, decreasing or stable levels of arousal. Depending on the signal, the lights change color, with increasing arousal triggering a transition to warmer (red) end of the spectrum and decreasing arousal signaling the lights to transition to the cooler (blue-violet) end of the spectrum. When either end of the scale is reached, a soft chime sounds.

### *Light, color and affect*

There are multiple theories regarding color, emotion, culture and physiology [cf. 3; 40]. Researchers have shown that exposure to light has both *visual* and *biological* effects [18; 37]; there are non-visual, biological impacts of being exposed to certain colors or levels of light under different circumstances. One example of this type of effect is the influence of light on circadian rhythms. There is also support for a positive association between arousal and color wavelength. Walters et al. [37] showed that subjects who made color preferences throughout the day exhibited a systematic tendency for long-wavelength colors (towards the red end of the spectrum) to induce feelings of high arousal and short-wavelength colors (towards blue) to induce feelings of low arousal.

Supported by this research and a pilot study exploring associations between different colors of light and levels of stress and relaxation, we designed MoodLight with the anticipation that most participants would associate relaxed states with cooler colors like blue and purple and heightened levels of arousal with warm colors such as red and orange.

## METHOD

There is limited research that makes an association between face-to-face public display of personal information and social dynamics of self-discovery; therefore, we designed an open-ended protocol that would allow us to observe participants using the system both on their own and in the presence of a friend or acquaintance.

Our study included four stages: 1) a preliminary interview during which we learned about participants' relationship with stress; 2) interaction with the MoodLight system singly providing an opportunity to explore the relationship between the system and self-discovery; 3) interaction with the system in pairs during which we observed a range of behaviors associated with emergent self-awareness in a social context; and 4) an exit interview during which we asked participants to reflect on their experience with MoodLight.

Each recruit for the study was asked to bring a friend or acquaintance when they came to the lab to participate in the study. All individuals completed a preliminary interview and individual session, and those who were able to bring a companion also participated in the second paired session.

### Setup

Two empty offices in an academic department close to the center of campus were used to run the study. Decorations, personal items and unneeded furniture were removed from the rooms. A table was set up in each room with a chair on either side, one for the researcher and one for the participant. A plain white cloth was spread over each desktop. There was a laptop computer in each room, as well as two desk lamps, each utilizing a programmable light bulb (Figure 1, right).

### Protocol

#### *Preliminary interviews*

A preliminary interview gathered information about typical experiences of stress and actions taken to mitigate stress. We asked participants about typical sources of stress, steps taken to mitigate negative feelings and the role that social interaction played in their approach to stress management.

#### *Single and Pair Play*

Individual sessions began with a brief introduction to the MoodLight system, including an explanation of the relationship between typical experiences of stress and relaxation in relation to the arousal data used in the system. Individual participants were asked to playfully interact with the MoodLight system by trying to make the lights respond to their EDA input (Figure 3). Most participants engaged with the system for approximately 10 minutes before indicating that they were ready to move on to the next phase of the study. At that point, a partner participant was brought into the room.

For the paired interactions with the MoodLight system (Figure 4), each individual held one of the PiPs. The lights were controlled using the aggregate of EDA input from both participants. We chose to combine the signals in the output in order to emulate the experience of being involved in a face-to-face conversation where it is not always completely clear who contributes what to the overall tone or mien of the discussion. For example, it is not uncommon to find oneself in a tense discussion with a spouse or partner and have competing beliefs about who instigated the conflict.

During paired interactions, the color encoding used was similar to that of the individual version, signaling changes in level of arousal with warmer color for increasing arousal and cooler color for decreasing arousal. For the pairs, we added an additional representation of synchronicity. When both participants were "in sync," meaning both were simultaneously experiencing either increasing or decreasing arousal, the light became brighter. This was intended to function similarly to the many ways we typically signal conversational coordination and involvement, such as mirroring body language, aligning speech patterns and synchronizing vocabulary.

