"We are researchers, but we are also humans": Creating a design space for managing graduate student stress

FUJIKO ROBLEDO YAMAMOTO, Department of Information Science, University of Colorado Boulder, USA
JANGHEE CHO, Department of Information Science, University of Colorado Boulder, USA
AMY VOIDA, Department of Information Science, University of Colorado Boulder, USA
STEPHEN VOIDA, Department of Information Science, University of Colorado Boulder, USA

Graduate students are facing a mental health crisis due to a combination of individual, community, and societal factors. Many existing stress management interventions engage with one factor at a time, typically focusing on providing a user with data about their stress state. We conducted co-design workshops with graduate students who work closely together to explore their strategies for managing stress and to learn about what types of technologies they envision to help address their stress. Using Ecological Systems Theory as an conceptual framework, our analysis of the designs and discussions from these workshops contributes an expanded design space for stress management—one that foregrounds the affordances and challenges of designing interventions that cut across ecological systems levels along with designs that approach stress management using a broader diversity of strategies: controlling, disconnecting, and normalizing stress. We argue that this expanded design space embraces a more holistic and human approach to designing stress management technologies.

CCS Concepts: • **Human-centered computing** → *Human computer interaction (HCI).*

Additional Key Words and Phrases: self-care; stress management; digital mental health; graduate students

ACM Reference Format:
Fujiko Robledo Yamamoto, Janghee Cho, Amy Voida, and Stephen Voida. 2023. "We are researchers, but we are also humans": Creating a design space for managing graduate student stress. *ACM Trans. Comput.-Hum. Interact.* , (April 2023), 31 pages. https://doi.org/10.1145/3589956

1 INTRODUCTION

Recent studies have found that graduate students, especially doctoral students, are six times more likely to experience mental health problems than the general population [18]. A large-scale survey of graduate students across disciplines revealed that 41 percent of students are experiencing severe anxiety, 39 percent are experiencing depression, and 82 percent are experiencing *excessive* stress on a daily basis [18]. The effects of stress include poor physical health, increased substance use, increased health-impairing behaviors, and even early death [69]. These effects are even more pronounced in students from historically-marginalized groups [12, 76]. The field of HCI may present a perfect storm as it relates to graduate student stress: it is not only a STEM-related field, where students typically report high levels of stress [50, 53], but it is also not uncommon for HCI research to involve close work with members of vulnerable populations. Other disciplines (i.e., social work, psychology) that

Authors' addresses: Fujiko Robledo Yamamoto, furo0108@colorado.edu, Department of Information Science, University of Colorado Boulder, UCB 315, Boulder, Colorado, USA, 80309-0315; Janghee Cho, jach9657@colorado.edu, Department of Information Science, University of Colorado Boulder, UCB 315, Boulder, Colorado, USA, 80309-0315; Amy Voida, amy.voida@colorado.edu, Department of Information Science, University of Colorado Boulder, UCB 315, Boulder, Colorado, USA, 80309-0315; Stephen Voida, svoida@colorado.edu, Department of Information Science, University of Colorado Boulder, UCB 315, Boulder, Colorado, USA, 80309-0315.

1073-0516/2023/4-ART
https://doi.org/10.1145/3589956

interact with vulnerable populations have conducted studies to explore possible interventions to combat the higher incidences of stress due to the challenging nature of the work [7, 19]. Most university programs however, typically do not provide training for graduate students on how to cope with the demands of their work [45, 53]. In addition to a lack of explicit training, other barriers make it difficult for graduate students to seek care for their mental health concerns, including stigma, lack of time, and limited availability of resources such as affordable and accessible mental health services [18, 23, 56]. Without intervention, these problems can persist and worsen when graduate students enter the workplace [25].

Most graduate-level stress non computational interventions have focused on targeting maladaptive thoughts, becoming aware of certain behaviors through tracking, and increasing mindfulness [15, 22, 78]. These individually-oriented interventions, although effective for some, have limited effects on the myriad structural factors that also contribute to graduate stress, such as strained financial resources for graduate students (i.e., living stipends, affordable health insurance, research funds) [23, 56], unclear expectations and roles [23, 34], a culture of busyness [44, 71], and a lack of explicit policies and norms for stress management [18]. There are few graduate-level stress interventions that have focused on addressing structural factors, with the ones that do focusing more on improving worker productivity through changing environmental factors [11, 29]. Most of these interventions, whether individually- or socially-oriented, are non-computational interventions. Opportunities exist to design technologies to help address individual and structural factors that affect graduate students.

Previous research has shown benefits of using technology for the purposes of stress management [2]. While there are no computational stress management interventions specifically for graduate students, there are several technologies that have been designed to help manage stress in different contexts (e.g., [2, 42, 83]). Most of these technologies focus on tracking and informing a user of several factors that may be contributing to a stressful state [52, 64]. Other technologies, mainly deployed in occupational settings, focus on technology that leverages the work environment to encourage stress management either by assessing the overall stress levels within an organization or using technology to encourage breaks throughout the workday [21, 32]. Technology design, then, focuses on intervening at *either* the individual or the community level. There are even fewer stress management technologies that are designed to create changes within the environment in which they are deployed (i.e., challenging the status quo). **Research on graduate student stress indicates that there are various individual, community, and structural factors that contribute to stress [18, 23, 56]; however, to the best of our knowledge, no current technologies simultaneously engage a combination of these factors.** There is a need to explore a design space of technology interventions that can effectively support stress management strategies across its diverse—individual- and community-level—factors and influences. In this study, we employ Ecological Systems Theory (EST, [6, 20]) as a theoretical framework to stretch our design imaginations about the potential for technology to cut across all systems levels where there are critical influences on graduate student stress. Using this framework, we conducted co-design workshops with graduate students who work closely with one another to discuss stress management and design for stress management across different levels—the individual, the lab group, and the institution.

There has been a call for the field to focus more scholarly attention on the design of stress management interventions for students (e.g., [42]); this call is one that we take up in this research. In this study, we recruited graduate students studying human-centered computing and related fields who all work in close proximity to further explore these concerns and to discuss possible technology-based stress management interventions. Through co-design workshops, we explore the following research question:

> *How do graduate students who work in high stress occupational work environments envision using technology for stress management across different system levels?*

We first provide a survey of approaches to stress management, as well as a review of existing stress management interventions. We then present details of our co-design workshops and what we learned. Our participants

discussed using three stress management strategies—controlling, disconnecting, and normalizing stress—and they envisioned technologies that support these different strategies and cut across all system levels (i.e., the individual, the lab group, and the institution). We present a design space based on the EST framework that expands current approaches for developing stress management technologies. We discuss the implications of these findings and the value of designing to support different strategies that cut across different system levels.

2 RELATED WORK

2.1 Different Approaches to Stress Management

Stress "occurs when demand exceeds the regulatory capacity of the organism" [10, p. 17]. In educational settings, stress can impair memory, cognitive processing, and decision-making abilities [57]. The effects of stress are even more pronounced with chronic, long-term stress, which is fairly common among graduate students [18].

The underlying assumption in most stress management technologies is that stress can be reduced by applying an appropriate intervention. While stress has been understood in a diverse range of constructs—from quantitatively measurable units to subjectively perceived symptoms—it is usually considered that stress is controllable if an individual takes a certain action. A philosopher Byung-chul Han [28] criticized current stress management techniques for functioning as a fuel that forces individuals to consistently and tirelessly work hard in order to be productive and successful. Mental health problems, or burnout, results from the exploitation of the self to maximize achievement and productivity. Han argued that the *unlimited Can*—the affirmation, "Yes, we can" [28, p.8]—epitomizes society's positive orientation, which forces people to make progress at the expense of their mental health. Current dominant approaches to stress management for individuals may trap people in the rat race in which they incessantly try to reduce stress to become more productive.

An alternative approach to stress management is not to use stress management techniques to become more productive, but rather to create changes in a working environment to create a safe, empowering, and equitable space. Researchers who study stress within organizations have highlighted the importance of designing stress management interventions that target working conditions rather than focusing on individual factors that may contribute to stress [66, 77]. These structurally oriented stress interventions assume that stress is a result of unsuitable working environments and that the key to stress reduction is fostering strong and healthy relationships within an organization [17, 66].

Reflecting and processing a stressor requires the use of cognitive processes [57]. In the case of graduate students, who often experience chronic stress due to the nature of graduate school, individuals may not have the cognitive resources to process their thoughts and feelings after facing a stressor [10, 57], elsewhere referred to as *reactive coping* [68]. Other stress management approaches that embrace rest, distraction, and connection as techniques to improve wellbeing may be more fitting for the graduate school environment. Instead of focusing on controlling the stressors or the thoughts surrounding the stressors, these approaches place emphasis on creating distance from the stressor. Behavioral neuroscience research on the effects of stress on the brain supports this perspective [10, 61]. A Taoism perspective goes even further, suggesting that any action against the natural rhythms of the present would make a situation worse (i.e., Wu-wei [81]) and that opposites, such as happiness and unhappiness, should be acknowledged as complements [9]. Each of these perspectives suggests that eliminating stress is not always the right approach. In this research, we explore the design space of digital technology for graduate students by taking account of multiple perspectives on stress management.

2.2 Technologies for Stress Management

The availability of high-quality sensors, speech recognition, face- and body-tracking systems, and health-related mobile apps allows researchers to better capture and act upon individuals' emotional states. For instance, by analyzing text typing data on smartphones [79] or assessing and annotating individuals' calendar events [41],

digital technology aims to provide more actionable insights to cope with stress. Data-driven interventions are one of the most prevalent classes of systems for supporting stress management on an individual level [52, 64]. These systems embody the assumption that knowledge of personal data (i.e., knowledge of stress states, knowledge about stress patterns) can be helpful for managing stress. Many of these systems focus on collecting data about users and communicating it back to them to encourage reflection on their current state [72], engagement in relaxation exercises [38, 83], and increased awareness of their physiological states [63]. From bodily reactions such as heart rate and the subjective evaluation of stress level to individuals' everyday behavior, previous research has aimed to detect stress more effectively and accurately (e.g., [4, 30, 58]). Genres of data commonly collected for this purpose of providing actionable insights include mood symptoms, sleep patterns, eating behaviors, etc. An example of such a system is *Delight*, which collects heart-rate variability information and provides its user feedback about their stress state through subtle lighting changes [83]. Using an LED lighting system, the user can also receive feedback on their breathing patterns. Other examples include *Affective Health*, which uses biometric data to communicate to the user data about the state of current state of their body [63] and *MoodLight*, another interactive ambient lighting system that provides the user information about their stress state [72].

Although many technical approaches to the diagnosis of stress allow people to make sense of their stress level, they have limitations to adequately account for the subjectivity of stress [31]. People often perceive their stress levels based on their own understanding from everyday experiences [16]. Adams et al. also found that a self-report approach to stress detection not only helps represent stress levels more accurately, but also complements automatic stress detection [1]. To overcome the limitations of a one-size-fits-all approach, there also have been efforts to develop more flexible and customizable features that help people reflect on their daily life and stress. For instance, by combining a qualitative approach (i.e., self-journaling) with a personal informatics system, users can make sense of triggers and patterns in their everyday life as a way to manage their stress better [33]. Sanches et al. [63] also argued that the opportunity in designing stress management technology is to help people reflect on their experiences to interpret their stress level rather than to diagnose stress.

While the above technologies are designed primarily for the individual, there have been some stress management technologies that have been designed not only to provide insight into personal stress patterns, but also to aggregate this data to provide insight into stress levels at an organizational level. For example, Bakker et al. [3] piloted a stress tracker for workers that tracks stress level as a function of calendar events and uses this information to provide personalized coaching for stress-management. The authors indicate that the eventual goal is not just to provide awareness into personal stress patterns, but to provide awareness into organization-wide stress patterns by using a dashboard to display aggregated stress levels. *AffectiveWall* is another technology that tracks physiological data in a work setting and uses a shared display to inform users of the overall health of workers [82].

Other technologies for stress management seek not to display measured stress levels, but rather, to display subjective stress or mood levels. *MoodCloud* consists of a mobile app and an ambient display where a user can express their mood through color animations [60]. The colors reflect emotional wellbeing, but since the colors are personally selected by each user, their meaning is ambiguous to those who are viewing the display. The ambient display therefore serves as a way to converse about mental health and to learn about the experiences of others rather than to indicate a particular mood state. A similar example is *Mood Squeezer*, in which workers interact with different colored balls to change the design of a semi-public display that shows their emotional state [21]. Finally, there is a genre of work-embedded technologies that seek to encourage wellbeing throughout the day in an effort to decrease stress and improve productivity. *Breakaway* [32] and *The Health Bar* [51] both use an ambient display to encourage users to take breaks throughout the day.

