



A Review & Analysis of Mindfulness Research in HCI

Framing Current Lines of Research and Future Opportunities

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ABSTRACT

Mindfulness is a term seen with increasing frequency in HCI literature, and yet the term itself is used almost as variously as the number of papers in which it appears. This diversity makes comparing or evaluating HCI approaches around *mindfulness* or understanding the design space itself a challenging task. We conducted a structured ACM literature search based on the term *mindfulness*. Our selection process yielded 38 relevant papers, which we analyzed for their definition, motivation, practice, evaluation and technology use around mindfulness. We identify similarities, divergences and areas of interest for each aspect, resulting in a framework composed of four perspectives and seven lines of research. We highlight challenges and opportunities for future HCI research and design.

CCS CONCEPTS

• **Human-centered computing** → *HCI theory, concepts and models*;

KEYWORDS

Mindfulness; Literature Review; Perspectives; Conceptualization; Practice; Meditation; Reflection; Interaction; Well-being

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1 INTRODUCTION

Mindfulness is a long-standing concept in Buddhism, introduced to psychology research in the 70's by Ellen Langer [32]. Jon Kabat-Zinn brought mindfulness into therapeutic practice and coined the term mindfulness-based stress reduction (MBSR) [24]. His work raised broad awareness and received attention from psychology, psychotherapy, neuroscience and military researchers, as well as therapists and meditation practitioners. Approximately one decade ago, human-computer-interaction (HCI) researchers got attracted by *mindfulness* as well. The growth of the number of emerged HCI publications around the term *mindfulness* shows a steady increase in recent years (s. Figure 1d). The communities around an emerging research topic need a clear and common understanding of *what* the topic comprises and what is out of its scope, which is usually supported by a definition. For mindfulness, there is a myriad of definitions and conceptualizations and no clear and mutual understanding of what it comprises and what not, as we elaborate further below.

Within this analysis, we review the HCI literature foregrounding mindfulness, to determine: where there may be a consensus in understanding, what the foundations in related work for these uses are, and how these understandings of mindfulness have informed associated designs and evaluations. Our goal is to create a framework of mindfulness in HCI (s. Figure 2) to help researchers both (1) to identify research gaps and opportunities and (2) to better communicate ideas by sharing a common understanding of mindfulness.

We approached these questions by performing a structured literature review, which, after a careful selection process, yielded 38 relevant papers. We analyzed these papers regarding research motivation, practice, evaluation and technology use in mindfulness research. We identified common motivations and topics, as well as understandings of mindfulness in HCI, and encapsulated these into a framework

consisting of current *lines of research*, as well as *perspectives* on mindfulness. We close this work by highlighting occurring opportunities and challenges for future HCI research.

2 CONCEPTS & DEFINITIONS OF MINDFULNESS IN OTHER DISCIPLINES

This section presents definitions of mindfulness from other research fields, in particular from the following three areas: Buddhism, therapeutic practices of mindfulness and psychological concepts of mindfulness. We depict the conceptualizations that were adopted and adapted most by our reviewed HCI publications and point at the ambiguity of conceptualizing mindfulness.

Buddhism. The word *mindfulness* translates the words *sati* from Pali and its Sanskrit counterpart *smṛti*, which mean "recalling", "having on mind" (e.g., [10]), into the English language. As one of the first attempts to verbalize mindfulness, Nyanaponika equalizes the notion of mindfulness to bare attention: "*the clear and single-minded awareness of what actually happens to us and in us, at the successive moments of perception*" [51]. However, these very simple conceptions of mindfulness do not pass without extensive debates [48]. Many scholars argue that the meaning of mindfulness in Buddhism surpasses pure perception and includes many other mental phenomena, among others, the "lucid awareness" [10] or a reflection or evaluation [10, 18, 19] of ones' inner and outer experiences. Classical texts on mindfulness from Buddhists' traditions explain mindfulness as an ineffable spiritual phenomenon [58]. A scientific approach to this spiritual concept is difficult and can hardly be expressed in definitions.

Therapeutical Practices. In psychotherapy, the concept of mindfulness is applied to help people in dealing with their disorders or coping with life and usually guided by a therapist or a technology. Jon Kabat-Zinn is attributed for secularizing meditation practices from Buddhism in the late 70s. He introduced them to western medicine, where he essentially coined the term mindfulness when he founded a clinic for stress reduction at the University of Massachusetts. Jon Kabat-Zinn first defined mindfulness as follows: "*[Mindfulness is] the awareness that emerges through paying attention on purpose, in the present moment, and nonjudgmentally to the unfolding of experience moment by moment*" [25]. Other scholars, as cited in [60], disputed this definition, for being non-exhaustive. Nonetheless, strongly tying this notion of mindfulness to "the heart" of meditation [51] led to the development of several mindfulness-based, psychological therapies: MBSR, Mindfulness-Based Cognitive Therapy (MBCT) or Dialectical Behavior Therapy (DBT), to treat, e.g., chronic pain [24, 26], depression relapse [50] or borderline personality disorders [34], respectively.

Psychological Concepts. There are a number of conceptualizations of mindfulness in broad psychology research (e.g., [46, 47, 50, 60]), for example, psychological well-being or mental health. We focus on the three definitions that we saw used most often in the reviewed HCI literature.

Langer [31] is a pioneer in researching mindfulness in the broad field of psychology. She defined mindfulness as a *cognitive process of noticing new things* and suggests that mindfulness is simply the *opposite of mindlessness*.

In order to promote the operationalization of mindfulness, Bishop et al. [9] proposed a two-component model of mindfulness: (1) *self-regulating attention*, i.e., maintaining focus over a period of time to an object (whereas object can be any attention-involved stimulus, such as experience, artifact, thought etc.) and (2) *orientating to experiences*, i.e., openness to whatever happens in and around a person.