Participants were not asked to complete a specific task, but were encouraged to playfully engage the system with their partner. Many participants began by negotiating a goal; for example, whether they would try to cooperate by simultaneously trying to reach an aroused or un-aroused state or try to compete by trying to reach opposite ends of the spectrum. When the paired participants had exhausted their play, they moved on to individual exit interviews.

#### *Exit interview*

At the conclusion of their session, participants were asked a series of questions about their interactions with the MoodLight system. They were asked to reflect on their abilities to control the lights, the appropriateness of colors in reflecting momentary experiences of arousal, and how they might use MoodLight in their day-to-day lives.

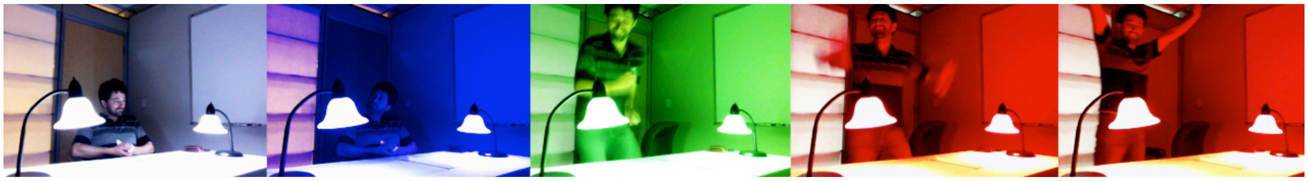

**Figure 3. Single play, light transitioning from blue (far left) to green (center) to red (right)**

**Figure 4. Pair play, light transitioning from red (left) to blue-violet (center) to white (right)**

### Participants

Thirty participants were recruited at a large university in the northeast of the US. During recruitment, participants were asked to bring a friend for the paired observations. Although not all were able to do so, many of the paired participants were friends or acquaintances prior to joining the study. This was a convenience sample, yet participants were reasonably representative of the underlying population. Our sample consisted of 68.8% undergraduate students, 21.8% postgraduates, 3.1% postdoctoral researchers and 9.5% staff members (underlying population: 66% undergrad, 33.5% postgrad). Genders were evenly distributed at 50%, compared to underlying sample of 51.5% male, 48.5% female. Most participants (87.5%) were in the 18 to 25 age range, with the rest being 26-34 years of age. The ethnic background of participants (59.5% American, 28.1% non-American and rest unknown) is similar to the underlying population (64.7% American, 29.6% non-American and rest unknown).

All 30 individuals completed the preliminary interview and were observed interacting with the MoodLight individually; and 22 were observed using the system in groups of two (11 pairs).

### Analysis

Qualitative analysis of individual and paired play involved reviewing field notes from all sessions; audio recordings of interviews (30 preliminary interviews and 27 exit interviews due to technical issues with recording equipment); and video recordings when available (26 single play videos, 9 pair play videos).

## RESULTS

Our analysis focused on (1) observing verbal and non-verbal practices related to self-revelation during engagement with the MoodLight system singly and in pairs; and (2) specific statements made by participants during play with the system or interviews in response to emergent self-awareness, self-discovery and representations of self.

### Engagement with MoodLight

All participants were able to intentionally change the color of the lights either by relaxing or stressing. Participants reported that in order to reach the high-arousal end of the continuum, they tried to think about a stressful situation in their current or recent experiences (62%); made a mental to-do list (15%); performed physical activities such as jumping, running in place or doing push-ups (15%); or think about relationships (12%). When attempting to reach the low-arousal end of the scale, participants indicated that they tried some sort of deep breathing technique (54%), followed in frequency by thinking about something relaxing or enjoyable (42%) like visits with family or trips to the beach. Others talked about trying to clear their minds (19%) or thinking about nothing (12%). Only one person used the term “meditating” to describe these activities.