There have also been some technologies designed specifically for stress management among college students. For example, through co-design workshops, researchers found that social connection is imperative for the design of mental health tools for undergraduate students [40]. Rodgers et al. focused on understanding the needs of undergraduate students to develop design recommendations for technology to help address a facet of stress

management, sleep [59]. Lee and Hong [42] conducted co-design workshops with graduate students to help them generate personalized plans to improve their mental wellness. This strand of scholarship is helpful for generating personal informatics systems that help students manage their stress by identifying their stressors, developing a plan to mitigate these stressors, and continuously re-evaluating whether their stress strategies were effective. The authors generally reflected how the social nature of the workshops appeared to be helpful in themselves—it was helpful to have a place to discuss and reflect about different stressors and stress strategies. Most existing research has focused on designing stress management technologies for undergraduate students [56]. However, the concerns and stressors among undergraduate and graduate students are significantly different. Notably, undergraduates are more likely to experience issues related to transitioning from teenagehood to adulthood, while graduate students are more likely to report higher rates of stress related to finances, career progress, family planning, work responsibilities (e.g., graduate/teaching assistantships), and inherent power dynamics present within graduate school [23, 56].

The current designs for stress management technologies consists of primarily tracking stress levels for the purpose of sparking individual or collective insights. However, tracking can have negative consequences, particularly for those who are already experiencing mental health issues [36]. There is a need to explore interventions that are not just focused on tracking presumably-negative indicators of mental health but on those that focus more holistically on wellness. This approach to stress management (see e.g., [32] as an exemplar) offers a more indirect way to address stress.

Overall, there is a need to better understand the stressors faced by graduate students and to provide space to hear their thoughts and perspectives on what types of technologies they could envision being helpful in addressing their particular needs. Rather than focusing on creating interventions targeted to either individual- or organization-specific stress management, the goal of our current study is to explore how to design for the intersections of these different ecological system levels.

3 CONCEPTUAL FRAMEWORK: ECOLOGICAL SYSTEMS THEORY

While individually oriented interventions for stress management are widespread [56], they do not address the social group and environment, which, as argued in the previous section, are integral to effective stress management [18]. Ecological Systems Theory is particularly well-positioned to help address this gap [6, 20]. The theory "posits that individuals constantly engage in transactions with other humans and with other systems in the environment, and that these individuals and systems reciprocally influence each other" [6, p. 15]. Systems theory identifies three such levels:

- *Micro-level*: the smallest unit of analysis, which is typically the individual, and includes components such as age, gender, life experiences, etc. In this case, the micro-level consists of an individual graduate student.
- *Meso-level*: the support structures in which an individual is actively involved (i.e., their social group memberships). In this case, the meso-level consists of family members, close friends, labmates, members of a degree program cohort, and co-workers.
- *Macro-level*: the largest unit of analysis, which includes societal ideologies and social representations that affect the individual, such as culture, policy, media, etc. In this case, the macro-level consists of the lab, departmental, and university culture, norms, and policies.

Based on our review of the literature, most current technology designs target either micro- or meso-level factors; few address the multifacetedness of stress by targeting more than a single level in their design. EST is heavily used within the social work field to design multi-level interventions to treat various mental health issues [24]. EST is a preferred theory within social work due to its focus on agency and empowerment, both of which are believed to be highly important for addressing mental health [62]. Within the field of HCI, EST has been used to design information interventions for mental health informatics with other populations [40, 55].

Instead of approaching empowerment as an individual effort, EST takes into account personal, social, cultural, and historical factors that support and hinder empowerment. Further, in contrast to other similar theoretical lenses commonly utilized in the study of complex human ecosystems in the HCI domain (e.g., sociotechnical systems theory [39, 70]), EST places a stronger focus on human development and relations. EST recognizes the mediating role—and potential usefuless—of technologies and technological intervention in multi-scale social systems, but does not place equivalent emphasis on the importance (or even necessity) of incorporating technology in all situations, allowing us to construct participant experiences and approach analysis with an open mind about the extent to which novel technological interventions are even the right solution in this context.

Here, we approach graduate school as a work setting—one with its own culture, policies, and norms that influence the experience of being a graduate student. We use EST as a lens to reflect on how the participants' designs and post-workshop discussions highlight design opportunities for supporting multiple stress management strategies across each of these three units of analysis.

4 METHOD

We conducted a series of co-design workshops [75, 84] in the summer of 2019 with graduate students to explore stress management techniques and the potential role(s) of technology in managing stress. We selected co-design workshops for this process because we were interested in hearing and learning from graduate students *themselves* about what types of stress management interventions could be the most helpful for them (e.g., [40, 42]). We also wanted to co-create a safe space to discuss potentially sensitive topics regarding mental health in graduate school and to help empower students in sharing and speaking about their experiences, which we believe is an important first step towards creating systemic change. Co-design experiences can be empowering in and of themselves and can help start a shift in cultural norms [48, 67]. We sought to create a space where graduate students are at the center of the design process and can speak about their experiences and needs as they relate to stress management.

4.1 Participants

We conducted three co-design workshops [65] with a total of twelve graduate students (9 female, 3 male; ranging in age from 24 to 56), with the first workshop consisting of 4 participants, the second consisting of 3 participants, and the third consisting of 5 participants. These participants are currently enrolled in one of a number of Ph.D. programs at a large public university in the western United States that bridge among computing, design, and the social sciences. We recruited participants by sending emails to graduate student email lists and posting recruiting messages on group pages in social media and group messaging applications (i.e., Slack). While all participants are currently enrolled as Ph.D. students, they are at different stages in their degree programs, ranging from first-year to fifth-year students. These participants also have diverse disciplinary training (e.g., journalism, computer science, linguistics, humanities, design) and have come to each of their programs with diverse experiences and backgrounds (i.e., some come directly from undergraduate programs, while others matriculated with many years of professional experience). Recruiting graduate students who had an understanding of the social implications of technology meant that we could engage in reflexive conversations about the potential uses of mental health technologies. For example, we could reflect and discuss power dynamics associated with technology use in ways we may not have been able to achieve with other students who did not have this domain knowledge.

The graduate students who participated in this research are members of 8 different research labs, each having its own distinct culture, but all of which share a large (approximately 6,500 square foot), open floorplan lab/studio space. Graduate students sit and work predominantly in alcoves with members of their own labs, but often walk through other lab spaces en route to their own lab spaces, and share meeting spaces, cooking spaces, and lounging spaces with students from all labs across multiple, related degree programs. In addition, many participants belong to one or more Slack channels that are used by various subgroups within and across labs and degree programs. All

of the participants had some overlap in macro- and meso- level influences: they attended the same institution and were subject to similar university- and department-level policies and procedures. The meso-level influences varied by lab and by each participants' group of friends and family. Having both similarities and distinctions among influences catalyzed vibrant conversations in the co-design workshops. Further, the shared environment helped to very concretely ground design explorations.' From an EST perspective and organizational stress management perspective, the working environment is considered to be an important factor in influencing mental health. Therefore, our choice to select participants within an open-plan lab space provided us with the opportunity to explore how the environment can play a role in potential stress management interventions. These characteristics of this particular working environment are referenced frequently in the context of our workshops, as discussed below.

4.1.1 Positionality Statement. The first and second authors of this paper co-facilitated the workshops and are both graduate students who work within the same large lab/studio space as the participants. As peers of the workshop participants, we believed it would be easier to create a safe space to discuss graduate student stressors. In addition, the first author of this paper, who also designed these workshops, has 7 years of experience as a licensed clinical social worker. She has extensive experience in creating safe spaces to discuss sensitive topics. The second author of this paper is an international student who has faced some of the more daunting systemic stressors encountered in graduate school; his experience, and the shared knowledge of his experience by many participants, likely helped to create an ethos of empathy across the workshops, as well.

4.2 Workshop Design and Data Collection

We designed the workshops to last approximately 2.5 hours and to unfold over three phases:

- *Phase 1: Exploring how participants conceptualize and externalize stress*
- *Phase 2: Co-constructing a design space for graduate student stress management*
- *Phase 3: Discussion about technology design for stress management*

Our goal with this structure was to use the first phase of the workshop to develop a safe space and to establish common ground by helping participants discuss different instantiations of stress. These discussions were then used to pivot to the creation of a design space for stress management strategies, which served as a springboard for the development of possible prototypes.

4.2.1 Creating a safe space. We obtained IRB approval for the research and informed consent from all participants. To further protect participant confidentiality, only the graduate student researchers had access to participant data and identity. The graduate student researchers anonymized all data—redacting any text or images that could be identified by the faculty member researchers—before undertaking any collaborative data analysis or writing.

While the primary focus of the workshops was to identify design themes for stress management, we strove to create an environment where graduate student participants felt safe and empowered to discuss their concerns. We conducted each workshop in a familiar place, as prior work suggests that participants tend to feel more at ease if workshops are held in the participants' own space [54]. To enable frank communication about the existing sources of graduate student stress, we did not audiotape Phase 1 and participants were told that only general field notes would be captured during this phase, so as to protect their identities. We were particularly careful with reducing the potential for participant re-identification during this phase of the workshop, anticipating that Phase 1 would be the part of the workshop during which participants might be most inclined to disclose stresses related to the faculty member researchers on the project or their colleagues in the department, and we did not wish to inhibit open discussion about these topics, especially if stresses related to advising or faculty–student power relations ended up being central to the strategies and interventions developed during later phases of the workshops. We did photograph their Phase 1 creations with participants' explicit permission and had them check

the resulting images to ensure they would be comfortable with our sharing these images in presentations of this research.

Subsequent phases of the workshop were video- and audio-taped—with participants' awareness and consent—once a sense of safety and common ground had been established within the workshop. We felt that the generative responses to stressors discussed during these portions of the workshop would likely take place at a more abstract level, moving away from specific details that might implicate or re-identify any particular participant or their colleagues. Additionally, because it would be important for us to be able to accurately and completely convey the details of the stress management design space and the rationale(s) behind possible technology designs in analysis and presentations of the research, we felt that it was more important to capture anonymized (coded) but verbatim accounts of the conversations that played out during these phases. We still granted the graduate student members of the research team wide latitude in redacting or excerpting portions of the transcripts generated in Phases 2 and 3 as necessary to maintain confidentiality in the discussion of sensitive topics that might have come up, but this ended up not being necessary.

4.2.2 Phase 1: Exploring how participants conceptualize and externalize stress. In phase 1, we focused on setting the stage and helping participants feel comfortable discussing the sources of their stress. The activities in this phase were intentionally selected to help ease into the conversation about stress, moving from abstract to more concrete conversations (i.e., the sculpting of a "stress monster" to the discussion of design themes).

In this warm-up phase, we focused on exploring how participants conceptualize and externalize stress. To help participants reflect on the role stress plays in their lives, we engaged in two activities:

"In the Head" Sketch: We asked workshop participants to think and reflect on what they spend time thinking about through an activity called "what's in your head?" We asked participants to draw a circle and partition it based on the proportion of time they spend thinking about a particular subject (i.e., coursework, research progress, publications, family, mental health concerns, etc.). This is a common therapeutic activity that helps individuals reflect on current concerns and also helps individuals externalize aspects of their experience [8]. We treated this activity as a private warm-up to help participants think about their stressors, and we did not collect their sketches. Instead, this warm-up activity was designed to help participants ease into the workshop and to prepare them to externalize their stress in a more playful way in the next activity, which was shared.

"Stress Monster": We asked participants to externalize their stress by using tangible materials (e.g., clay, paper, googly eyes, pipe cleaners, pom poms, and other craft materials). Externalizing is also a common therapeutic strategy that aids in surfacing, discussing, and understanding difficult topics [35]. We then asked participants to take a photograph of their finished stress sculpture at a site where they most often experience their stress (e.g., a salient location within the lab, a particular classroom, etc.). When they were done, we asked participants to share their sculpture with the group in an effort to understand the different ways that participants experience stress.

4.2.3 Phase 2: Co-constructing a design space for graduate student stress management. In the second phase of the workshop, we focused on understanding different instantiations of stress and stress management strategies to create and flesh out a design space for stress management.

Creating design themes for stress management: To elicit 'tacit knowing' [5] (i.e., personal, experienced knowledge), we asked participants to share stories about their stress based on the photographs they took during the previous phase. We then asked participants to discuss possible stress management techniques in response to their specific stress story to aid in creating design clusters. For example, if a participant identified time management as a stressor, the rest of the participants would discuss different strategies that may be helpful to address this specific stressor. As participants shared their own stories and experiences about their stress sources and management strategies with the others, they collectively organized these into themes related to stress and management. The research participants used these themes as a springboard for the creation of possible prototypes that would support different stress management strategies.

Fig. 1. Examples of the inspiration cards (after [26, 27, 49]) provided to workshop participants to seed their brainstorming about potential stress management intervention technologies.