The conceptualization of Brown & Ryan [12] is of particular interest for the framework described below. They mention two perspectives on mindfulness as (1) a *state or mode a person rises to*, thus becoming (more) mindful in a particular moment of time; and (2) a long-term *trait everyone bears*, i.e., a mindful capacity that, however, "*varies within persons, because it can be sharpened or dulled by a variety of factors*". We refer to these aspects throughout the rest of the paper as *state* and *trait* mindfulness.

These researchers express their conceptualizations of mindfulness in different, yet, overlapping ways. According to Nicholas T. Van Dam, a somewhat critical of the mindfulness movement, the term mindfulness has "*a plethora of meanings*" and is "*an umbrella term used to characterize a large number of practices, processes, and characteristics, largely defined in relation to the capacities of attention, awareness, memory/ retention, and acceptance/ discernment*" [54] – the ambiguity of conceptualizing mindfulness is also what we experience in HCI. We emphasize that we do not consider any of the listed definitions or notions as *true or false*. Instead, we see them as descriptive points for orientation within the research space.

3 METHODOLOGY

We conducted a structured literature review that targeted full and short papers as well as works-in-progress and posters. We draw the reviewed literature exclusively from the ACM Digital Library as our aim was to understand mindfulness research within the HCI community solely.

Search & Paper Set Extraction

The ACM Advanced Search resulted in 3,017 hits for the search string "mindfulness"¹. Sorted by relevance, we exported the publication information (without abstract) of the first $N = 2,062$ results (limited by ACM Digital Library). To

¹Searching additionally for the 'mindful' yielded the same amount of papers.

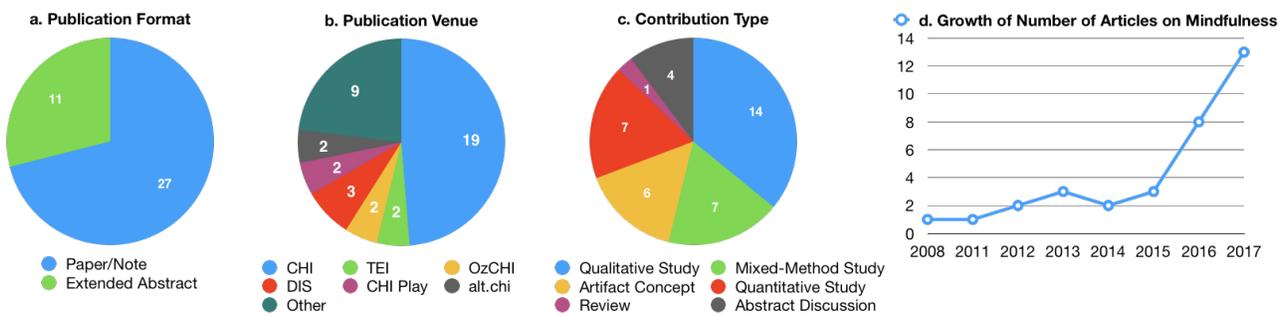


Figure 1: The pie charts show the (a) publication format, (b) venue and (c) contribution type of the reviewed HCI papers. The line chart shows the publication trend.

further narrow down the resulting set, we developed a parser that searched the publication information for a set of terms and assigned points for each term². The parser calculated an overall score for each paper:

$$\text{overall_score} = \sum \text{points}(\text{keyword})$$

We then sorted the publications by the overall score and reviewed the list manually. We excluded all papers scoring lower than ten, as these papers did not contain one of the terms mindfulness and meditation³ or a subset of other relevant terms. Furthermore, we reviewed these papers manually and did not find any relevant ones among these. We thereby reduced the set of papers to $N = 225$.

We proceeded to exclude articles manually and independently (two raters). Papers with scores between 10 and 29 points ($n = 174$) were judged based on their title and keywords. For papers that scored equal to or higher than 30 points, we additionally reviewed the abstracts ($n = 51$).

We independently excluded papers that (1) did not mention mindfulness or a related term (e.g., meditation), (2) were clearly not related to mindfulness, (3) were concerned with mindfulness for a group instead of individuals, and (4) did not belong to the targeted publication formats (i.e., full and short papers, works-in-progress and posters).

Then, both raters compared their lists of relevant papers and discussed each inconsistency until consensus was reached. In case this inconsistency concerned a paper of which the abstract was not reviewed in the first place, it was now considered in order to make a final decision (again independently). This process yielded a set of $N = 49$ papers.

² We parsed the titles and keywords for the following terms. The terms *mindfulness* and *meditation* received ten points. The terms *intervention*, *practice* and *definition* received eight points. The terms *effect*, *measurement*, *assessment* and *evaluation* received six points. All remaining terms were given four points: *reflection*, *understanding*, *self*, *mind*, *body*, *attention*, *focus*, *awareness*, *knowledge*, *consciousness*, *cognition*. Variations of a words received the same amount of points, e.g., meditating receives ten points.

³ We searched for meditation as it is many times related or even set equal to mindfulness.

We then read the full texts of the remaining papers and excluded additional 11 articles due to the missing or loose relationship to mindfulness. This resulted in our final set of $N = 38$ articles. Figure 1 provides an overview of the publication formats, venues and the contribution types of the resulting paper set as well as the publication trend.

Analysis & Coding

We coded the research type (study, review and concept), motivation and topic, cited mindfulness definitions and authors' conceptualization, researched co-aspects of mindfulness (e.g., meditation), mindfulness practice, evaluation, measurement, findings and technology use for each paper.