Interestingly, there were a small number of people who said that they did not need to try to reduce their level of arousal (12%), it just happened naturally. An equal number attempted to relax their neck and shoulders by rolling their head or loosening their posture (12%). A smaller percentage of participants told us that they simply thought about some form of physical activity that they found relaxing (8%).

As participants tried to control the lights, they manifested outward, non-verbal indicators of their internal state. When attempting to become increasingly aroused, they exhibited some common physical characteristics: rapid blinking, sitting forward in their chair, staring intently, short or constricted breathing, clenched jaw, and increased micro-movements or fidgeting. Participants who were attempting to decrease arousal tended to close their eyes, to lean back in their chair, to keep their head/gaze turned downward, or to be very still.

The paradigm of playful engagement with the system enabled us to provide a minimal amount of structure to the paired interactions without drawing attention to a specific goal. In fact, most paired play sessions began with a negotiation between participants regarding whether they would try to get “stressed” or “relaxed,” or if they would try to reach opposite ends of the continuum. While social interactions “in the wild” do not always explicitly begin with this sort of alignment work, we know from sociolinguistic research that similar implicit coordination behaviors are highly typical in face-to-face interactions [14; 39]. Regardless of the strategy selected, during the paired play, participants used many of the same techniques they had tried during single play (deep breathing to decrease arousal, fidgeting or other tense physical movements to increase arousal).

During the single play observations, social interactions such as asking participants to describe aloud what they were experiencing or participants asking the researcher a question appeared to increase the arousal level of some participants. In contrast, during paired play, informal chatting appeared to reduce arousal in some people. We observed a distinct pattern in physical proxemics [24] between the pairs. When attempting to become increasingly aroused, participants were more likely to confront each other, look each other in the eye, be facing each other, and mirror each other’s movements. When attempting to become less aroused, the pairs were more likely to sit at an angle to each other, to not make direct eye contact and to curtail mimicking or mirroring behaviors.

### Risks and rewards of technology-mediated self-discovery

Participant quotes from exit interviews provided some of the richest insights related to user attitudes, assumptions and expectations about the intersection of emergent self-discovery and social engagement provided by the MoodLight system. Therefore, we focus the remainder of the results on reporting these qualitative observations.

#### *Is that me?*

Through behaviors such as peeking at the lights after sitting with eyes closed for a period of time, it was clear that participants used the light for feedback about how they were doing, as a tool for achieving the “exquisite attention” described by Levenson as a hallmark of self-revelation [22]. Although the majority of students in the study told us that they know when they are stressed, there was still curiosity about how the lights would represent their momentary arousal level and transitions between states. In this sense, the color of the light revealed to the participant information about his or her own internal affective state. A student explained, “*When I saw the red lights, I was, like, happy and I thought I was achieving what I wanted to do, so then I could relax and just take a deep breath.”*

Another participant also expressed a belief that the system would help her to see herself more clearly, imagining using the lights at home: “*I can't fall asleep when I'm stressed and that'd be a good indicator because sometimes I'm not always aware."*

For some of the students, the representation of their internal state was not a welcome discovery. They were susceptible to a negative feedback loop created by the red light not only revealing a state of high arousal, but at times *causing* elevations in stress levels: *“Looking at the light makes me stressed, so I am not going to look at it!”* When asked about using MoodLight at home, a participant articulated the tension between the unconscious experience of self-revelation and the intentional act of self-disclosure by remarking that he did not *“want to wear my emotions on my sleeve.”* Another student expressed her hesitation by explaining: “*I already know I'm stressed and I have these...lights that are reflecting how I feel and I already know I'm having a bad day."*

During exit interviews there was a range of responses regarding whether people thought the hue was representative of how they were feeling. While some thought the red and blue extremes accurately depicted their maximum stress and relaxation states, others thought the colors should be different. One participant said she would have preferred a soft green instead of blue-violet at the relaxed end since she considers blue to be sad and dark. Another participant thought the white color was equally as stressful as red.