Brainstorming Technology Designs: We then used inspiration cards [26, 27, 49] as scaffolding to help participants imagine how different technologies might be used in different contexts to help graduate students manage their stress (Figure 1). We provided participants with two "decks" of these cards: technology cards and social cards. The technology cards depicted examples of different technologies that could plausibly be employed as part of a stress management system, such as ambient displays, self-tracking devices, social media platforms, mobile apps, etc. We included social cards because, based on EST, the social context is an important component of stress management. The social cards depicted different contexts in which the technology could be used, such as whether it is for an individual, for a social group (i.e., lab group, cohort), or for a particular setting (i.e., lab space, university). We also provided some blank cards to encourage participants to create their own examples and to fill gaps in our pre-constructed decks. To encourage more blue sky, out-of-the-box ideas, we encouraged participants to develop as many pairings as they wished and reminded them that there is no "right" answer. Also, to promote all participants' voices, we split participants into smaller groups (2–3 people) during this activity. We asked participants to select their favorite inspiration card pairings that evoke a system or systems that they would personally like to use for stress management (i.e., pairing an ambient display card with a lab space card) and to discuss ways in which they could imagine such a system working.

Ideation Sketches: After each group reviewed the inspiration card pairings developed in the previous activity, they were asked to select one of their pairing ideas and to create a sketch of the proposed prototype suggested by these cards in their small groups. We encouraged participants to think about a stress management system

they would be likely to adopt themselves and to situate their system in a particular context (i.e., *how would this work in a lab setting?*). We also asked participants to write comments on their sketches about how their proposed prototype would be used on a day-to-day basis. Each small group created between one and three prototypes. For the remainder of the phase, participants iterated on their sketches, culminating in a presentation of their prototypes to the researchers and other participants.

4.2.4 Phase 3: Discussion about technology design for stress management. In the final phase of the workshop, we conducted a focus group with participants to gather thoughts and reflections about the entire workshop experience. We asked questions related to initial design ideas and the final prototypes themselves (e.g., *Which of these would you be most likely to use? What about this prototype appeals the most to you?*) and then expanded the conversation to encompass their more general thoughts about the role of technology in stress management.

4.2.5 Data Collection. During each workshop, we collected data via photographs, audio/video recording, and field notes to better understand personal definitions and manifestations of stress, brainstorming of possible stress management technologies, and participants' self-reported thoughts about the different artifacts created. We intentionally did not audio/video record Phase 1 of the workshop to encourage open conversations about instantiations of graduate student stress and to protect participants' identities.

4.2.6 Data Analysis. We transcribed audio from the workshops and analyzed these transcripts alongside images of workshop artifacts that were designed and/or discussed during the workshops.

First, we compiled field notes and pictures taken during Phase 1 to characterize classes of graduate student stressors. We deductively coded stressors mentioned into the different system levels: micro, meso, and macro [18]. We used these findings primarily to provide context for understanding the foci of the emergent designs, but in doing so, we also verified that the stressors experienced by this participant population resonated with other research findings about the types of stressors faced by graduate students [18, 23, 56].

We then analyzed the artifacts designed by participants (i.e., the sketches from Phase 2) alongside the audio transcripts of Phase 2 and Phase 3. Our aim here was to better understand the different approaches to stress management explored by the workshop participants through their design work and to compare and contrast how different groups approached the design problem. The entire research team met weekly over the course of several months to discuss coding. In the first analysis, the two graduate student researchers each separately conducted inductive, open coding [13] of the transcripts responding to the guiding question: *"How are these interventions designed to help with stress management?"* The entire research team then discussed both researchers' sets of overlapping and synergistic open codes to collectively converge upon three broad classes of stress management strategies: *controlling stress*, *disconnecting from stress*, and *normalizing stress*.

In the second round of analysis, we focused on the relationship among these three stress management strategies and the three EST systems levels. Here, then, we asked: "At what system level(s) are each of these interventions addressing stress?" We used the following definitions of each systems level for our coding:

(1) *Micro-level*: Intervention focuses on the individual. No interaction with others or data sharing are suggested or implied through system affordances or use case scenarios;
(2) *Meso-level*: Intervention focuses on interacting and/or sharing data with others in the immediate surroundings (such as one or more peers in the lab); and
(3) *Macro-level*: Intervention is envisioned to influence larger culture (especially at the departmental and/or program level).

After writing a nearly-final version of this paper, we shared our findings and analysis with all participants as a form of member check [47], validating that our analysis resonated with their stress experiences and their experiences in the co-design workshop.

5 FINDINGS

We first provide an overview the commonly mentioned graduates student stressors mentioned by our participants and present three stress management strategies that our participants identified: controlling, disconnecting, and normalizing stress. We then present how participant prototypes embody and employ multiple stress management strategies across multiple system levels.

5.1 Graduate Student Stressors

Through the "stress monsters" and discussions around design themes, participants shared the sources of stress they faced, which ranged from difficulties prioritizing tasks to coping with unclear expectations (Figure 2).

Fig. 2. "Stress monster" sculptures: (a) P1 embodied the pressure she feels to publish a paper by showing her stress monster in front of the ACM website; (b) P5 described how her stress originates from within her and flows like water (sometimes fast, sometimes slow); (c) P6 emphasized the importance of being gentle with her stress since her stress lives in her brain; (d) P10 represented her stress through a snake, stating that her stress snake changes size depending on the week; (e) P12 described her stress is derived from a family problem and shows this by creating a sculpture to show the difficulty in balancing family with work .

We categorized stressors presented by participants as either micro, meso, or macro stressors, following Evans et al. [18] and the EST model. Micro-level stressors mentioned in the workshops included time management problems, publication goals and deadlines, and mental health issues (see also [18]). Meso-level stressors included family concerns, issues related to advisors/supervisors, issues with relationships in the lab setting (see also [23, 34]). Macro-level stressors included unclear expectations of how to be a successful graduate student, the culture of busyness and the need to constantly feel productive, and immigration policies, especially those set by the Trump administration, affecting students' opportunities to travel outside the country, whether to present research at conferences or travel home to visit family (see also [44, 71]). We present these stressors here (Table 1), then, primarily to offer verification that the participants in the co-design workshops raised issues that are similar to those found elsewhere in empirical research with a broader diversity of graduate students, as well as to provide important context for understanding the design work that follows.

5.2 An Overview of Three Stress Management Strategies

Below, we present the clustering and analysis of the different stress management strategies that the participants identified: (1) controlling stress, (2) disconnecting from stress, and (3) normalizing stress. We present the defining characteristics of each strategy in the language that participants used.

5.2.1 Controlling Stress: "Reflecting on your status". Four out of the twelve participants focused on controlling stress by creating prototypes that support the user in actively attempting to control (or, at least, to *feel* in control

Table 1. Examples of stressors and stress management strategies that were identified by participants.

Example of Stressor	Corresponding Systems Level	Stress Management Strategies Suggested by Participants
Overwhelming to-do list	Micro	• Seeking support from advisor and peers • Creating checkboxes and checking off small tasks • Time management strategies (such as tracking one's time)
Family issues (i.e., work/life balance, family not understanding PhD-related stressors)	Meso	• Seeking support from campus resources (i.e., counseling) • Creating space and time for self-care (i.e., exercise, spending time with family/friends)
Political policies (i.e., limitations on travel based on Visa status)	Macro	• Seeking support from advisor • Connecting with other students who are experiencing similar concerns • Finding resources in the university and community

of) their stress by gaining information about their bodies' stress response, receiving recommendations on how to handle their stress, and/or gaining insight into their current internal state. Most commonly, prototypes in this category collected and displayed biometric data related to stress. For example, P1 and P2 describe a scenario for their prototype where a galvanic stress response sensor monitors a user's stress level and helps the user optimize his/her workload:

> *They sit down at their desk. They have basically a watch that has a galvanic stress response sensor as well. And it communicates via Bluetooth to their computer, and there's an app on their computer that's monitoring the work they're doing.* (P1)

> *The notion of tracking your stress levels, but also with taking into account your priority levels for each task, and how your work flow is going, and how quickly you're working on things. Try[ing] to optimize the experience.* (P2)

Many of the prototypes that fit this category also included a journaling component, where participants could write about their daily experiences and use this information to reflect on their emotional states (Figure 3). For example:

> *The journal could help you keep track of how you're expressing certain things and words that you associate with stress. The journal would only be just flagging things that happen, or showing you patterns... And maybe if you were to design something that had a... record of what's going on.* (P6)

Most participants emphasized the importance of having *agency* to provide input to the system about their stress states, either to correct other data or to add more context. While feedback on one's own physiological data can be helpful, participants wanted to be able to subjectively evaluate and contextualize those data. P3 and P4, for example, designed a system that is able to track stress markers (e.g., skin conductivity, heart rate), built on top of *Slack*, a team collaboration tool. In addition to tracking these sensor data, the proposed system

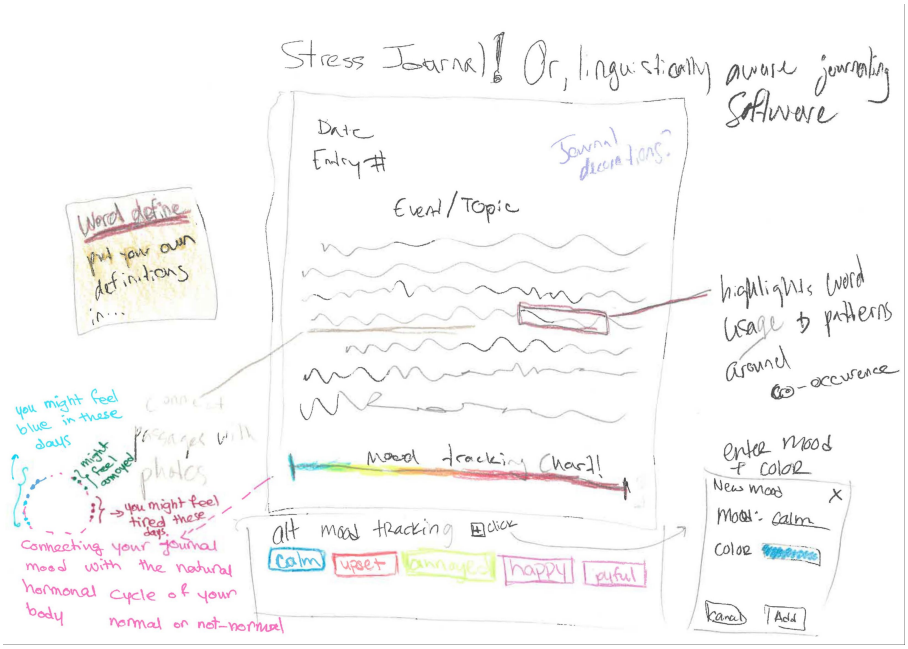

Fig. 3. A stress journaling app developed by P6—an example of controlling stress

would also include a private journaling component, allowing users to provide qualitative feedback on these more quantitative physiological markers:

> *The other input is your daily reflection, where you're going in and kind of journaling and critiquing the algorithm's interpretation of your stress... and kind of using that as a mechanism for reflecting on your status.* (P3)

For these participants, collecting and interpreting data regarding one's own stress levels were key aspects of designing for stress management; however, it was also essential to have the right context of emotional resources for reflecting and acting on these data. In the right circumstances, these data were imagined to be helpful in regaining a sense of *control*. For example, P4 describes the motivation behind his prototype:"Just everything about grad school is feeling like you're not in control. So this was an attempt to bring control back to your life" (P4). Controlling stress was also primarily a micro-level; there was no emphasis in sharing this personal data with anyone else.

5.2.2 Disconnecting from Stress: "It's not about knowing that I'm stressed". While some participants focused on design as a mechanism for exerting a sense of control over their stress, other participants envisioned technological interventions that would enable them to *disconnect* from the sources of their stress, often by fostering connections with others. The majority of prototypes in this category focused on creating spaces and communities for that disconnection from stress and connection with others.