In order to unify the coding, four papers were coded independently by both raters. We discussed the extracted content until we agreed upon a common coding approach. Then, each rater coded a set of papers independently. Since we found the motivation difficult to code, both raters coded this aspect independently and again revised them together. Thematic analyses of the definitions, practices, co-aspects, research motivations and topics resulted in four *perspectives on mindfulness* and seven *lines of research*, displayed in Table 1. We eventually classified each paper according to the perspectives and connected its perspectives to its line of research, which resulted in a deeper analysis of the research practices in HCI and an alluvial diagram (see Figure 2).

Methodological Limitations

We excluded libraries other than ACM DL and other research fields, such as medical and mental health literature, as these would water down the focus on HCI research. Yet, for a more broad understanding of mindfulness, HCI researchers may want to refer to literature from other fields as well.

Papers that did not refer to "mindfulness" or related terms in their title, keywords or abstract, were excluded from our review. However, some of these papers might have yielded

interesting insights in their full texts. We also excluded papers that targeted mindfulness for more than one person. Finally, our analysis may not be considered exhaustive.

4 RESULTS OF THE LITERATURE REVIEW

Below, we summarize the definitions and conceptualizations, the practice of mindfulness as well as the technology developed for mindfulness research.

Definitions & Conceptualizations of Mindfulness

We catalogued the definitions mentioned in the reviewed publication corpus and adopted any additionally stated interpretations or aspects of mindfulness. We traced the definitions and aspects of mindfulness back to the original source (s. section 2). The majority of papers adopt one or more definitions or interpretations of mindfulness ($n = 20$). Some works ($n = 9$) discuss and acknowledge the difficulty of defining mindfulness, but do not explicitly state a definition or take a position, leaving their notion of mindfulness unclear to the reader. Authors of the remaining articles ($n = 9$) did not define or conceptualize mindfulness.

Adopted Definitions. Most commonly ($n = 14$), authors referred to the related definition(s) of Kabat-Zinn (e.g. [24, 25, 27] or Walsh & Shapiro [59] ($n = 11$), Baer [5] ($n = 2$) or Nyanaponika [51] ($n = 1$). The operational definition of Bishop et al. [9] and Brown & Ryan's [12] state-or-trait perception of mindfulness were adopted twice each.

Some authors [1, 2, 13] explicitly rejected these modern definitions due to their perceived oversimplifications and instead referred to what they framed as the more holistic notion in Buddhism. For example, Chen et al. [13] referred to the extensive debates of Buddhist scholars Dreyfus [18], Dunne [19] and Bodhi [10] and proposed their own operational definition that extends present-centered mindfulness by recollection and evaluation of experiences.

Alternative views include mindfulness as a state in which one performs a certain task (according to [43], as cited in [38]), mindfulness as a break or detour from reality [1], mindfulness as the process of gaining new knowledge [3], or as the opposite to mindlessness [15] or mind-wandering [41, 61].

Mindfulness Aspects. To identify the aspects which seem to be most interesting to HCI researchers, we broke the definitions and interpretations down to single terms and counted their appearance. The aspects mentioned most were attention ($n = 13$), presence ($n = 9$), experience ($n = 9$, covering experience, thoughts, feelings, sensations, etc.; similar to what we call *object*), non-judgmental ($n = 8$), moment-to-moment ($n = 7$) and awareness ($n = 7$). These are followed by acceptance, reflection and intention ($n = 4$ each). Mindfulness was interpreted as or equalized to a state, meditation or MBSR, or noted as not goal-oriented ($n = 3$ each). The remaining

aspects include mindfulness as opposed to mind-wandering ($n = 2$) or mindfulness as a mediator of performance ($n = 4$).

Practice of Mindfulness

Mindfulness practice is commonly subdivided in *formal* and *informal* practice. Formal practices are regimented sessions in which a person is dedicated solely to the mindfulness practice. Informal practice refers to non-regimented practices and the cultivation of mindfulness in everyday life.

The majority of papers ($n = 20$) provide examples for informal practices, e.g., self-observations by means of self-tracking or simplified, abstract captures of a mindful experience ($n = 7$), *slow* interaction ($n = 5$), or mindfulness promotion in daily life behaviors ($n = 3$).

Further 16 papers contain examples for formal practices, almost exclusively in the form of a self-regulative meditation exercise in which participants had to be attentive to their own breathing sensations or body parts (e.g., [39, 42, 44, 57]).

Technology for Mindfulness

The majority of researchers examined how technology can support mindfulness ($n = 34$). Researchers developed and applied various types of technology for mindfulness such as virtual reality (VR) systems [21, 29, 30, 37, 40, 41, 45], mobile applications [14, 53] or tangibles [6, 52, 55]. Although a large percentage of projects included sensing technology to provide bio- or neuro-feedback on participants' sensations ($n = 14$), only a few ($n = 4$) deployed it to measure physical indicators of mindfulness (see section 4). Instead, most works used bio-sensing to track the participants' physical state as an indicator of the participants' mental state, most commonly in VR meditation sessions ($n = 6$). Feedback here is provided through various modalities: audio ($n = 6$), visual ($n = 7$), touch and haptics (i.e., tangibles; $n = 4$), or combinations of them ($n = 4$). Few papers are concerned with the mediating effect of trait mindfulness on user's performance in interacting with technology ($n = 4$).

Evaluation of Mindfulness & Technology

We additionally examined how mindfulness was evaluated in the reviewed papers. We report how mindfulness and its co-aspects are evaluated and the metrics and scales used.