Although the students talked about customizing the color of the lights, surprisingly, none of them questioned whether the lights were accurately representing their internal state. Based on our observations, participants had different understandings about how the system worked, typically erring on the side of attributing omniscience to MoodLight, even when the output of the lights contrasted or conflicted with the way they were currently feeling. For example, one participant felt that she was highly aroused, “stressed” in her words, although the output of the lights was a steady blue-violet. Rather than questioning the accuracy of the reading, she concluded, *“I guess I've gotten better at not being totally enraged.”*

#### *Which one of us is that?*

Typically, participants initiated a paired session with a brief conversation about their experience interacting with the system singly and then decided on an approach to the paired session. Conversation generally dropped off after this initial coordination; however, two pairs continued to chat informally about a range of topics not related to the study for the duration of the paired play. These exchanges were characterized by a willingness to share details about their personal experiences and preferences, clear examples of traditional socially driven self-disclosure that stood in contrast to the automated disclosure provided by the lamps. In both cases, the lights indicated a high degree of coordination and steady decrease in level of arousal. The relaxed state achieved by the two chatting pairs supports observations by psychologists that healthy self-disclosure has measurable physiological implications [12].

In the majority of other cases, as talking decreased there was a reduction in standard markers of conversational involvement such as mirroring of gestures and body position, eye contact, leaning towards each other [15; 24]. Particularly when trying to decrease arousal, participants in a pair would often become silent, physically turn away from each other and turn gazes downward indicating internal reflection. During exit interviews, we learned that, in fact, many of these participants were engaged in a form of *indirect coordination*. Although eyes might appear closed, they were often just softened, allowing the participants to use the colored light reflecting off the walls and ceiling to gather information about the state of their joint interaction [7].

During paired interactions, variations in the lights became not only an external representation of the pairs combined arousal level, but also a collaborative platform for the practice of passive self-revelation in a social context. This became evident through statements such as, *"One of us is getting stressed, that's for sure!"* as the room filled with a red-orange glow. Along with this passive self-revelation came a sense of responsibility: *"I don't want to be the one who turns it red."*

We saw evidence of a continuum between self-revelation and automated disclosure through statements such as, *"I don't want to be the person to just make the...light bad— or like stressed out, so I tried to relax myself even more."* Another student felt that the presence of another person inhibited her ability to use the light in a reflective way:

> *"I just felt like everything that we tried to do together we'd get like the opposite. We tried to relax and it was stressful lighting, and tried to get pale lighting and it was a dark purplish. So it was kind of the opposite of what I was trying to achieve. But when I was by myself, I was like, 'I want a pale green,' and I could almost imagine what it would take to get that color."*

The passive nature of the display prompted some participants to think more explicitly about their role in the conversation. While subtle linguistic adjustments to increase rapport or alignment are common during predominantly verbal conversations, the feedback provided by the lights highlighted the fact that a participant was getting information about both themselves and their conversation partner, to which they were not accustomed. One participant explained,

> *"When both of us talk and like the colors suddenly change, it also affects me because I start thinking about why it's changing: is it because of me, or is it because of my partner, what is he thinking, what am I thinking? I also think the color affects me a lot."*

Another student articulated the way in which the lights made him aware of the fact that he and his partner were actually at odds with each other:

> *"Or, I guess with the changing intensity thing...I don't know, I felt like that was harder to— 'cause it was somebody else too, so it was harder to gauge what was...affecting the lights, you know what I mean? I didn't know if—'cause it was dim for a lot of it, which means that [maybe] he was more stressed and I was going the other way trying to relax."*

These findings are closely related to statements from the therapists in our focus group who expressed an interest in visually and externally representing the effects of self-awareness in group settings. In the MoodLight system, the automatic nature of data collection and representation removes the locus of choice from the user and places it in the system, while the representation of self offered by that system still performs some of the social functions of traditional self-disclosure. Statements from participants reflect tensions between the inadvertent act of self-revelation and automated disclosure practices when bio-sensing devices are used for self-awareness in social contexts.