Several participants added a community component to their prototypes. Part of community-building involved addressing cultural constraints that may be a barrier to stress management, such as challenging the assumption that one must always be busy in order to be successful in a graduate program. For example, in the post-workshop discussion, participants mentioned the importance of fostering a supportive environment with peers:

> *I think there's a lot of de-stressing in connecting with people and doing so in a way that isn't related to work. Having opportunities to do stuff in community is always important.* (P9)
>
> *We all talked about stress relief being interacting with other people and creating community. It's not about knowing that I'm stressed.* (P10)

P7 talked about developing an ambient display that rotates through artwork created by lab members (Figure 4). The idea of this proposal is that lab members can collaboratively create and edit different digital art through a mobile phone app. P7 stated that the goal of the display is to enable a sense of community:

> *An interactive design in a room: So you can interact with it with your phone… you can just change the shape. It can be a game or artistic design.… Create something to release the stress.* (P7)

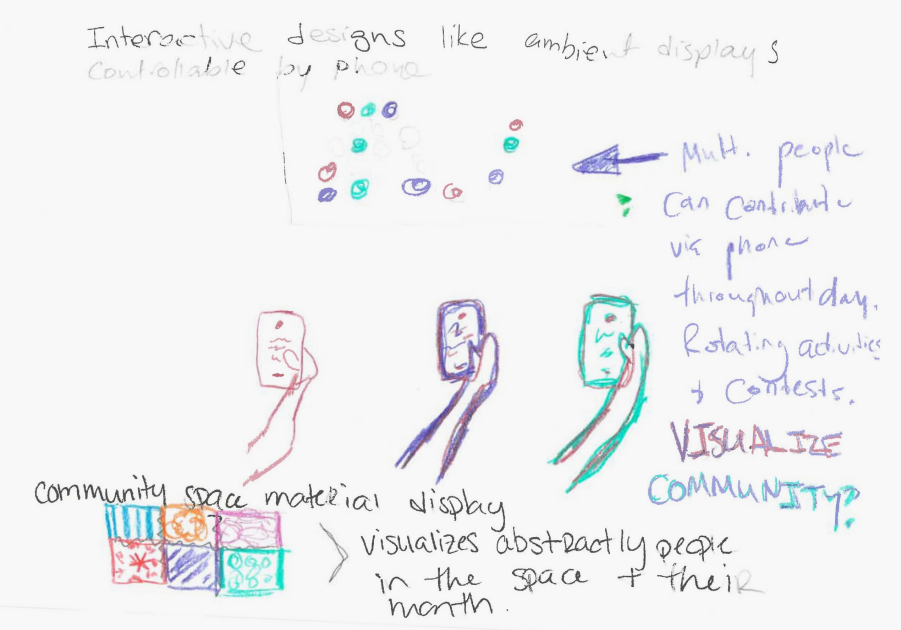

Fig. 4. An ambient display suggested by P7 situated in a common area and populated with artwork that users can create or edit on their phones—an example of disconnecting stress

Others discussed re-designing the graduate students' physical space or introducing elements in the lab environment to promote a sense of playfulness:

> *I think making public spaces like the fridge with the fridge magnets is a good idea. Like purposely building a thing that can be repurposed for play and for just collaborative goofiness. Like this isn't a tool to synergize or make your workplace do better. Like if fricking Slack had more playfulness built into it or something.* (P6)

A key component in designing for disconnecting from stress included a supportive environment where self-care (i.e., taking breaks, bonding with peers) is encouraged and fostered. This supportive environment seemed to be a prerequisite to the technological intervention. In contrast to prototypes that helped participants control their stress through collecting individual data, the emphasis of these prototypes was on community building by taking breaks, playing with one another, and changing the physical environment (i.e., through various displays in the lab space). Personal data collection was not necessarily an important component of these prototypes.

5.2.3 Normalizing Stress: "We're all feeling stressed". A third theme that emerged in a significant portion of the design prototypes was validating the experience—or experiences, plural—of graduate student stress. Many of the proposed designs included functionality for *normalizing* stress, or obtaining validation of one's feelings and thoughts by learning about what others in similar situations are experiencing. As an example, P11 and P12 created a system where users can see what their peers are working on by plugging their computers into a "sharing station" in the lab space.

> *I think that seeing what other people are up to is helpful for people's own choice. Knowing that other people have just as many tabs open, have a lot of the same things going on.* (P12)

P3 and P4 developed a system that integrates a user's stress status into Slack (Figure 5). The user's stress status is determined from a wearable device, which is displayed next to a user's name on Slack. According to P3 and P4, the display of the stress status helps normalize feelings of stress and also allows for the creation of a supportive community. There is also a physical display that one can put on their desk to share their stress status to other lab members:

> *There would be a dashboard of everyone in the lab on Slack that would show... stress level. And then there's a physical display. There's a little square thing that sits on your desk and displays to the world your current stress. So when you're walking around the lab, you can see, "Oh, this person's really stressed-out right now, so I should probably talk to them."* (P4)

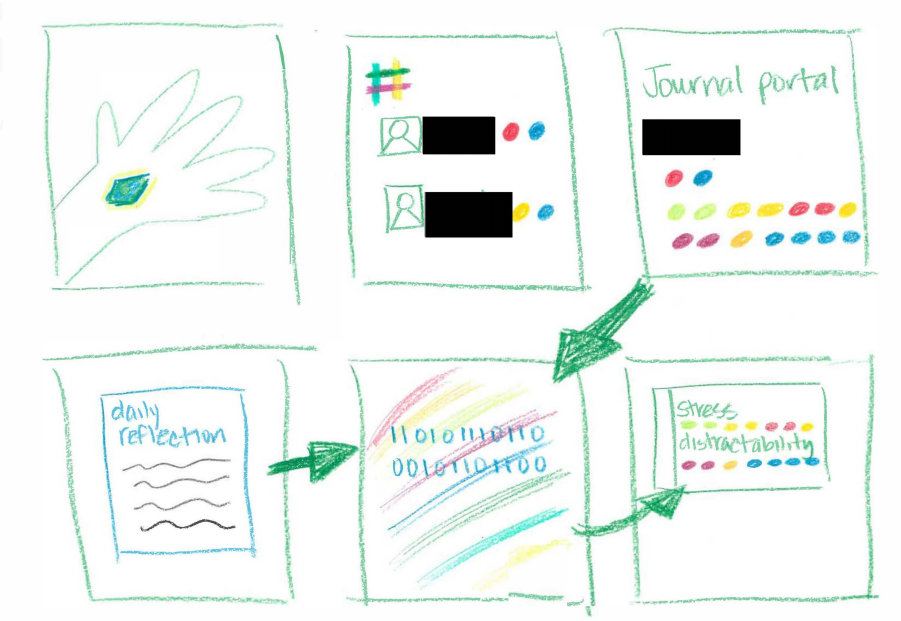

Fig. 5. Prototype suggested by P3 and P4 that integrates stress status with Slack—an example of controlling stress and normalizing stress

While this design is similar to prototypes motivated by a design to control stress (e.g., the reflection journal via Slack), the difference is the motivation behind their system:

> *Being able to display it to the group so that there can be some consensus around "yeah, we're all feeling stressed" or "we're all in a place of needing distraction because it's that time this semester." So there's a personal aspect to it, but it also can become a community aspect to it.* (P3)

The act of normalizing appears to be an integral component of stress management, especially when it involves peers who are in similar situations. While some of the prototypes supported controlling stress through the collection of individual data and others supported disconnecting from stress through community building, others encouraged normalizing stress by sharing experiences. Participants also suggested that prototypes that help normalize stress can shape lab culture by graduate students sharing their experiences with the community (either directly or abstractly).

5.3 How Participants' Design Proposals Responded to Stress Across System Levels

While most stress management interventions in the research literature target either the individual or the organization, most participants suggested prototypes that could be used to address stress *across* multiple system levels simultaneously. In the following sections, we closely examine the intersections and interactions as stress management strategies are designed to be addressed across system levels.

5.3.1 Design Proposals Spanning the Micro- and Meso- Levels. A team of participants in Workshop 1 envisioned a prototype that cut across the micro- and meso-levels in its support for managing stress (Table 2). Participants proposed using a communication tool that is already used by graduate students in a lab, such as Slack. The participants envisioned that a user's stress level would be tracked throughout the day through a wearable device. The stress level would be displayed on Slack and would be available to all users (i.e., normalizing stress at the meso-level). At the end of the day, Slack will prompt the user to reflect on their stress status through an embedded journal. This journal is meant to be a place of private reflection - this data will not be shared with others (i.e., controlling stress at the micro-level). The participants' also proposed that there be a physical display that will also show the student's stress level, so that those around the lab can be aware of each other's stress level and reach out when needed (i.e., normalizing stress at the meso-level).

Table 2. Prototype Addressing Stress at the Intersection Between the Micro- and Meso- Levels.

Group	**Description of Prototype**	**Stress Management Strategy**	**System Level**
P3 & P4, Workshop 1	Use of Slack to display stress and distractibility information (obtained through biometric sensor)	Controlling stress	Micro
	Also consists of a physical display on desk to show data	Normalizing stress	Meso
	Journaling app embedded into Slack to provide qualitative data on stress level	Controlling stress	Micro

We identified two stress management strategies that were supported by this prototype: controlling and normalizing stress. P3 and P4 discussed how understanding one's own stress level requires some level of comparison with others, especially when it comes to feelings related to one's progress and productivity in a graduate program.

While this was the only prototype from our co-design workshops that transected the micro- and meso- levels, this is the intersection that most closely resembles existing prototypes for stress management in the literature where there is a frequent emphasis on tracking stress levels, displaying these data back to the user, and then using a display to communicate the stress status to others around the space (e.g., [72, 82]).

5.3.2 Design Proposals Spanning the Meso- and Macro- Levels. Three of the seven prototypes addressed stress across the meso- and macro- levels (Table 3). Participants seemed to design prototypes that emphasized social support by encouraging engagement in activities together, deploying ambient displays in common areas, or creating dedicated spaces where connection and support can occur (such as having a 'support station' in the lab). Through these design concepts, participants also envisioned that their prototypes would help to reinforce a culture in which breaks and self-care are expected and welcomed (i.e., influencing the macro-level).

Table 3. Prototypes Addressing Stress at the Intersection Between the Meso- and Macro- Levels. *Note that because of the size of workshop 2, each participant created an initial prototype that was then passed around and iterated on.

Group	Description of Prototype	Stress Management Strategy	System Level
P5*, Workshop 2	Interconnected music app to encourage taking breaks and interacting with lab mates	Disconnecting from stress	Meso & Macro
P8, P9, P10, Workshop 3	Interactive bulletin board to help students connect with each other	Disconnecting from stress	Meso & Macro
P11 & P12, Workshop 3	Cyberspace pods: users can plug in their computers at a station when they need help	Disconnecting from stress	Meso
		Normalizing stress	Macro

The "sharing station" prototype (Figure 6), suggested by P11 and P12 and described previously, was based around a station where users could plug in their computers specifically to receive support from their peers:

> *You can choose to go in this little station, and there's little pods. So you go sit in these little chill share stations, and then it will match you and pair you with people who have what would be a compatible level of usage [i.e., type of issue, such as anxiety around returning emails], so then you can talk about it.* (P12)

With this design, if a student is having difficulties returning emails on time and is feeling stressed about it, they could go to the station and ask for support in email management. This not only helps the user receive help with a certain task, it helps them connect with other peers who may be struggling with similar topics (i.e., normalizing stress): *"I think it would be helpful. Whenever you're on your screen and something that maybe brings you stress. So you go to the station and talk about it" (P12).* Within one prototype, a participant could obtain data about their behaviors (i.e., amount of emails, amount of time spent reading), build relationships with peers by going to the station, and obtain validation and support by sharing their experiences.

The three prototypes represented here mainly supported the stress management strategies of disconnecting and normalizing stress. Most of the stressors that these prototypes attempted to target consist of those that do not have a straightforward solution or whose solution is not within the control of the individual, such as

Fig. 6. P11 and P12 designed a pod where users can receive different types of support—an example of controlling, normalizing, and disconnecting from stress

family concerns, dealing with rejection and feelings of inadequacy, or feeling isolated and disconnected from others. In all of the workshops, participants reflected a desire to connect with others rather than fixating on the causes of their stress. For example, participants reflected about how their technology designs might be helpful in establishing or positively reinforcing connections across members of the lab:

> *We all talked about stress relief being interacting with other people and creating community. It's not about knowing that I'm stressed.* (P10)

In particular, the prototype suggested by participants P8–P10 reinforced the need to have a sense of belonging and connection with the community. Their prototype consisted of a physical, interactive bulletin board where members of the community can post via Slack important milestones they have achieved (i.e., passing preliminary exams), extra-curricular activities they participate in (i.e., hiking, going to the movies), and other events that may be occurring at a particular time (i.e., lunch plans). *"Our idea updated to a combination Slack channel plus digital*

screen bulletin board that you can update from anywhere but is also a physical location where you can see what's going on. It would have a variety of channels for outdoor events or food or game time" (P10). The idea is to post this information in a communal area to help those who need to disconnect. This sentiment is stated by P9:

> *It's also bonding over non-research related things, because we are researchers, but we are also humans. It's easy to forget that everybody around you has lives outside of research.* (P9)

When designing for stress, it is imperative to be mindful of how designers are shaping cultural expectations, such as helping to create an environment where disconnecting from stress is supported. For example, P4 reflects that, even though a particular technology does not appeal to him personally, he can still imagine how the technology could help shape the culture within the lab setting:

> *I really like the VR aspect, which I'm shocked saying that, because I hate VR, but I think it's really unique, because it kind of combats that idea that everyone has to be working.* (P4)

In our co-design workshops, prototypes that afforded stress management by cutting across the meso- and macro- levels were the most common. There are several types of affordances that we identified at the intersection of the meso- and macro- levels. Because no personal data needs to be collected for this class of prototypes, there are fewer concerns related to privacy and ethics of collecting and/or sharing individual stress data. There is also the possibility of influencing the lab culture by normalizing the act of taking breaks, developing hobbies, and encouraging connections among graduate students that are not related to academic matters. Finally, prototypes that intersect the meso- and macro- also support stress strategies that invoke fewer cognitive resources, which researchers suggest may be helpful when dealing with chronic stress [10, 57].