Evaluating Mindfulness & Co-Aspects. 14 of the papers containing a study ($n = 28$) did not evaluate mindfulness *per se*. Frequently, researchers investigated aspects that they associate with mindfulness. For example, they considered the quality of the meditation technique (e.g., [30]), sustained respiration pace (e.g., [39]) or relaxation and attention level (e.g., [23]). The authors, hence, equalize improvements in these proxies to improvements in mindfulness, which blurs the findings and benefits associated with mindfulness.

Table 1: The *lines of research* describe the topics and motivations of mindfulness research in HCI.

Line of Research	Description	Publications
A. Meditation Practice	Technologies that facilitate, enhance or mimic a meditation practice or experience	[17, 23, 29, 30, 36, 37] & [39–42, 44, 53, 56, 57]
B. Therapy	Technologies that cultivate mindfulness in mental health therapy	[6, 21, 45, 52]
C. Reflection & Knowledge Gain	Self-tracking and self-observing to gain new insights about oneself	[3, 4, 35]
D. Mindfulness in Daily Life	Technologies that promote mindfulness in everyday life behaviors	[7, 20, 22]
E. Mindfulness in Interaction	Objects and technologies for cultivating mindful interactions	[1, 2, 13–15, 38, 55]
F. Performance Enhancement	Effect of mindfulness on task performance	[8, 28, 33, 61]
G. Meta-Level Research	Reviews & design discussions (of technology) around mindfulness	[16, 62, 63]

Metrics & Scales. Self-reporting questionnaires dominate the used evaluation methods, which some researchers find inappropriate (e.g., [44]). These include the Mindfulness Attention Awareness Scale or the Toronto Mindfulness Scale, which root in psychology research. Furthermore, questionnaires that examine aspects related to mindfulness are applied, such as the Subjective Happiness Scale or the Meditation Depth Questionnaire. Sas et al. [44] argue that the standardized questionnaires from psychology evaluate the *trait* mindfulness and that there is no (established) questionnaire for evaluating mindfulness as a *state* and, hence, designed their own scale. In four papers, the results from the self-reporting questionnaire were complemented with measures from physiological sensors, e.g., electroencephalogram (EEG), heart rate, respiration or skin conductance. Researchers, thereby, assessed various aspects related to mindfulness, such as relaxation, stress, focus or meditation quality. Few researchers ($n = 7$) conducted interviews or questionnaires to obtain qualitative insights. These mostly examined users' feelings that were induced by or directed towards a technology for mindfulness (e.g., [14]). In exceptional cases authors compare the feelings that emerged from using the system with feelings produced by a mindfulness practice (e.g., [40, 56]). 23 papers (60%) did not include any evaluation of mindfulness, a proxy or a co-aspect. Instead, these papers investigate user's perceived value of and experiences with the developed system ($n = 8$), the design of technology for mindfulness ($n = 5$) or the mediating effect of mindfulness on other phenomena, such as task performance or mind-wandering ($n = 4$). The remaining papers ($n = 10$), which propose a technology or practice for mindfulness, do not report an evaluation to underpin the claim of enhancing mindfulness or being designed mindfully.

Findings of HCI Research about Mindfulness

Qualitative findings on users' experiences with the proposed technology were notably positive. For example, the ease of use [36], users' engagement with the system [20, 37, 55, 56] or the appropriateness of the intervention method to cultivate mindfulness [4, 39, 53] were mostly rated positively. In

many of these cases, participants reported developing feelings which seem related to mindfulness, for example, higher relaxation [14, 23, 40, 56], a sensation of flow [37, 56], enhanced focus [14, 23], increased awareness of oneself and the environment [20, 36, 37, 56] or enhanced well-being [3, 4]. Few studies showed a positive mediating affect of mindfulness or its practice on task performance [8, 33], media mind-wandering [61], and gaming competence [28].

5 FRAMEWORK

We further analyzed the publication set to identify the perspectives on mindfulness as well as how these perspectives relate to the works' common motivations, i.e., research topics. This thematic analysis resulted in a framework consisting of (1) four different approaches and views to mindfulness in HCI, that we call *perspectives* on mindfulness, and (2) seven common research topics, which we label as *lines of research*. Figure 2 visualizes the resulting seven lines of research that emerged from our publication corpus through the lens of our framework's perspectives. The vertical pillars represent the lines of research (most left), as well as the four perspectives on mindfulness and their categories. Each horizontal line represents one paper of our literature set. Effectively, the diagram illustrates which perspectives on mindfulness each paper foregrounds. For example, it shows that the main research motivation in HCI evolves around supporting formal meditation practices (line of research: *meditation practice*), and equates mindfulness with meditation (co-aspects: *meditation*). On the other hand, HCI research has yet to explore long-term effects of technology assisting mindfulness, i.e., trait mindfulness (longevity: *trait*). We note that some papers could be assigned to more than one line of research. In this case, the secondary line is commonly meditation. We did not assign these papers to meditation because the paper's primary intention was not to investigate meditation, i.e., meditation was rather a mediator. Similarly, we assigned the publications to the perspectives' categories to the best of our knowledge and understanding, as these are often not directly stated by the authors themselves.