## LIMITATIONS

As mentioned above, there are limitations to the current system related to 1) the system-wide representation of the arousal matrix, 2) individual differences in associations between colors and affective states, and 3) the ability of EDA technology to measure nuances in an individual's experience of arousal. However, observing participants engage with MoodLight during this design probe study provided the opportunity to engage with these limitations, as discussed in the next section. Now we move on to implications of this work for the display of personal information through low-level biometric data.

## DISCUSSION

One of the most promising aspects of bio-sensing technology lies in the potential for these devices to help us see ourselves more clearly and more completely. This was at the heart of our interest in developing the MoodLight system to assist therapists in their work introducing stress management techniques to college students. However, the representation of self that is offered through biosensors and other affective systems can be problematic: "A central issue faced by affective computing systems is how to balance the personal, subjective nature of experienced human emotions with the external, objective representations of emotions which computers require to function" [19, p. 425].

Further complicating this issue is the likelihood that, as low-level biometric sensors become more deeply embedded in our environments, the resulting data will find its way more quickly into social media channels and ubiquitous displays. This convergence of personal information and increasingly public display will require a more refined understanding of the dynamics of technology-mediated self-revelation and an appreciation of the risks of minimally controlled automated disclosure [21; 32].

### Dialectics of technology-mediated revelation and disclosure

Psychologists refer to the process of deciding what personal information to share with whom as the *dialectics of self-disclosure* [28]. Making a conscious decision to reveal information about oneself can be an important part of building lasting relationships. However, not all forms of disclosure are beneficial or healthy. Sharing personal details too soon in a relationship or sharing information that is too private can be inappropriate, especially when not reciprocated. Our study revealed tensions between these dialectics and the passive revelation offered by "always-on" activity trackers and biometric sensors. The process of intentionally deciding what to reveal and to whom is disrupted because the system has the ability to display personal information that users might not be aware of themselves.

By using a very simple game-like paradigm for the design probe, we were able to highlight basic social practices of coordination and alignment that we typically perform throughout our daily interactions, often unconsciously. Some users of MoodLight approached the passive revelation offered by the system as an opportunity for self-reflection and self-discovery. In the context of paired interactions, the momentary display of arousal level through the colored lights provided real time feedback about the current state of their social interaction, enabling users to adjust themselves to try to optimize their shared experience. The aggregated nature of the display also provided an opportunity for participants to reflect on their own complicity in co-constructing the overall tone of their conversation. From a therapeutic perspective, the process of untangling who contributes what to an exchange is an important step to exploring a range of interpersonal dynamics.

Höök et al. talk about this in terms of *affective loop experiences*, described as "experiences where it is not possible to separate the intellectual from sensual experiences, nor to single out what is [an] individual experience from the overall experience arising in a dialogue with a friend or in dialogue with a system" [16, p. 248]. In observing participants interacting with each other through the MoodLight system, we saw these affective loop experiences become increasingly complex when participants were involved in dialogue with a friend *and* in dialogue with the system. The simplicity of our system enabled us to begin to grapple with the ways that the representation of biosensor data played a role in these dynamics.

The use of ambient colored light also allowed us to observe the ways in which the form and format of the representation of personal information could serve as both description and inadvertent intervention. *Negative feedback loops* occurred when some participants experienced high levels of arousal that triggered the lights to transition to the red end of the spectrum. Immersive exposure to the red light heightened arousal further, making it very difficult for these users to break out of what they perceived as an undesirable cycle. Although Höök et al. talk about loop experiences as being a constructive feature of affective systems, our study highlights the potential of interactional loops to be a negative experience for users.

### Agency, skepticism and uncertainty

Although students had varying opinions about the hue associated with their level of arousal, surprisingly no one questioned the authority of the system itself. There was a marked lack of skepticism about the omniscience of the system. This may be due, at least in part, to working with students in a research lab setting, lending the experience an overall sense of credibility. However, this observation did prompt us to review interviews and video recordings of interactions with the system with a particular eye to understanding the ways in which the students *assumed* the system worked.