5.3.3 *Design Proposals Spanning the Micro-, Meso-, and Macro- Levels.*

> *It's good for us to have some feedback to say, "Yesterday was okay, and here's the hills and valleys that you're kind of naturally going through the semester, and it's okay. This is just part of the experience. So don't fight it. Just know when you're at a place where you need to get some help, some distractions, some stress relief, and it'll be okay."* (P3)

Two of the seven prototypes cut across all systems levels; only one of these two employed all stress management approaches (described in Section [6.1]). P1 and P2 suggested a prototype that consists of a watch that provides feedback to an individual about their current stress level (Figure 7). The idea is that the watch *"feeds into a model that can make suggestions about what [the user] should do at different times"* (P1). The focus in this case is on providing individuals feedback about their own individual state (i.e., controlling stress). In addition to this feedback, P1 and P2 also added a social component to their prototype, to both encourage disconnecting from stress and also normalizing the habit of taking breaks:

> *It could also do things like maybe, after you've worked for a certain amount of time, or if you've completed something, it can tell you to reward yourself and take a break. And so we're thinking about maybe there's some kind of game that everyone in the lab space is playing that's like AR, and it augments the lab space. And it's kind of competitive, so people want to take a break while they're working and play it. And it creates a culture of expecting that it's okay to take breaks.* (P1)

During the focus group, both of the participants who designed these prototypes that cut across all system levels mentioned the importance of thinking about how their intervention could help create a supportive environment where self-care is acknowledged and prioritized. For example, P7 mentioned the following about her prototype:

> *"So the thing I like about collaborative play is that it's not just you, you're participating with other people. I think that might also encourage more involvement, and it doesn't feel like guilt. Like I'm sitting here by myself doing nothing. I know I'm sitting here hanging out with other people doing something with them."* (P7)

Table 4. Prototypes Addressing Stress at the Intersection Among the Micro-, Meso-, and Macro- Levels. *Because of the size of workshop 2, each participant created an initial prototype that was then passed around and iterated on.

Group	Description of Prototype	Stress Management Strategy	System Level
P1 & P2, Workshop 1	Use of biometric stress data to recommend interventions (i.e., stand-up, take a break, tackle this task)	Controlling stress	Micro
	Break from work (AR game)	Disconnecting from stress	Meso & Macro
P7*, Workshop 2	Biosensor to sense stress levels	Controlling stress	Micro
	When stress level is high, encourage movement/interaction with others	Disconnecting from stress	Meso
	Creation of a communal ambient display (not related to biometric data)	Normalizing stress	Meso & Macro

There are several advantages that we identified related to designing across all system levels. With these types of prototypes, users are able to access different stress management strategies, depending on their needs. They are able to reflect on their personal stress data, disconnect by connecting with peers, or passively interact with others by playing with an ambient display. This flexibility and adaptability resonates well with the different approaches for stress management [2]. Also, these types of technologies have the potential to not only change the culture within a lab space, but they can also be diagnostic of the current environment. For example, the individual stress data could be a useful tool for understanding the effects of the disconnecting and normalizing. Are individuals more stressed out after interaction with lab mates? What does this say about the types of relationships in the lab? Embedding these types of prototypes in a lab space and observing how they are used can also provide useful information about power dynamics within the space. For example, are there certain groups that are benefitting more? Who makes the decision on whether to use the technology (i.e., the students, the faculty, the institution)?

6 DISCUSSION

6.1 Designing for Stress Management Within and Across Systems Levels

Following our two-phase analysis of the prototypes and discussions with participants as described in section 4.2.6 (i.e., coding each design proposal first by the stress-management strategy it embodied and then by the ecosystem level(s) that it implicated), we constructed an expanded design space for stress management with two axes: system levels and stress management strategies (Table 5). This was, by and large, a straightfoward task that was carried out collaboratively by all members of the research team in group analysis meetings and with little disagreement in assigning various design proposals to strategies or ecosystem levels.

Ten out of the twelve prototypes selected for in-depth exploration by participants embodied more than one stress management strategy. And while no single stress management strategy cut across all three of the system

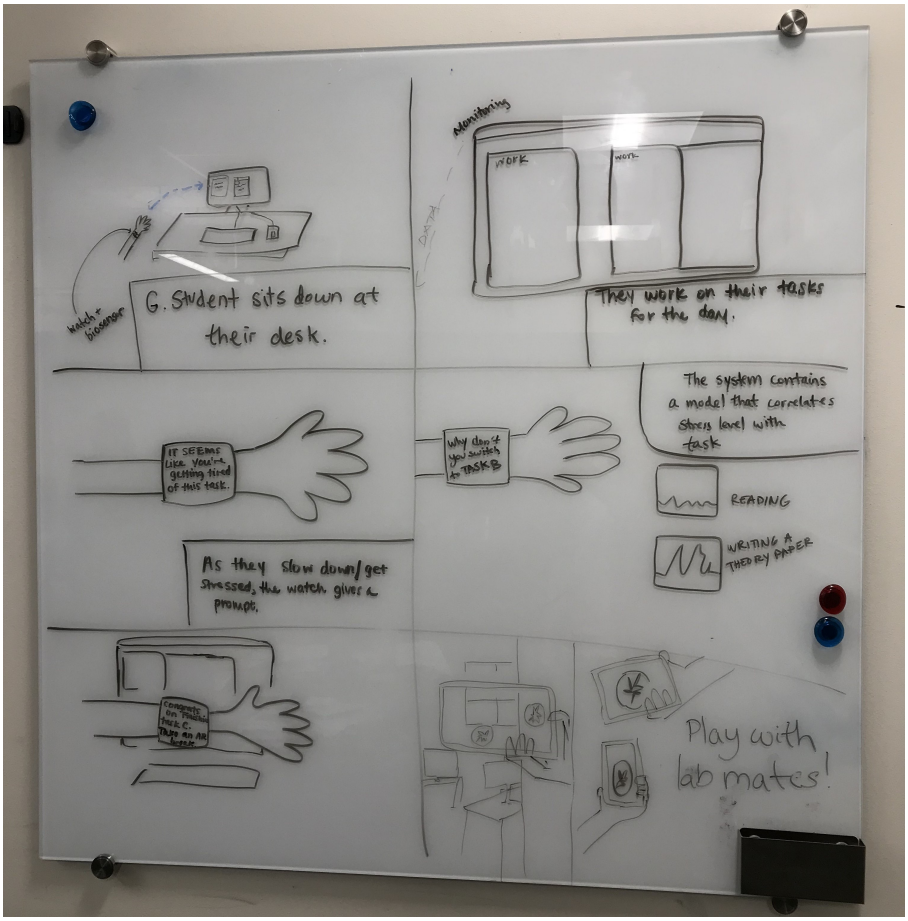

Fig. 7. Smart watch prototype suggested by P1 and P2 which monitors a user's stress state and recommends ways to cope with stress, including suggesting an AR game that can be played with other lab members—an example of controlling stress and disconnecting from stress.

levels, a majority of the prototypes cut across at least two levels by employing multiple strategies. Rather than focusing on creating interventions for either individual- or for organization-supported stress management at the micro- or macro- levels, our co-design workshops foreground the value and importance of designing systems for stress management that transect multiple systems levels. Our analysis of the suite of prototypes and design rationale has demonstrated both the benefits and challenges of doing so. In the following sections, we present a summary of key design challenges and considerations for creating computational stress support interventions that span various level boundaries.

6.1.1 Design Implications: Considerations for Supporting Stress Spanning Individuals and Small Groups. One of the affordances of designing for the intersection of the micro–meso is the ability to reflect on individual data in the context of data from a local community which ideally serves as a safe space or support network. Controlling individual stress levels while normalizing that stress within a community serves to pair two key

Table 5. Expanded design space inspired by the prototypes suggested by our participants.

Participant Prototype	System Levels			
	Micro	Meso		Macro
P1/P2	Controlling	Disconnecting		Disconnecting
P3/P4	Controlling	Normalizing		
P5		Disconnecting		Disconnecting
P6	Controlling			
P7	Controlling	Disconnecting	Normalizing	Normalizing
P8/P9/P10		Disconnecting		Disconnecting
P11/P12		Disconnecting		Normalizing

stress management strategies, serving them up in concert with each other. Despite the benefits, however, there are critical design tensions that exist at this intersection:

- Workshop prototypes that embodied the strategy of controlling stress often involved the collection of very detailed personal information, such as biometric or behavioral data (e.g., a measure of distractibility, presumably mined by logging low-level interactions with an individual's electronic devices and documents). Although data like these might be useful—or even essential—for facilitating reflection on individual practices [46], they are also likely to be data that individuals would be uncomfortable sharing with others, even for purposes of normalization.
- Normalization is useful for tasks that everyone has in common and can relate to, and these can help influence and/or (re)set cultural norms within a particular setting. However, this act of normalization may not be very useful for individualized tasks that are very specific to a particular project or a particular individual, especially since there are many ways to manage workload and tasks in the small [37]. This introduces a challenge in data collection. Furthermore, in the prototype suggested by P3 and P4, there is an assumption that the data obtained through the biometric sensors would be helpful and meaningful to not only the individual, but also to others. Giving data meaning, however, can be a personal experience. This design concept raises the question of whether this type of data is the best to support feelings of normalization (i.e., is this the "right" type of data to collect and show to others?). Biometric data could be helpful because it makes the stressor irrelevant, therefore the data generic.
- P3 and P4 selected to leverage an open-ended computer-mediated communication tool that is already used by the majority of the community. They believed that participation may be higher and onboarding may be simpler if an existing tool was used. For example, P3 stated: *"having it there is part of your daily routine... I go into Slack every day, right?"* However, using a tool that is about narrating experiences and providing subjective context on what is being shared as a mechanism to build alignment across groups can require a lot of additional overhead, which can greatly affect its adoption and ease of use.
- Some participants also suggested that stress data be displayed in abstract ways so that the user can play a more active role in interpreting the data, especially since, at times, it may not be wise to reflect on stress levels: *"You have to be in a place where you feel capable of reflecting. Sometimes, you're just, "Oh my God. The world is collapsing. I don't want to hear about anything. I just want to get that shit done" (P4).* Furthermore, some participants expressed a desire for ambiguity in how their data is displayed, stating that it is helpful for them to provide their own interpretation. For example, P5 indicated that *"it's nicer for it to be reflective*

versus telling you what you're feeling. Giving you room to interpret and think about what might have happened in your day to cause that spike. Maybe not telling you that your heart rate increased 60 beats per minute. Maybe just be like at this point, you had an increase. We're not going to tell you how much or so, but it gives you space to be like, what was I doing in that instance?"

- The prototype developed by P3 and P4 also introduces the question of responsibility. If a student's status shows that they are consistently stressed, whose job is it to intervene? The faculty? Other students? P1 shared the following thoughts regarding this tension: *"I feel like maybe some people would reach out and some people wouldn't, and then it puts the burden on the people who are more affected by this. I don't know who wants to do that"*. Introducing technological interventions that support normalization may raise flags for those who are outliers, which can introduce or reinforce power dynamics and culture norms that may not be conducive to a healthy and safe environment.

As highlighted here, designing for the micro–meso boundary involves understanding and assessing how group dynamics may affect individual stress interventions. Normalizing stress involves a degree of vulnerability, which may be difficult to achieve in certain environments. One recurrent theme that emerged in the designs at this intersection is an emphasis on playfulness or fun, suggesting that one way to balance this sense of data-driven vulnerability is an with tools that promote breaks of fun and distraction. In any case, allowing an individual to maintain agency over their stress data and the degree of vulnerability exposed to others appears to be key to creating an environment for healing and empowerment.