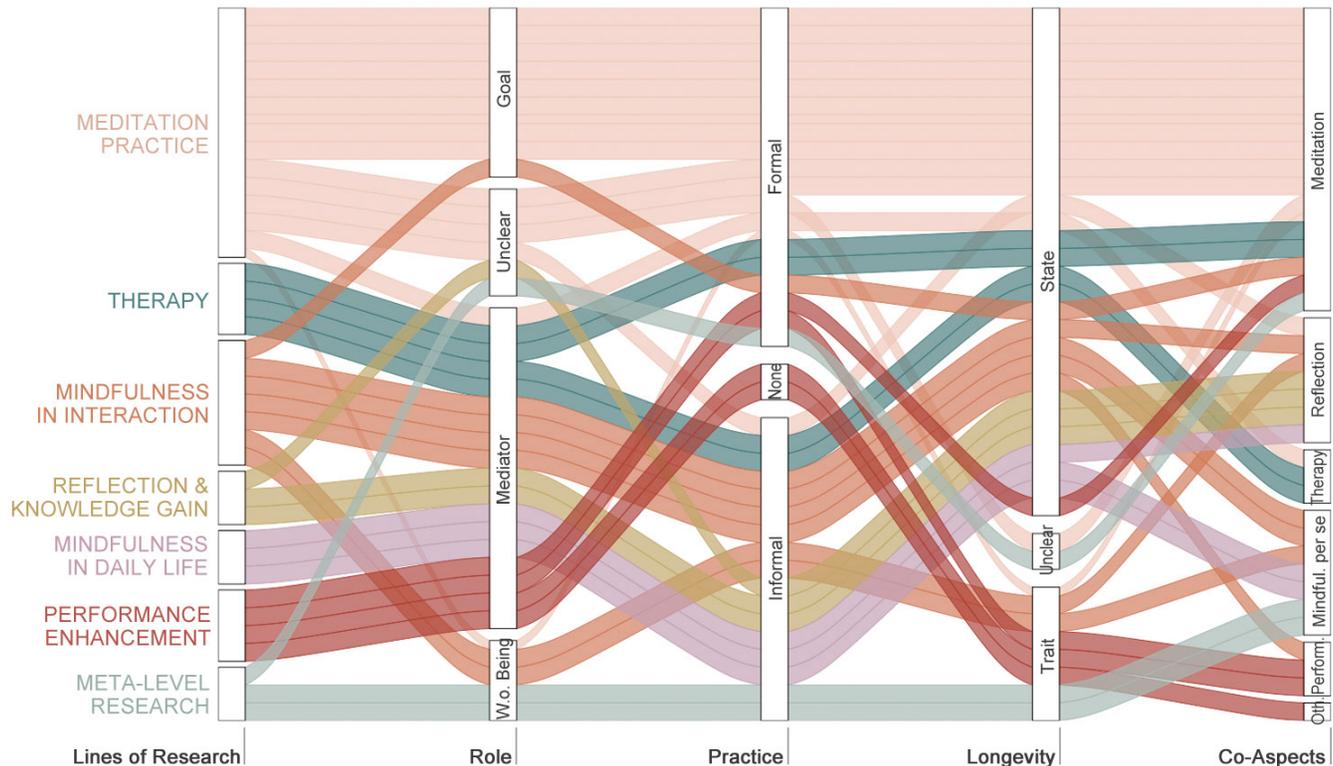


Figure 2: Alluvial diagram of the seven emerged lines of research categorized based on the four perspectives of mindfulness. The columns of the diagram display (from left to right): (1) the line of research, (2) role, (3) practice, (4) longevity and (5) co-aspects of mindfulness.

Perspectives on Mindfulness

Our analysis revealed four different *perspectives* on mindfulness: (1) **Role**, (2) **Practice**, (3) **Longevity** and (4) **Co-Aspects** of mindfulness. Prospective authors on mindfulness might want to declare their conceptualization and operationalization of mindfulness and to refer to the perspectives for a more unified and clear communication. Below, we briefly explain each perspective and its categories.

1. Role: Goal, Mediator or Way of Being. The *role of mindfulness* describes whether someone regards it as a *goal* to reach, *mediator* to reach something else or simply a *way of being*. The latter means that someone cultivates mindfulness in a rather passive manner in daily life contexts, for example by “washing the dishes for washing the dishes” [11]. In contrast, *goal* and *mediator* have an active character, meaning that someone is actively pursuing a goal and deliberately performing a formal or informal practice to achieve this goal. The *mediator* role notes mindfulness as a road to certain achievements such as stress reduction in MBSR or higher task performance, suggesting that one may stop practicing

mindfulness when this goal is reached. In contrast, the category *goal* regards mindfulness as a trait at the end of a road and the road being a process such as meditation or slow interaction. However, an improvement pursued by practicing mindfulness (mindfulness as mediator) by one person could also occur as a side-effect that results from the trait mindfulness for another person. Furthermore, Buddhists strongly reject the perspectives *goal* and *mediator*. They say that the one whose goal is to reach mindfulness will never quite reach it, as in Zen, *everyone is a beginner, always* [49].

2. Practice: Formal or Informal. There is a common distinction between informal and formal ways [8] of practicing mindfulness within the analyzed articles. Under informal practices we understand cultivating mindfulness during everyday actions with no strict regimen. We encountered two major ways of informal practices: (1) Stimulating the user to take a break and reflect on inner and outer experiences with or through technology; (2) Providing new or redesigning existing technology for a more thoughtful and slow – mindful – interaction. Formal practices, most commonly meditation, are a set of more or less strict rules to exercise focus and attention. These rules can include the duration of the exercise,

body posture, respiration patterns and others. We note that, if practiced intentionally and repeatedly, informal practices may become formal for an individual.

3. Longevity: State or Trait. We draw this perspective from the definition of mindfulness by Brown & Ryan [12], who differ between state and trait aspects of mindfulness, as denoted in section 2. Researchers have diverging perspectives regarding the longevity of mindfulness, meaning the manifestation of mindfulness in oneself on the short- or long-term. We adopt the notion that mindfulness *state* refers to short-lived changes in one’s *mindfulness capacity* [12, 42]. For example, mindfulness meditation or other formal practices can increase this capacity on the short-term but aim at long-term effects. Most HCI studies investigated mindfulness as a state. They often measured mindfulness directly after a formal or informal practice but did not investigate or track long-term changes, i.e., not exceeding a certain amount of sessions. In contrast, mindfulness *trait* refers to enduring changes in one’s capacity and is, hence, closely related to the perspective *mindfulness as a way of being*. The research work on *Inner Garden* [41], makes a clear distinction of these perspectives and investigates both the level of mindfulness a person has through everyday life (trait) compared to the level induced by meditation (state).