In many ways, the design of the MoodLight system aligns with principles of empowerment through affective tools advocated by Höök et al. [16], Leahu et al. [19], and Boehner et al. [2]. From this perspective, affective systems have the potential "to embody a different kind of interaction, one that positions the user as an expert who makes sense of his or her emotional states with the help of the system, in contrast to a more rigid interaction between a passive user and an expert system" [19, p. 433].

In spite of the relatively open-ended ambient display, the interactive nature of the system, and the co-constructed aggregated signals in the paired interactions, we did not reach a state of pervasive interpretive and interactive empowered across all of our participants. In fact, many of the students in our design probe abdicated the role of self-awareness to the system, seeming to expect (and trust) the lights to tell them how they were feeling. There was a tendency to give more credit to the system than to themselves in terms of knowing how they were feeling in the moment. This was true even in cases when subjective feelings contradicted the information displayed via the lights.

These issues raise questions about the ways in which we present low-level biometric feedback to participants and responsibly explain the uncertainty and complexity that underlies much of this information. When working with biometric data, readings need to be made consistently and analysis depends on identifying patterns in the data. It is rarely a case of definitive black and white declaration, and more typically an instance of identifying a trend in a particular direction. This is due as much to the nature of the signals themselves as to the specifics of the sensing technology.

While it is relatively easy to spot check the accuracy of some types of activity monitors, such as step trackers, it is not as easy for users to check the reliability of biometric sensors such as EDA. Arousal is a complex physical and psychological phenomenon that some users in our study tended to reduce to a binary stress-relaxation axis. Future iterations of the MoodLight system will seek to represent emotion as a balance of subjective and objective interpretation [19] co-constructed through interaction with the system and the revelations provided by it [2], taking into consideration the social influences on this process identified through this design probe.

## DESIGN IMPLICATIONS

### Ephemerality of Ambient Light

The use of ambient light is a particularly promising medium to cultivate healthy self-awareness in social contexts, including both therapeutic and home settings. Feedback in the form of ambient light places minimal constraints on users: they can maintain a conversation, remain facing each other and sustain eye contact – all common features of therapeutic work. In particular, the use of ambient light supported a rich variety of physical positioning, in ways not possible via screen-based displays. Pairs were able to remain connected even with their eyes almost shut or when facing away from each other. Additionally, there are distinguishing qualities to light that are particularly suited to supporting mindfulness practice. Ambient light provides momentary feedback with an emphasis on the present moment. Unlike a graph, the past is invisible, thereby placing a focus on the present, a key aspect of therapeutic mindful, meditative and reflective practices. Lastly, this technology can be embedded in everyday environments (e.g., a therapeutic clinic, a living room, a bedroom) and serve multiple purposes, enabling individuals to easily pick up the system for brief periods of use without any prior setup, and then to easily return to prior activities.

### Understanding the signals

Mindfulness involves being aware of a broad range of mental components and associations that make up everyday perception and experience [4]. Effective design of affective systems that rely on biosensor data means ensuring that users have the information and freedom they need to interpret technology-mediated representations of themselves. It also means enabling users to negotiate inadvertent self-revelation and the risks of automated disclosure. Based on the findings of this design probe study we believe MoodLight will be most effective when used alongside or after a period of training during traditional face-to-face therapeutic sessions. The system is currently being piloted by clinicians in this context as a tool for introducing self-awareness practices to their patients.

### Individual Control

To account for individual and cultural differences and variance, monitoring/feedback systems should allow users to choose the display parameters that are meaningful to them. For MoodLight, this entails allowing users to choose the hues that are meaningful to them. Choosing the colors that represent arousal states acts essentially as a private key that only the individual knows, preventing others from interpreting the meaning behind the signal. Enabling color choice is not just about supporting personal preference. Perhaps more importantly, it returns a measure of control to the individual over self-revelation that was taken away by the mediation of technology. Although it is possible with most personal informatics to turn sensors off or opt out of sharing data, for biofeedback systems measuring and representing underlying physiological factors in real-time, this output is less controllable by users. As reflected by Höök et al.'s work on interactional empowerment [16], giving individuals the ability to be involved in the representation of this information ensures the locus of control remains with them.