6.1.2 Design Implications: Considerations for Supporting Stress Spanning Groups and the Larger Organization. Even though technological interventions that cut across the meso- and macro- levels can work towards creating a more supportive work environment—both in the small and in the large—there are certain design challenges to consider for the meso- and macro-level:

- While introducing a stress management intervention can prompt changes in the current norms of a community, the community also has to be open to trying out the intervention in the first place. There has to be a certain degree of trust within the members of the community for these interventions to function as intended. For example, in the case of the prototype suggested by P11 and P12, *"the sharing station"*, students would need a certain level of trust when asking others for help. Similarly, there should also be students who are comfortable and willing to dedicate time to helping others. Crafting this type of environment can be challenging, suggesting that these types of interventions may only work within certain settings.
- There is a certain degree of novelty effect to these interventions; initially, they may be well-accepted and used within the community. Over time, however, their use may diminish. Participants from Workshop 3 discussed this phenomenon, stating that while an interactive bulletin board may help people connect, people may become acclimated to its presence and displayed content over time and stop engaging with it. They suggested that the prototype, especially if it resides within a shared space, should be *"bright and colorful, people will notice. And if it moves when it updates people will also notice"* (P9). Furthermore, the proposed activities suggested by all of these prototypes may only work for a subset of individuals. If these activities are helping to craft the culture around the lab, it may shift group dynamics in an asymmetrical way where certain coping skills are reinforced over others. For example, P10 talked about grabbing lunch as a way to cope with a stressful day, but stated that it is difficult when they post on Slack asking other people to join and no one comes: *"no one comes, it feels a little icky."*
- Normalizing stress can involve a certain degree of conformity; that is, coming to the conclusion that these experiences of high stress are normal and part of the graduate school process. However, part of the culture should, at times, be challenged in order to create a healthier environment (i.e., the high-stress environment is not normal and should be addressed). How can designing for stress management foster these two simultaneously?

We can also imagine how designing across the meso- and macro- system levels leads not only to the empowerment of the individual, but could also empower the community to advocate for and create change. One of the key questions related to the use of technology for stress management is whether or not the use of the technology itself can lead to systemic changes in the environment in which it is implemented. Stress management systems could support groups in changing their environment to better foster the mental wellbeing of the community, such as encouraging the communal taking of breaks or engagement in non-work related activity (i.e., *disconnecting* from stress, as exemplified by the interconnected music app and 'Cyberspace Pods' design proposals presented in section 5.3.2). Simply having discussions about stress management interventions could be helpful in an environment to normalize stress and create a culture in which it is acceptable to discuss mental health issues, especially since social support has been identified as being protective against stress [34]. However, these technologies could also reinforce a culture of busyness, depending on how they are introduced and used. Implementing these technologies, especially in graduate student spaces, could lead to fruitful conversations about the type of environment that is desired and more explicit setting of norms. For example, some graduate students could feel uncomfortable about having their data collected, so designing a stress management technology that intersects between the meso- and macro- level may be a better fit than one that cuts across all levels.

According to the EST framework, micro- and meso- variables can influence macro-variables such as policies and broader societal ideologies [6]. Our participants highlighted the potential ways in which their designs could help to generate larger changes. For example, a stress management technology that cuts across all system levels could, if the students are comfortable doing so, use aggregate stress data to inform those in positions of power about the difficulties faced by graduate students. Or, alternatively, if the technology itself—or its log data—is not appropriately brought to bear directly on policy, the technology could be a tool to foster connections with others in ways that help to raise awareness about issues that graduate students are facing and lead to more collective advocacy across the department.

6.1.3 Design Implications: Taking a Wider, More Holistic View of Stress and the Role of Connection. Most interventions in the research literature emphasize the need for tracking and displaying stress levels, either at the individual or group level [3, 38, 63, 72, 82, 83]. However, our participants talked about how this is not always useful or helpful. Our participants did not dismiss the power of tracking and increasing self-awareness–they mainly emphasized that it is not always the best strategy to deal with the multitude of stressors associated with graduate school. Our proposed design space opens up the possibility for imaginative designs that are less focused on increasing awareness and are more focused on fostering connections.

Our participants provoked the idea that stress management requires a holistic, multidimensional approach that empowers users to adopt different stress management strategies. Based on the prototypes suggested by our participants, *controlling* stress strategies are well situated within the micro-level. Gaining control of stress does appear to be an individual activity—a sense of agency is achieved by targeting one's own thoughts and behaviors [57]. *Normalizing* and *disconnecting*, however, both of which are situated spanning the meso- and macro- levels, can work together towards helping an individual gain agency to better control their stress. For example, by normalizing the experience of stress after receiving a rejection from a conference venue, users can cognitively reframe their situation so that they feel more capable and able to control their reactions to the situation. Disconnecting from the stressor can also be helpful in providing emotional distance from the stressor.

Designing across systems levels presents many similar challenges to those identified above. Here, we focus primarily on potential ethical concerns that may arise when using student data—which are a particular concern when designing to cut across the micro-level in which individual data is most likely to be collected and the macro-level, at which institutional power dynamics become significantly influential in the design space:

- There must be careful attention placed to protecting the privacy of users, especially when mental health data has the potential to be shared. For example, P1 shared the following concern: *I don't think I would want*

mine [i.e., stress data] shown to people. I'm more on the private end, so I don't think I would want people to know where I was at. It's a very vulnerable position to be in." There is tension however, between controlling one's own private data and then sharing in an attempt to normalize the experience of being stressed.

- If stress data is shared, then participants preferred ambiguous displays that emphasize fun and connection rather than insight. P6 stated the following: *"If you're going to have a public thing, it has to be abstractions, which is why games are so fun 'cause there's not insight into whatever's tormenting a person, it's just playing"*. The ambiguity of the displays help foster connection through dialogue and are less prescriptive than other insight-driven approaches. These prototypes suggest the importance of a safe environment—if students feel unsafe to share information about their stress states, we posit that they are unlikely to use and/or benefit from a technological intervention.

Expanding the design space to embrace systems that transect the micro-, meso-, and macro- levels should also challenge designers to engage with multiple strategies for managing stress within a system—not merely supporting the controlling of stress, which may not always be the most supportive strategy and which can backfire by reinforcing productivity as the optimal outcome. Our participants highlighted the importance of normalizing and creating space for connecting with their peers. Our expanded design space supports the design of different types of technologies that support the *relational* aspect of stress management. Through their designs, our participants emphasize how stress management can be realized through the creation of human experiences, where the goal is to develop relationships rather than to *work* to reduce stress. These findings suggest that we in the HCI/CSCW community need to focus on developing more holistic interventions that support the type of culture we want in graduate school settings.

Even though some of the most complex and nuanced design implications arise when considering the design of systems that span the greatest breadth of levels (micro- to macro-), we believe that there is much to be gained at the institutional level by more formally acknowledging, giving voice to, and facilitating various strategies for managing the stresses experienced at the individual student level. The widespread nature of significant stress in this context [12, 18, 23, 76] and its worrisome impact on student success and wellbeing have already provoked limited exploration into the design of institutionally supported, non-computational interventions to help address this unfolding crisis [7, 15, 19, 22, 78]. Our design workshops revealed that graduate students were readily able to imagine novel technologies that might help to fill gaps in existing recognition of stress and potentially help to build community around managing and responding to stress in groups of various sizes (i.e., research labs, departments, the University-at-large) by reifying different strategies.

Further, computational interventions like these might serve as a valuable tool that organizations can employ as part of a coordinated response in support of their students and employees, especially since stress is pervasive and interconnected. The EST model suggests that successfully addressing employee (e.g., faculty, staff, administrator) stress may have an effect on graduate student stress, since changes to one part of the system can result in effects throughout the entire ecosystem. Furthermore, these types of interventions could also aid in fostering and developing a move universal culture of care, where these stress interventions do more than simply provide information about stress states—they aid in the development of community, awareness, and action around issues by empowering graduate students and providing shared support experiences across the organization. Researchers have noted that stress interventions in the graduate school setting tend to be more successful when they involve multiple stakeholders and address issues related to academic culture to ensure that the environment is inclusive and welcoming to all [73, 74]. Researchers have also noted the ways that faculty advisors and administrators can impact graduate student health, particularly students from historically marginalized groups, and how stress interventions should involve faculty and administrators to address institutional norms that may be perpetuating a toxic climate [80].

Taking into account macro-level issues is integral to stress management, and without addressing or acknowledging these, some interventions are going to be more unilateral solutions. These tailored solutions may be impactful,

but it is important to question whether these solutions focus on improving productivity and reinforcing a culture of busyness or whether they help shift cultural norms in a more holistic and healthy way. Intentional design could help to illuminate and challenge power structures [67] that contribute to graduate student stress; it could also reinforce the status quo, depending on what values are embodied in the interventions. Our data suggest that interventions that cut across all system levels can not only increase access to stress management strategies, but also lead to individual and community empowerment—helping bring the graduate student community together. Individual empowerment can be helpful in motivating individuals into taking control of their mental health, while community empowerment can lead to collective efforts to improving the graduate school environment, which can then continue to motivate and invest individuals into take care of their mental health.

6.2 Methodological Reflections, Limitations, and Future Work

Within our current setting, our participants were open and willing to share about their experiences. The workshop in itself was an intervention [48]—it created space for graduate students, who are directly affected by the outcomes of the design process, to discuss concerns and solutions to various graduate school stressors [14]. Design experiences can be empowering [67] and can begin to propagate changes within a community [85]. However, we could imagine settings in which such a workshop may not work or settings in which a technological intervention could be used to exert control over graduate students. There are significant power/control dynamics in graduate school [23] and the effects of these dynamics must be evaluated and addressed when designing interventions for this setting. It is important to take into account the cultural and normative climate in which a stress management intervention is being introduced and to take into account the perspectives and experiences from those who the technology is designed to help.

Using the Ecological Systems Theory model [6] helped us to identify both technical and human elements that could affect the implementation of possible stress technologies. These technologies do not exist and function in a vacuum—there are many other social factors, such as quality of relationships or lab culture, that can significantly affect their use and that can mediate their impact. EST also helped us to scaffold conversations with our research participants about imagining how technologies may cut across different system levels. More research is needed to evaluate how stress management technologies influence each systems level (micro-, meso-, and macro-), and, in particular, how technologies that are designed for a particular environment do (and do not) create a sense of community. This lens also suggests future research about how the formation of community mediated by artifacts of this kind might potentially impact the individual experience and the culture of the broader institution or the department.

We acknowledge that there are limitations within our work. In order to understand the context in which stress management occurs, we recruited participants from a specific lab space at a specific university. While this research design decision helped us explore the meso- and macro-level factors that graduate students may face, it could also limit the types of conclusions we are able to draw from our data. Future research should engage with graduate students from a diversity of disciplines and from different countries that might have different academic cultures and policies affecting graduate students to better understand the transferability of our findings.

Additionally, future work should include not only obtaining the perspective of graduate students, but also reaching out to the broader social ecosystem (e.g., faculty, university staff and administrators, etc.) to design and evaluate more holistic interventions.

7 CONCLUSION

Our research set out to explore the open-ended question of *how do graduate students who work in high stress occupational work environments envision using technology for stress management across different system levels?* Through a series of co-design workshops intentionally organized to foster safe sharing of existing student stresses

and based around a series of activities intended to elicit both design proposals for novel stress support technologies and a community dialog about the rationale and considerations embedded in those design proposals, we learned both about the characteristics of graduate student stress and perspectives on how it can be managed by individuals, groups, and larger institutional entities. Our participants faced a range of stressors with varying degrees of controllability, from un-ending to-do lists to social norms around work culture to policies that make it difficult for some students to access quality healthcare or leave the country. Through the participant prototypes, we have identified three different approaches to stress management: **controlling, disconnecting, and normalizing**, and we have deconstructed a suite of technology designs to better understand the value and challenges of designs that cut across system levels. Stress, as expressed through both design and language by our workshop participants, was not a singular construct—it was multifaceted and multidimensional. This research highlights the need for a broader-based, more human perspective on stress management—one that addresses stress across micro-, meso-, and macro- levels.

Most of the prototypes suggested by the participants in our study focused on *connection*, which seems to be a key element in stress management that is not currently supported in the majority of existing interventions. Several researchers have highlighted the need to humanize the STEM field, stating that efforts should be placed into transforming our work-obsessed, burnout inducing culture into a culture of care [43]. Their call to action focuses primarily on undergraduate students, but these ideas meaningfully extend to graduate students since graduate students do eventually play a significant role in contributing to the culture within STEM related fields as educators and/or researchers. Developing stress interventions that are embedded within graduate environments that support more diverse stress strategies could be one step in fostering a culture of care within departments.

The results of this study challenge designers to separate productivity from stress management and to consider expanding current designs to include more holistic interventions with a higher sphere of influence beyond the individual. Doing so could yield more impactful interventions for graduate student stress and could potentially challenge some of the more toxic cultural norms of the academy. Our expanded design space opens up the possibility to shift from a culture of burnout to a culture of care [43] by helping graduate students to manage stress not just through controlling it individually but through normalizing, disconnecting, *and* controlling their stress both individually and as a community.