4. Co-Aspects: Meditation, Reflection and Others. This category summarizes the foci researchers sometimes set when studying mindfulness. We observe that several works strongly relate mindfulness to other terms or use those terms as a proxy for achieving mindfulness, most notably to *meditation* (e.g., [39, 44]), *self-reflection* (e.g., [4, 13]) and *therapy* (e.g., [52]). Although this generally acknowledges the complex nature and wide applicability of mindfulness, it introduces confusion and ambiguity when not explicitly stated. We often found the terms of mindfulness and the co-aspect used interchangeably, suggesting that mindfulness is limited to this aspect. In these cases, we refer to a co-aspect of or a *proxy* for mindfulness, instead of *mindfulness per se*.

Lines of Research in HCI

A *line of research* represents a common research motivation and topic. Our thematic analysis yielded seven lines of research: (A) **Meditation Practice**, (B) **Therapy**, (C) **Reflection & Knowledge Gain**, (D) **Mindfulness in Daily Life**, (E) **Mindfulness in Interaction**, and (F) **Performance Enhancement** (see Table 1). Below, we explain each line of research and underpin the line by illustrative examples from the reviewed publication set. We further relate them to the perspectives on mindfulness, as visualized in Figure 2.

A. Meditation Practice. 15 of the 38 analyzed papers are *primarily* concerned with facilitating, enhancing or mimicking meditation practices. Most commonly, technology aids users in attaining and maintaining attention on inner or outer experiences such as respiration [36, 37, 39, 40, 57], touch movements [23, 42] or brain activity [29, 30, 44]. Such technologies support the attention regulation process by detecting changes in the user’s focus through physiological measurements, usually during formal practices of mindfulness. For example, the users of *SonicCradle* stated to have experienced feelings similar to those known from meditation [56, 57]. Another trending topic is VR, which is often researched together with bio-feedback, as mindfulness or meditation tool [29, 30, 37, 40, 41, 45]. For example, Kosunen et al. [30] investigated a VR meditation tool with neuro-feedback. The brain activity is implicitly presented in the environment and explicitly by a levitation of the user’s virtual body. They showed that the system can elicit deeper relaxation and meditation, particularly for novices. Variations in user’s attention sensation and feedback modality exist. For example, *MeditAid* [44], a wearable, EEG-based system, can identify different meditative states and help users deepen their meditation by providing aural neuro-feedback. On the other hand, Detherick [17] investigated in an ethnography study how meditators and meditation communities use technology in everyday life meditation.

B. Therapy. Researchers who investigate mindfulness in the context of therapy seem to regard mindfulness as a mediator to alleviate mental disorders and, e.g., mitigate depression or panic disorders. People who undergo a MBSR therapy have to follow a formal meditation regiment, which some HCI researchers aim to support by technology (e.g., [21]). Other researchers aim to support therapies in an informal way by strengthening the sense of the self and the surroundings through observation [6, 45, 52]. For example, Thieme et al. [52] developed a tangible called *Sphere*. The Sphere measures a person’s heartbeat and feeds it back through colorful lights and soft pulsating vibrations. It aims to help DBT patients in focusing attention and regulating the self. Similarly, Seol et al. [45] work on a tangible with heart beat for CBT. The tangible *Sprite Catcher* [6] captures pictures of events and objects from the environment and reduces them to time of occurrence, color and brightness. The *sprites* aim to help patients with depression to engage in self-reflection without focusing on details. All approaches provide a minimal amount of information to the user to promote focusing on what is real and important in the presence.

C. Reflection & Knowledge Gain. Research that belongs to this line regards mindfulness rather as a practice of self-reflection and recollection. Practicing mindfulness means observing the self as well as reflecting about the past, presence

and future and, thereby, gaining more intimate and deeper knowledge [10]. By now, in this line of research mindfulness is practiced primarily informally. Ayobi and colleagues [3, 4] propose to use journals for cultivating a way of mindful, positive thinking. Mind Pool [35] is an interactive artwork based on an exploratory Brain-Computer Interface. It uses the auditive and visual modality to provide feedback about one's brain activity. To encourage sustained interaction and self-reflection, feedback is presented ambiguously.

D. Mindfulness in Daily Life. In this category, we summarized papers that evolved around achieving mindfulness in daily life contexts such as sleep [7], nutrition [20] or technology disengagement [22]. In these works, mindfulness seems to be regarded as a raised awareness when making everyday life decisions or acting around the referred contexts. By now, all examples of this research line regarded mindfulness in everyday life as informal practice, by taking a step back and contemplating about the common, everyday happenings in and around oneself. Mindfulness in everyday food decisions can be promoted with the help of *Crumbs* [20], which are daily nutritional or non-nutritional food challenges. The user is challenged with a new *crumb* every day and accomplishes it by taking a photograph of food that meets the challenge and later consuming it. Another example is *MyTime* [22], a system that reminds the user of self-defined smartphone usage limits. It periodically prompts *aspirations* when the user spends time with distracting apps, to remind the user of the goals of the day and to encourage reflection. Finally, Bauer et al. [7] promote users' awareness and, thereby, mindfulness of how activities that are performed throughout the day may disrupt their sleep.