## CONCLUSION

The passive nature of data capture and the ambient display of personal information provided a compelling opportunity for observing the mechanics of technology-mediated self-awareness and the negotiation of automated disclosure in face-to-face social engagement. Data are only meaningful and useful when the user has the ability to understand what is being represented about him or herself. Our design probe showed that the display of momentary arousal levels via ambient light supports self-discovery, enabling students to develop awareness of communication practices related to self-revelation. The study also revealed tensions between control over presentation of self and passive sensing devices that will be increasingly important to address in personal informatics displays designed to be embedded in daily work and living environments.

## REFERENCES


[1] Bishop, S.R., Lau, M., Shapiro, S., Carlson, L., Anderson, N.D., Carmody, J., Segal, Z.V., Abbey, S., Speca, M., and Velting, D., 2004. Mindfulness: A proposed operational definition. *Clinical Psych: Sci and Prac, 11*, 3, 230-241.

[2] Boehner, K., Depaula, R., Dourish, P., and Sengers, P., 2007. How emotion is made and measured. *IJHCS, 65*, 4, 275-291.

[3] Butterfield, J., 1996. *The art of light and space*. Abbeville.

[4] Carmody, J., 2009. Evolving conceptions of mindfulness in clinical settings. *J Cogn Psychotherapy, 23*, 3, 270-280.

[5] Carroll, E.A., Czerwinski, M., Roseway, A., Kapoor, A., Johns, P., Rowan, K., and Schraefel, M.C., 2013. Food and Mood: Just-in-Time Support for Emotional Eating. *Humaine Assoc ConfAffective Computing and Intelligent Interaction.*

[6] Church, K., Hoggan, E., and Oliver, N., 2010. A study of mobile mood awareness and communication through MobiMood. *Proc NordiCHI*, 128-137.

[7] Clark, H.H., 1996. *Using Language*. Cambridge University Press, NY.

[8] Cohen, S., Kessler, R.C., and Gordon, L.U., 1995. *Measuring Stress: A Guide for Health and Social Scientists*. Oxford Unive Press, Oxford, UK.

[9] Darling, C.A., Mcwey, L.M., Howard, S.N., and Olmstead, S.B., 2007. College student stress: the influence of interpersonal relationships on sense of coherence. *Stress and health 23*, 4, 215-229.

[10] Ferreira, P., Sanches, P., Höök, K., and Jaensson, T., 2008. License to chill!: how to empower users to cope with stress. *Proc NordiCHI*, 123-132.

[11] Frank, K.A., 1997. The role of the analyst's inadvertent self-revelations. *Psychoanalytic Dialogues 7*, 3, 281-314.

[12] Greene, K., Derlega, V.J., and Mathews, A., 2006. Self-disclosure in personal relationships. In *The Cambridge Hdbk of Personal Relationships*, 409-427.

[13] Grossman, P., Niemann, L., Schmidt, S., and Walach, H., 2004. Mindfulness-based stress reduction and health benefits: A meta-analysis. *J Psychosomatic Res, 57*, 1, 35-43.

[14] Gumperz, J.J., 1982. *Discourse Strategies*. Cambridge Univ Press, Cambridge, UK.

[15] Harrigan, J.A., 2005. Proxemics, Kinesics and Gaze. In *The New Handbook of Methods in Nonverbal Behavior Research*, J.A. Harrigan, R. Rosenthal and K.R. Scherer Eds. Oxford Univ Press, NY, 137-198.

[16] Höök, K., Ståhl, A., Sundström, P., and Laaksolaahti, J., 2008. Interactional Empowerment. *Proc SIGCHI,* 647-656.