ACKNOWLEDGMENTS

We would like to thank all of the graduate students who participated in this study and who helped us create a safe environment so we could explore elements of graduate student stress and discuss creative, fun, and potential effective stress management interventions. This project would not exist without your insight, compassion, and expertise.

REFERENCES

[1] Phil Adams, Mashfiqui Rabbi, Tauhidur Rahman, Mark Matthews, Amy Voida, Geri Gay, Tanzeem Choudhury, and Stephen Voida. 2014. Towards Personal Stress Informatics: Comparing Minimally Invasive Techniques for Measuring Daily Stress in the Wild. In *Proceedings of the 8th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth '14)*. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), Brussels, Belgium, 72–79. https://doi.org/10.4108/icst.pervasivehealth.2014.254959

[2] Ane Alberdi, Asier Aztiria, and Adrian Basarab. 2016. Towards an automatic early stress recognition system for office environments based on multimodal measurements: A review. *Journal of Biomedical Informatics* 59 (Feb. 2016), 49–75. https://doi.org/10.1016/j.jbi.2015.11.007

[3] Jorn Bakker, Leszek Holenderski, Rafal Kocielnik, Mykola Pechenizkiy, and Natalia Sidorova. 2012. Stess@Work: From measuring stress to its understanding, prediction and handling with personalized coaching. In *Proceedings of the 2nd ACM SIGHIT International Health Informatics Symposium (IHI '12)*. ACM Press, New York, NY, 673–678. https://doi.org/10.1145/2110363.2110439

[4] Andrey Bogomolov, Bruno Lepri, Michela Ferron, Fabio Pianesi, and Alex (Sandy) Pentland. 2014. Daily Stress Recognition from Mobile Phone Data, Weather Conditions and Individual Traits. In *Proceedings of the 22nd ACM International Conference on Multimedia (MM '14)*. Association for Computing Machinery, New York, NY, USA, 477–486. https://doi.org/10.1145/2647868.2654933

[5] Tone Bratteteig, Keld Bødker, Yvonne Dittrich, Preben Holst Mogensen, Jesper Simonsen, Keld Bødker, Yvonne Dittrich, Preben Holst Mogensen, and Jesper Simonsen. 2012. Methods: Organising principles and general guidelines for Participatory Design projects. In *Routledge International Handbook of Participatory Design*, Jesper Simonsen and Toni Robertson (Eds.). Routledge, London, UK. https://doi.org/10.4324/9780203108543-13

[6] Urie Bronfenbrenner. 1979. *The Ecology of Human Development.* Harvard University Press, Cambridge, MA.

[7] Billy Bryan and Kay Guccione. 2018. Was it worth it? A qualitative exploration into graduate perceptions of doctoral value. *Higher Education Research & Development* 37, 6 (2018), 1124–1140. https://doi.org/10.1080/07294360.2018.1479378

[8] Susan I Buchalter. 2009. *Art Therapy Techniques and Applications.* Jessica Kingsley Publishers, London, UK.

[9] Yu-Hsi Chen. 2006. The way of nature as a healing power. In *Handbook of Multicultural Perspectives on Stress and Coping*. Springer Science+Business Media, New York, NY, 91–103. https://doi.org/10.1007/0-387-26238-5_5

[10] Tamara Cibrian-Llanderal, Montserrat Melgarejo-Gutierrez, and Daniel Hernandez-Baltazar. 2018. Stress and Cognition: Psychological basis and support resources. In *Health and Academic Achievement*, Blandina Blandal-Morales (Ed.). IntechOpen, London, UK, 11–29. https://doi.org/10.5772/intechopen.72566

[11] Sidney Cobb. 1976. Social support as a moderator of life stress. *Psychosomatic Medicine* 38, 5 (1976), 300–314. https://doi.org/10.1097/00006842-197609000-00003

[12] Kevin Cokley, Shannon McClain, Alicia Enciso, and Mercedes Martinez. 2013. An examination of the impact of minority status stress and impostor feelings on the mental health of diverse ethnic minority college students. *Journal of Multicultural Counseling and Development* 41, 2 (2013), 82–95. https://doi.org/10.1002/j.2161-1912.2013.00029.x

[13] Juliet Corbin and Anselm Strauss. 2015. *Basics of Qualitative Research.* SAGE Publications, Los Angeles, CA.

[14] Sasha Costanza-Chock. 2018. Design justice: Towards an intersectional feminist framework for design theory and practice. In *Proceedings of the Design Research Society International Conference 2018*. Design Research Society, London, UK, 529–540. https://doi.org/10.21606/drs.2018.679

[15] Tom Cox. 1993. Stress research and stress management: Putting theory to work. Health and Safety Executive Contract Research Report 61/1993. https://www.hse.gov.uk/research/crr_pdf/1993/crr93061.pdf

[16] Xianghua (Sharon) Ding, Shuhan Wei, Xinning Gui, Ning Gu, and Peng Zhang. 2021. Data engagement reconsidered: A study of automatic stress tracking technology in use. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21)*. ACM Press, New York, NY, Article 535, 13 pages. https://doi.org/10.1145/3411764.3445763

[17] Kimberly C Dreison, Lauren Luther, Kelsey A Bonfils, Michael T Sliter, John H McGrew, and Michelle P Salyers. 2018. Job burnout in mental health providers: A meta-analysis of 35 years of intervention research. *Journal of Occupational Health Psychology* 23, 1 (2018), 18–30. https://doi.org/10.1037/ocp0000047

[18] Teresa M Evans, Lindsay Bira, Jazmin Beltran Gastelum, L Todd Weiss, and Nathan L Vanderford. 2018. Evidence for a mental health crisis in graduate education. *Nature Biotechnology* 36, 3 (March 2018), 282–284. https://doi.org/10.1038/nbt.4089

[19] Rebecca Fischbein and Natalie Bonfine. 2019. Pharmacy and Medical Students' Symptoms, Experiences with, and Attitudes about Mental Health Issues and Help-Seeking Behaviors. *American Journal of Pharmaceutical Education* 83, 10, Article 7558 (Dec. 2019), 12 pages. https://doi.org/10.5688/ajpe7558

[20] Anthony Forder. 1976. Social work and system theory. *The British Journal of Social Work* 6, 1 (Jan. 1976), 23–42. https://doi.org/10.1093/oxfordjournals.bjsw.a056695

[21] Sarah Gallacher, Jenny O'Connor, Jon Bird, Yvonne Rogers, Licia Capra, Daniel Harrison, and Paul Marshall. 2015. Mood Squeezer: Lightening up the workplace through playful and lightweight interactions. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing (CSCW '15)*. ACM Press, New York, NY, 891–902. https://doi.org/10.1145/2675133.2675170

[22] Tholakele Sindisiwe Gcumisa and Anne Harriss. 2019. Stress and conflict in the workplace. *Occupational Health & Wellbeing* 71, 2 (Feb. 2019), 24–28. https://search.proquest.com/docview/2248886118/abstract/80799CB55B1549DAPQ/1

[23] Rebecca K Grady, Rachel La Touche, Jamie Oslawski-Lopez, Alyssa Powers, and Kristina Simacek. 2014. Betwixt and Between: The Social Position and Stress Experiences of Graduate Students. *Teaching Sociology* 42, 1 (Jan. 2014), 5–16. https://doi.org/10.1177/0092055X13502182

[24] Roberta R Greene. 2017. General systems theory. In *Human behavior theory and social work practice*, Roberta R Greene (Ed.). Routledge, New York, NY, 215–249. https://doi.org/10.4324/9781351327404

[25] Susan Guthrie, Catherine Lichten, Janna van Belle, Sarah Ball, Anna Knack, and Joanna Hofman. 2017. *Understanding Mental Health in the Research Environment: A Rapid Evidence Assessment.* RAND Corporation, Santa Monica, CA. https://doi.org/10.7249/RR2022

[26] Kim Halskov and Peter Dalsgaard. 2007. The emergence of ideas: The interplay between sources of inspiration and emerging design concepts. *CoDesign* 3, 4 (2007), 185–211. https://doi.org/10.1080/15710880701607404

[27] Kim Halskov and Peter Dalsgård. 2006. Inspiration card workshops. In *Proceedings of the 6th conference on Designing Interactive systems (DIS '06)*. ACM Press, New York, NY, 2–11. https://doi.org/10.1145/1142405.1142409

[28] Byung-Chul Han. 2020. *The Burnout Society.* Stanford University Press, Stanford, CA.

[29] M Kim Holton, Adam E Barry, and J Don Chaney. 2016. Employee stress management: An examination of adaptive and maladaptive coping strategies on employee health. *Work* 53, 2 (Jan. 2016), 299–305. https://doi.org/10.3233/WOR-152145

[30] Karen Hovsepian, Mustafa Al'Absi, Emre Ertin, Thomas Kamarck, Motohiro Nakajima, and Santosh Kumar. 2015. cStress: Towards a gold standard for continuous stress assessment in the mobile environment. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '15)*. ACM Press, New York, NY, 493–504. https://doi.org/10.1145/2750858.2807526

[31] Noura Howell, John Chuang, Abigail De Kosnik, Greg Niemeyer, and Kimiko Ryokai. 2018. Emotional biosensing: Exploring critical alternatives. *Proceedings of the ACM on Human-Computer Interaction* 2, CSCW, Article 69 (2018), 25 pages. https://doi.org/10.1145/3274338

[32] Nassim Jafarinaimi, Jodi Forlizzi, Amy Hurst, and John Zimmerman. 2005. Breakaway: An ambient display designed to change human behavior. In *CHI '05 Extended Abstracts on Human Factors in Computing Systems (CHI EA '05)*. ACM Press, New York, NY, 1945–1948. https://doi.org/10.1145/1056808.1057063

[33] Eunkyung Jo, Austin L Toombs, Colin M Gray, and Hwajung Hong. 2020. Understanding parenting stress through co-designed self-trackers. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. ACM Press, New York, NY, Article 232, 13 pages. https://doi.org/10.1145/3313831.3376359

[34] Beth Johnson, Abigail S Batia, and Jolie Haun. 2008. Perceived stress among graduate students: Roles, responsibilities, & social support. *VAHPERD Journal* 29, 3 (March 2008), 31–36. https://link.gale.com/apps/doc/A180748348/AONE

[35] Margaret L Keeling and Maria Bermudez. 2006. Externalizing problems through art and writing: Experience of process and helpfulness. *Journal of Marital and Family Therapy* 32, 4 (2006), 405–419. https://doi.org/10.1111/j.1752-0606.2006.tb01617.x

[36] Christina Kelley, Bongshin Lee, and Lauren Wilcox. 2017. Self-tracking for mental wellness: Understanding expert perspectives and student experiences. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM Press, New York, NY, 629–641. https://doi.org/10.1145/3025453.3025750

[37] Alison Kidd. 1994. The marks are on the knowledge worker. In *Proceedings of the SIGCHI conference on Human factors in computing systems (CHI '94)*. ACM Press, New York, NY, 186–191. https://doi.org/10.1145/191666.191740

[38] Josephin Klamet, Denys J C Matthies, and Michael Minge. 2016. WeaRelaxAble: A wearable system to enhance stress resistance using various kinds of feedback stimuli. In *Proceedings of the 3rd International Workshop on Sensor-based Activity Recognition and Interaction (iWOAR '16)*. ACM Press, New York, NY, Article 2, 6 pages. https://doi.org/10.1145/2948963.2948965

[39] Lisl Klein. 2014. What do we actually mean by 'sociotechnical'? On values, boundaries and the problems of language. *Applied Ergonomics* 45, 2, Part A (March 2014), 137–142. https://doi.org/10.1016/j.apergo.2013.03.027

[40] Emily G Lattie, Rachel Kornfield, Kathryn E Ringland, Renwen Zhang, Nathan Winquist, and Madhu Reddy. 2020. Designing mental health technologies that support the social ecosystem of college students. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. ACM Press, New York, NY, Article 235, 15 pages. https://doi.org/10.1145/3313831.3376362

[41] Kwangyoung Lee, Hyewon Cho, Kobiljon Toshnazarov, Nematjon Narziev, So Young Rhim, Kyungsik Han, YoungTae Noh, and Hwajung Hong. 2020. Toward future-centric personal informatics: Expecting stressful events and preparing personalized interventions in stress management. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. ACM Press, New York, NY, Article 348, 13 pages. https://doi.org/10.1145/3313831.3376475

[42] Kwangyoung Lee and Hwajung Hong. 2018. MindNavigator: Exploring the stress and self-interventions for mental wellness. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM Press, New York, NY, Article 572, 14 pages. https://doi.org/10.1145/3173574.3174146