E. Mindfulness in Interaction. Researchers that are concerned with mindfulness in interaction seem to limit their research to informal mindfulness practices. A common theme is slowing down interactions with technology and reducing the focus on efficiency (e.g., [15, 55]). Cox et al. [14, 15] argue that deliberate interruptions or frictions in interaction can prompt positive moments of reflection and, thus, promote a more "mindful" interaction. Rheden and Hengeveld [55] propose that mindful interactions "*stimulate a more direct involvement with [whatever a technology is concerned with], leading to more engagement with and care for what you are doing*". To explore slow interactions, they developed and examined three interfaces for a kitchen blender that require careful use. The *PAUSE* App [14] draws upon principles from Tai Chi and mindfulness meditation by extracting the essential qualities of slow, continuous and gentle bodily movements, and transferring them to finger movements – performing a "mindful touch". All three publications share the paradigm of slow interactions, hoping that this slowness exceeds interaction and slows down other aspects of one's life. Chen et

al. [13] approached mindful interactions differently. They developed a tool called *ColorAway*, which removes colors from photographs and requests the user to re-color these photos in order to elicit moments of recollection and, ultimately, mindfulness.

F. Performance Enhancement. This line of research focuses on enhancing the performance in tasks other than meditating. Accordingly, research that belongs to this line regarded mindfulness as a mediator, a means to reach a goal, but not as the goal itself or as a way of being. So far, only few works investigated the relationship between mindfulness and performance ($n = 4$). One of these works investigated the influence of mindfulness meditation sessions on students' performance in conceptual modelling of software problems [8]. They reported that these students did not deliver higher quality models but that they were more efficient in the modelling task, i.e., required less time for comparable results.

Two other papers were concerned with multitasking performance: Yildirim et al. [61] investigated the effect of mindfulness on the relationship between media multi-tasking and mind-wandering. In this research, mindfulness is regarded as a trait and participants did not have to perform any practice. The researchers showed that (trait) mindfulness correlates negatively with multi-tasking as well as with mind-wandering, which supports the notion that mind-wandering and mindfulness are opposing concepts. Levy et al. [33] investigated the influence of meditation sessions on the multi-tasking performance of office workers. They found no influence on the task efficiency but showed that participants engaged less in multi-tasking, had a better task recall and a lower stress level.

G. Meta-Level Research. Several researchers [16, 62, 63] aimed at getting a better *meta-level* understanding of (the technologies created for) mindfulness. For example, Dauden Roquet analyzed 16 mindfulness meditation apps in an evaluation study [16]. Zhu et al. [63] proposed four levels of "digital mindfulness" for classifying mindfulness apps. The highest level, "*Digital Mindfulness 4.0*", suggests that technology may not be a tool but a companion for mindfulness practice in everyday life. Also the work at hand belongs to this line of research.

Framework Discussion

Our framework is based on the *current* body of literature and classifies the conceptualizations and the sub-fields of the recently emerging and growing research field in HCI on mindfulness. We analyzed and grouped the papers thematically and primarily based on the overarching research goal and field of application since these (seem to have) influenced

the other research aspects such as methodology and evaluation of mindfulness and are, hence, fundamental to the work. Nonetheless, a different way of grouping the papers might have revealed other perspectives, lines of research and opportunities. In some cases, it happened that we had to assign research papers with fundamental commonalities to different lines of research. For example, works that explicitly researched meditation practices are separated from the ones that only utilized them. Also, some publications might have been assignable to multiple lines of research and perspectives – in these cases we decided for the more prominent research goal. With the framework, we intend to help other researchers interested in mindfulness to quickly understand the field and the state of research, to find relevant or related work and to better position their own research in the landscape of mindfulness research in HCI. We emphasize that the framework should be regarded as a snapshot of the *current* state of research. We invite other researchers to adapt and extend the framework by, e.g., introducing new perspectives or sub-dividing lines of research – but also by pursuing the research opportunities and questions raised below.

6 OPPORTUNITIES & CHALLENGES FOR FUTURE MINDFULNESS RESEARCH IN HCI

Next to the mutual lines of research, our analysis also revealed contradicting and diverging research and design approaches. In our opinion, some of these antitheses are relevant to fundamental design decisions or represent interesting research opportunities and directions. Below, we discuss the ones that seem most relevant to the research community or are most thought-provoking – in order to think beyond the current or upcoming studies and to ponder long-term goals valuable to the research community and, more importantly, the users.

Capturing & Sharing Mindfulness. Akama and colleagues [1, 2] describe how they (personally) repetitively evoke a mindful state at certain places and with certain objects. They also tried to capture their moments of mindfulness in artifacts, e.g., photographs and videos, and say that they could sometimes re-evolve mindfulness when looking at them again. Also, sharing these artifacts with others, discussing about them and explaining why they induced a feeling of mindfulness could sometimes induce a mindful feeling in others. Also, Barker et al. [6] suggest the use of artifacts (abstracted pictures, e.g., of ones environment) to promote mindful reflection. In contrast to these personal artifacts, Thieme et al. [52] and Seol et al. [45] designed tangibles with haptic feedback, simulating a heart beat, that aim to help mindfulness and reflection.

These findings raise a number of questions: If mindfulness really can be captured in and evoked by artifacts, this

would suggest that a mindful moment is not a personal experience one has when focusing on it, but that it is really "carried" by the artifact and potentially abstractable to specific characteristics – making it reproducible. Could, for example, photographs of nature (nature is commonly associated with mindfulness, e.g., [2, 41, 44]) or objects such as stones (like in Zen) already evoke such feelings? Would that mean that we could have a store selling mindfulness? Presumably not, but maybe there is a way in which people can capture mindful moments and carry it in their pockets, e.g., on their phones.