[17] Joinson, A.N., 2001. Self-disclosure in computer-mediated communication: The role of self-awareness and visual anonymity. *Euro J Soc Psych, 31*, 2, 177-192.

[18] Knez, I., 2001. Effects of colour of light on nonvisual psychological processes. *J Envir Psych, 21*, 2, 201-208.

[19] Leahu, L., Schwenk, S., and Sengers, P., 2008. Subjective objectivity: negotiating emotional meaning. *Proc DIS,* 425-434.

[20] Lederer, S., Mankoff, J., and Dey, A.K., 2003. Who wants to know what when? privacy preference determinants in ubiquitous computing. *Proc SIGCHI,* 724-725.

[21] Lederer, S., Mankoff, J., Dey, A.K., and Beckmann, C., 2003. *Managing personal information disclosure in ubiquitous computing environments.* Report No. UCB/CSD-3-1257. Computer Science Division (EECS), Univ. of California Berkeley.

[22] Levenson, E.A., 1996. Aspects of self-revelation and self-disclosure. *Contemp Psychoanalysis 32*, 2, 237-248.

[23] Malaney, G.D., 2004. Student use of the internet. *J Educ Tech Sys 33*, 1, 53-66.

[24] Manusov, V. and Patterson, M.L., 2006. *The Sage Handbook of Nonverbal Communication*. Sage Publications, Thousand Oaks, CA.

[25] Matsumoto, M. and Smith, J.C., 2001. Progressive muscle relaxation, breathing exercises, and ABC relaxation theory. *J Clinical Psych, 57*, 12, 1551-1557.

[26] Mcduff, D., Karlson, A., Kapoor, A., Roseway, A., and Czerwinski, M., 2012. AffectAura: an intelligent system for emotional memory. *Proc SIGCHI*, 849-858.

[27] Moodjam.Org, Verified 9/23/2010.

[28] Petronio, S. and Bantz, C., 1991. Controlling the ramifications of disclosure:" Don't tell anybody but…". *J Lang and Soc Psych. 10*, 263.

[29] http://developers.meethue.com/coreconcepts.html.

[30] Powers, M.B., Zum Vörde Sive Vörding, M.B., and Emmelkamp, P.M.G., 2009. Acceptance and commitment therapy: A meta-analytic review. *Psychotherapy and psychosomatics 78*, 2, 73-80.

[31] Sanches, P., Höök, K., Vaara, E., Weymann, C., Bylund, M., Ferreira, P., Peira, N., and Sjölinder, M., 2010. Mind the body!: designing a mobile stress management application encouraging personal reflection. *Proc DIS*, 47-56.

[32] Sapuppo, A. and Seet, B.C., 2012. An Empirical Investigation of Disclosure of Personal Information in Ubiquitous Social Computing. *Intl J Computer Theory & Eng, 4*, 3.

[33] Schwartz, M.S. and Andrasik, F.E., 2003. *Biofeedback: A practitioner's guide*. Guilford Press.

[34] Smith, A., Rainie, L., and Zickuhr, K., 2011. College students and technology. *Pew Internet & American Life Project 19*.

[35] Suler, J., 2004. The online disinhibition effect. *Cyberpsychology & Behav, 7*, 3, 321-326.

[36] Vaara, E., Silvăşan, I., Ståhl, A., and Höök, K., 2010. Temporal Relations in Affective Health. *Proc NordiCHI*, 833-838.

[37] Walters, J., Apter, M.J., and Svebak, S., 1982. Color preference, arousal, and the theory of psychological reversals. *Motivation and Emotion 6*, 3, 193-215.

[38] Waltz, E., 2012. How i quantified myself. *IEEE Spectrum 49*, 9, 42-47.

[39] Wardhaugh, R., 1985. *How Conversation Works*. Blackwell, NY.

[40] Ware, C., 2012. *Information Visualization: Perception for Design*. Elsevier.