[43] Chelsea LeNoble, David LeNoble, and Mica Estrada. 2021. Filling the sieve and wondering why we're still thirsty: A call to humanize the STEM workplace for educators and students. AAAS Improving Undergraduate STEM Education Initiative (IUSE) Blog. https://www.aaas-iuse.org/filling-the-sieve-and-wondering-why-were-still-thirsty/

[44] Gilly Leshed and Phoebe Sengers. 2011. "I lie to myself that I have freedom in my own schedule": Productivity tools and experiences of busyness. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM Press, New York, NY, 905–914. https://doi.org/10.1145/1978942.1979077

[45] Katia Levecque, Frederik Anseel, Alain De Beuckelaer, Johan Van der Heyden, and Lydia Gisle. 2017. Work organization and mental health problems in PhD students. *Research Policy* 46, 4 (May 2017), 868–879. https://doi.org/10.1016/j.respol.2017.02.008

[46] Ian Li, Anind Dey, and Jodi Forlizzi. 2010. A stage-based model of personal informatics systems. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. ACM Press, New York, NY, 557–566. https://doi.org/10.1145/1753326.1753409

[47] Yvonna S Lincoln. 2007. Naturalistic inquiry. In *The Blackwell Encyclopedia of Sociology*, George Ritzer (Ed.). Wiley-Blackwell, Chichester, UK. https://doi.org/10.1002/9781405165518.wbeosn006

[48] Silvia Lindtner, Shaowen Bardzell, and Jeffrey Bardzell. 2018. Design and intervention in the age of "no alternative". *Proceedings of the ACM on Human-Computer Interaction* 2, CSCW, Article 109 (Nov. 2018), 21 pages. https://doi.org/10.1145/3274378

[49] Andrés Lucero and Juha Arrasvuori. 2010. PLEX Cards: A source of inspiration when designing for playfulness. In *Proceedings of the 3rd International Conference on Fun and Games (Fun and Games '10)*. ACM Press, New York, NY, 28–37. https://doi.org/10.1145/1823818.1823821

[50] Sharon Mallon and Iris Elliott. 2019. The emotional risks of turning stories into data: An exploration of the experiences of qualitative researchers working on sensitive topics. *Societies* 9, 3, Article 62 (Sept. 2019), 17 pages. https://doi.org/10.3390/soc9030062

[51] Victor Mateevitsi, Khairi Reda, Jason Leigh, and Andrew Johnson. 2014. The Health Bar: A persuasive ambient display to improve the office worker's well being. In *Proceedings of the 5th Augmented Human International Conference (AH '14)*. ACM Press, New York, NY, Article 21, 2 pages. https://doi.org/10.1145/2582051.2582072

[52] David C Mohr, Mi Zhang, and Stephen M Schueller. 2017. Personal sensing: Understanding mental health using ubiquitous sensors and machine learning. *Annual Review of Clinical Psychology* 13 (2017), 23–47. https://doi.org/10.1146/annurev-clinpsy-032816-044949

[53] Wendy Moncur. 2013. The emotional wellbeing of researchers: Considerations for practice. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. ACM Press, New York, NY, 1883–1890. https://doi.org/10.1145/2470654.2466248

[54] Michael Muller. 2007. Participatory design: The third space in HCI. In *The Human–Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications* (2nd ed.), Andrew Sears and Julie Jacko (Eds.). CRC Press, Boca Raton, FL, 1061–1081. https://doi.org/10.1201/9781410615862

[55] Elizabeth L Murnane, Tara G Walker, Beck Tench, Stephen Voida, and Jaime Snyder. 2018. Personal informatics in interpersonal contexts: Towards the design of technology that supports the social ecologies of long-term mental health management. *Proceedings of the ACM on Human-Computer Interaction* 2, CSCW, Article 127 (2018), 27 pages. https://doi.org/10.1145/3274396

[56] Sara B Oswalt and Christina C Riddock. 2007. What to do about being overwhelmed: Graduate students, stress and university services. *College Student Affairs Journal* 27, 1 (2007), 24–44. https://eric.ed.gov/?id=EJ899402

[57] Benjamin A Pyykkonen. 2021. Cognitive processes and the impact of stress upon doctoral students: Practical applications for doctoral programs. *Christian Higher Education* 20, 1–2 (2021), 28–37. https://doi.org/10.1080/15363759.2020.1852134

[58] Soyoung Rhim, Uichin Lee, and Kyungsik Han. 2020. Tracking and modeling subjective well-being using smartphone-based digital phenotype. In *Proceedings of the 28th ACM Conference on User Modeling, Adaptation and Personalization (UMAP '20)*. ACM Press, New York, NY, 211–220. https://doi.org/10.1145/3340631.3394855

[59] Shannon Rodgers, Brittany Maloney, Bernd Ploderer, and Margot Brereton. 2016. Managing stress, sleep and technologies: An exploratory study of Australian university students. In *Proceedings of the 28th Australian Conference on Computer–Human Interaction (OzCHI '16)*. ACM Press, New York, NY, 526–530. https://doi.org/10.1145/3010915.3010961

[60] Shannon Rodgers, Bernd Ploderer, Brittany Maloney, and Jason Hang. 2019. Designing for wellbeing-as-interaction. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems (CHI EA '19)*. ACM Press, New York, NY, Article LBW1817, 6 pages. https://doi.org/10.1145/3290607.3312901

[61] Jerry W Rudy. 2008. *The Neurobiology of Learning and Memory.* Sinauer Associates, Sunderland, MA.

[62] Izumi Sakamoto and Ronald O Pitner. 2005. Use of critical consciousness in anti-oppressive social work practice: Disentangling power dynamics at personal and structural levels. *The British Journal of Social Work* 35, 4 (2005), 435–452. https://doi.org/10.1093/bjsw/bch190

[63] Pedro Sanches, Kristina Höök, Elsa Vaara, Claus Weymann, Markus Bylund, Pedro Ferreira, Nathalie Peira, and Marie Sjölinder. 2010. Mind the body!: Designing a mobile stress management application encouraging personal reflection. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems (DIS '10)*. ACM Press, New York, NY, 47–56. https://doi.org/10.1145/1858171.1858182

[64] Pedro Sanches, Axel Janson, Pavel Karpashevich, Camille Nadal, Chengcheng Qu, Claudia Daudén Roquet, Muhammad Umair, Charles Windlin, Gavin Doherty, Kristina Höök, and Corina Sas. 2019. HCI and affective health: Taking stock of a decade of studies and charting future research directions. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. ACM Press, New York, NY, Article 245, 17 pages. https://doi.org/10.1145/3290605.3300475

[65] Elizabeth B-N Sanders and Pieter Jan Stappers. 2008. Co-creation and the new landscapes of design. *Co-design* 4, 1 (2008), 5–18. https://doi.org/10.1080/15710880701875068

[66] Wilmar B Schaufeli, Michael P Leiter, and Christina Maslach. 2009. Burnout: 35 years of research and practice. *Career Development International* 14, 3 (June 2009), 204–220. https://doi.org/10.1108/13620430910966406

[67] Hanna Schneider, Malin Eiband, Daniel Ullrich, and Andreas Butz. 2018. Empowerment in HCI - A survey and framework. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM Press, New York, NY, Article 244, 14 pages. https://doi.org/10.1145/3173574.3173818

[68] Ralf Schwarzer and Nina Knoll. 2003. Positive coping: Mastering demands and searching for meaning. In *Positive Psychological Assessment: A Handbook of Models and Measures*, Shane J. Lopez and C. R. C. R. Snyder (Eds.). American Psychological Association, Washington, DC, 393–409. https://doi.org/10.1037/10612-025

[69] Stacey B Scott, Jennifer E Graham-Engeland, Christopher G Engeland, Joshua M Smyth, David M Almeida, Mindy J Katz, Richard B Lipton, Jacqueline A Mogle, Elizabeth Munoz, Nilam Ram, and Martin J Sliwinski. 2015. The Effects of Stress on Cognitive Aging, Physiology and Emotion (ESCAPE) Project. *BMC Psychiatry* 15, 1, Article 146 (July 2015), 14 pages. https://doi.org/10.1186/s12888-015-0497-7

[70] Katie Shilton, Jes A. Koepfler, and Kenneth R. Fleischmann. 2013. Charting sociotechnical dimensions of values for design research. *The Information Society* 29, 5 (Oct. 2013), 259–271. https://doi.org/10.1080/01972243.2013.825357

[71] Robert L Smith, Kenneth Maroney, Kaye W Nelson, Annette L Abel, and Holly S Abel. 2006. Doctoral programs: Changing high rates of attrition. *The Journal of Humanistic Counseling, Education and Development* 45, 1 (2006), 17–31. https://doi.org/10.1002/j.2161-

1939.2006.tb00002.x

[72] Jaime Snyder, Mark Matthews, Jacqueline Chien, Pamara F Chang, Emily Sun, Saeed Abdullah, and Geri Gay. 2015. MoodLight: Exploring personal and social implications of ambient display of biosensor data. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing (CSCW '15)*. ACM Press, New York, NY, 143–153. https://doi.org/10.1145/2675133.2675191

[73] Christiane N Stachl and Anne M Baranger. 2020. Sense of belonging within the graduate community of a research-focused STEM department: Quantitative assessment using a visual narrative and item response theory. *PloS one* 15, 5 (2020), e0233431.

[74] Christiane N Stachl, Emily C Hartman, David E Wemmer, and Matthew B Francis. 2019. Grassroots efforts to quantify and improve the academic climate of an R1 STEM department: Using evidence-based discussions to foster community. *Journal of chemical education* 96, 10 (2019), 2149–2157.

[75] Marc Steen, Menno Manschot, and Nicole De Koning. 2011. Benefits of co-design in service design projects. *International Journal of Design* 5, 2 (2011), 53–60. http://www.ijdesign.org/index.php/IJDesign/article/view/890

[76] Karen W Tao and Alberta M Gloria. 2019. Should I stay or should I go? The role of impostorism in STEM persistence. *Psychology of Women Quarterly* 43, 2 (2019), 151–164. https://doi.org/10.1177/0361684318802333

[77] Einar B Thorsteinsson and Jack E James. 1999. A Meta-analysis of the effects of experimental manipulations of social support during laboratory stress. *Psychology & Health* 14, 5 (Oct. 1999), 869–886. https://doi.org/10.1080/08870449908407353

[78] Liza Varvogli and Christina Darviri. 2011. Stress management techniques: Evidence-based procedures that reduce stress and promote health. *Health Science Journal* 5, 2 (2011), 74–89. https://www.hsj.gr/medicine/stress-management-techniques-evidencebased-procedures-that-reduce-stress-and-promote-health.php?aid=3429

[79] Rafael Wampfler, Severin Klingler, Barbara Solenthaler, Victor R Schinazi, and Markus Gross. 2020. Affective state prediction based on semi-supervised learning from smartphone touch data. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. ACM Press, New York, NY, Article 377, 13 pages. https://doi.org/10.1145/3313831.3376504

[80] Kerrie G Wilkins-Yel, Amanda Arnold, Jennifer Bekki, Madison Natarajan, Bianca Bernstein, and Ashley K Randall. 2022. "I can't push off my own Mental Health": Chilly STEM Climates, Mental Health, and STEM Persistence among Black, Latina, and White Graduate Women. *Sex Roles* 86, 3 (2022), 208–232.

[81] Eva Wong. 2011. *Taoism: An Essential Guide.* Shambhala Publications, Boston, MA.

[82] Mengru Xue, Rong-Hao Liang, Bin Yu, Mathias Funk, Jun Hu, and Loe Feijs. 2019. AffectiveWall: Designing collective stress-related physiological data visualization for reflection. *IEEE Access* 7 (2019), 131289–131303. https://doi.org/10.1109/ACCESS.2019.2940866

[83] Bin Yu, Jun Hu, Mathias Funk, and Loe Feijs. 2018. DeLight: Biofeedback through ambient light for stress intervention and relaxation assistance. *Personal and Ubiquitous Computing* 22, 4 (Aug. 2018), 787–805. https://doi.org/10.1007/s00779-018-1141-6

[84] John Zimmerman and Jodi Forlizzi. 2014. Research through design in HCI. In *Ways of Knowing in HCI*, Judith S Olson and Wendy A Kellogg (Eds.). Springer, New York, NY, 167–189. https://doi.org/10.1007/978-1-4939-0378-8_8

[85] Marc A Zimmerman. 2000. Empowerment theory. In *Handbook of Community Psychology*, Julian Rappaport and Edward Seidman (Eds.). Springer Science+Business Media, New York, NY, 43–63. https://doi.org/10.1007/978-1-4615-4193-6_2