User Control versus Acceptance. In HCI, one interaction paradigm is to give control to the user. In contrast, many definitions and conceptualizations around mindfulness emphasize the aspect of *acceptance*. What happens when mindfulness and technology meet?

For example, van Rheden and Hengeveld [55] noted the need to design mindfulness technology for control. Other researchers (e.g., [41, 52, 62]) suggested that mindfulness technology and its design should promote acceptance of, e.g., technology limitations or control over a VR world, hoping that this "attitude" of acceptance holds beyond its usage and transfers to other aspects of daily life.

But can technology actually promote acceptance or will a reduction of control lead to its rejection? If a technology can promote acceptance within the interaction process, does this acceptance really transfer to life? How could or should we then change the design of technology we use frequently, aiming for mindfulness? What are the socio-political implications of designing a technology that foregrounds practicing acceptance rather than say, resistance, or at least intellectual interrogation? Since control is a central concept in HCI and acceptance in mindfulness, we think it is crucial to investigate what happens when mindfulness meets technology.

Minimalism versus Richness. Researchers also discuss the richness of an interface – whether it should be rich in detail or rather minimalist. For example, Kosunen et al. [30] aim to make interactions and the virtual worlds rich in detail, in order to promote presence and immersion. In contrast, other researchers (e.g., [6, 21, 41]) minimize interactions and interfaces in order to promote the focus on one particular aspect. Focusing on a single detail and being present are both part of many mindfulness conceptualizations. Whereas they are not contradicting in these definitions, a conflict may appear when designing an interface, in particular for VR. A rich VR world promotes the feeling of presence but might distract the user from the object or experience which should be in the focus of attention. A too simple VR world might fail in terms of users' presence but help the user in focusing. How does a VR world for presence *and* focus need to be designed? How can we guide a user's attention towards the self or (internal, invisible) aspects of it by means of an (external,

visual) interface – which demands the user’s attention to be perceived and understood and, hence, competes for the same resource? More fundamentally, is VR at all appropriate for mindfulness practice and particularly meditation – which is often exercised with eyes closed?

Efficiency through Mindfulness. Some researchers noted that *slow* interactions, e.g., slow finger and touch movements on a phone or with kitchen devices, can lead to a heightened awareness and mindful interaction [14, 42, 55]. Similarly, Cox et al. [15] suggested to incorporate *design frictions*, meaning small obstacles, into interaction with technology. They aimed to reduce automation and promote mindfulness and “deeper levels of involvement”. These interactions rather *reduce* speed and efficiency for mindfulness. Bernardez et al. [8] investigated if mindfulness meditation can enhance efficiency and showed an increase in such for conceptual modelling of software systems.

We have an opportunity here to consider how interactions with such designs foregrounding efficiency may use up what may be our mindful capacity by, for example, having slowed down before. If so, how does a task or an interface need to be designed in order to compensate for this *reduction* of mindfulness? Is there a threshold or a certain point which needs to be overcome in order to *remain* mindful without having to practice or focus on it – in other words, when does the state become a trait? It seems there is an opportunity if not need to explore how we might craft such assessment metrics of mindfulness state or capacity – bearing in mind that mindfulness *per se* also asserts a kind of antithesis of measurement.

Operationalization of Mindfulness. Measuring and evaluating mindfulness is attempted primarily through post-experience self-reports, also in psychology and therapy [44]. Although a lot of research utilizes physiological measurements to provide feedback, e.g., about a person’s meditation quality, it seems that HCI researchers have not yet attempted to draw conclusions from this data. From large-scale studies one might gather data that could (1) reveal correlations between physiological data and mind, (2) develop a mindfulness *scale* that potentially represents one’s mindfulness capacity and (3) automatically assess one’s mindfulness state based on this scale. Researchers already identified predictors of mindfulness such as multi-tasking behavior [61], which might be a first step towards a future research topic – quantifying mindfulness by means of technology.

Technology Disengagement. The pervasive and intrusive nature of technology, in particular of smartphones, causes an increasing digital obsession and dependency of humans. Could technology for mindfulness help fighting these symptoms or even causes or would it actually feed the problem of

digital supersaturation and overload? In this way, digital technology may actually embody anti-mindfulness, so there is a certain irony to be mindful of in looking to human-computer-interaction for new strategies to re-balance us. Social movements, e.g., #unhashtagvienna⁴ or successful smartphone applications, such as Forest⁵, motivate users to disengage from using their smartphone. Is it possible that a reduced use of the smartphone already facilitates or even directly increases a person’s mindfulness – for example, one’s presence in the real world? Is such technology still needed to reach the individuals stuck in the world of technology needing support in finding back into the analog world? We invite researchers, designers and also users to contemplate about the appropriateness as well as the need for technology for mindfulness.

7 CONCLUSION

In this paper, we contribute (1) a key review of mindfulness work in HCI and (2) a framework mapping out current directions and future work opportunities. In (1) our review consolidates the definitions, conceptualizations, practices, technologies, evaluations and scientific findings that have been developed around mindfulness. In (2) we offer from our analysis, a framework for mindfulness, namely *perspectives*, as well as seven *lines of research*, which represent common research motivations and topics. By means of an alluvial diagram, we visualize which line of research adopts which perspectives on mindfulness. Furthermore, we interrelate the ideas, approaches, and findings of the reviewed literature and highlight several opportunities for future research around mindfulness. This work provides a tool for researchers navigating through recent HCI literature on mindfulness to establish a better understanding of the various nuances of mindfulness as a concept and practice. We provide a basis from which the concept of mindfulness can be specified more clearly, both to reduce ambiguity and improve understanding of opportunities for future work.

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