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ORIGINAL ARTICLE

Broken probes: toward the design of worn media

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Abstract This article describes the development and use of broken probes: prompted processes of degradation that produce unique identifiers with which to associate and retrieve digitally recorded histories. We offer our design and deployment of Broken Probes as a methodology for eliciting insights into how broken objects and acts of breakage may be given new life through their integration with ubiquitous computing technologies. Based on these developments, we introduce the genre of *worn media*—a variety of computational material with which to frame and critically examine the manifestation of wear among digital things. We end by discussing how the genre of worn media sensitizes designers and Ubicomp researchers to issues of incompleteness, impermanence, and imperfection to help account for the ethical, material, and historical terms of endurance in a digital age.

Keywords Craft · Interaction · Aesthetics · Everyday life · Social impact

1 Introduction

When our technologies break, they are often relegated to the landfill—the resting place for many a toy, instrument, and most recently, computational device. This contrasts with heirloom artifacts, such as a suitcase that the first author recently recovered from family storage (Fig. 1). Its worn-down edges and its crack on one side indicate the harsh conditions of its use in a Japanese internment camp; the sweet smell of leather, reminiscent of an old book, reveals the many years that passed by since World War II; and the government-issued spray-painted black lettering recalls the difficult political circumstances her grandfather, its owner, had witnessed. Marks of wear become important not only for the memories of use they evoke but also for the sense of time and historicity they bring to life.

Yet these details are not immediately perceptible. Stories of time, place, and circumstance become apparent through careful inspection: eying cracked corners and smelling aged leather. They become perceptible through traces of breakage and use wherein material interactions help to recall aspects of an object's life and past relations. This apparent disconnect between broken technologies and heirloom artifacts, like the suitcase, prompts us to ask: how do our decaying artifacts accumulate enduring personal and sentimental value? What role might digital technologies play in shifting our perceptions of breakage and wear? How might we use breakage and wear to cultivate more responsible and reflexive design practices?

The current article confronts questions of endurance by linking our recent elaboration of material traces and provenance in design [27, 29] with a renewed interest in brokenness from the field of technology studies. Specifically, we turn to what Jackson [15] has called *broken world thinking,* a mode of reflection and analysis that offers a critical entry point for examining "the nature, use and effects of information technology and new media today" (2013:1). From Jackson, we take the processes of erosion, breakdown, and decay as a means to explore how the seemingly unconventional practice of making something broken may help us extend the time-of-use ordinary artifacts. As part of this process, we rely on design methods in

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Fig. 1 The suitcase, as a family heirloom, reveals meaningful traces of time, use, and the places it has been

which storytelling techniques and probes [8, 12] provoke conversations and reflection on new and uncertain relationships to designed technologies. Drawing on the work of Sengers and Gaver [31], Dunne [6], and others [1, 3], the practice of storytelling is used to ground critical reflection on degradation and its possibilities for reuse. As we will see, different ways of thinking about digital media develop from creating, engaging, and reflecting on regressive change. We further suggest that by identifying the kinds of sensibilities and politics that emerge from degradation, ubiquitous computing researchers may more effectively design and account for this regressive change and, by extension, lifetimes of use.

To arrive at these design insights, we describe the development of *Broken Probes* (Fig. 2). Broken Probes are prompted processes of degradation that produce unique identifiers with which to associate and retrieve digitally recorded histories. We use the act of breakage to better understand people's reuse of artifactual remains across a range of material practices. Cracked mass-produced plates and bowls are turned into uniquely customized artifacts through digital annotation, prompting self-reflection and reminiscence. Specifically, computer vision techniques are used to associate physical marks of creation and attrition with digital records of material engagement—ascribing new value to fractured goods. We use these findings to conceptualize *worn media*, a genre of computational material with which to frame manifestations of wear in the digital realm. Worn media sensitizes designers and Ubicomp researchers to issues of incompleteness, impermanence, and imperfection, emphasizing material difference over time (see [19]).

Building on a range of recent design-oriented explorations of age, temporality and wear [9, 11, 13, 14, 17, 18, 21, 23, 34] this article makes two central contributions to materials-focused HCI research. First, it offers the Broken Probes methodology as a design-oriented mode of inquiry with which to examine the possibilities and responsibilities that intentional acts of breakage introduce for the design of ubiquitous computing technologies. Second, we identify issues of imperfection, impermanence, and incompleteness as prescient themes with which to design for worn media.

The remainder of this article is structured as follows. We first ground our concerns for breakage in the related Ubicomp, HCI, and new materialist literatures. We then discuss our findings and Broken Probes interviews, distilling key themes around breakage and decay. We end by describing an approach to the design of Ubicomp technologies that takes into account the historical and material terms of endurance.

2 Background

While it is clear no simple definitions of *breakage* and *wear* can hold, we wish to provide some broad strokes that we hope may guide our understanding of these terms. According to common wisdom, breakage tends to imply a malfunction or fracture that may or may not connect with engagement, while wear often suggests degradation through usage. Both acts frequently leave behind traces of their existence that are both intentional and accidental: marks that indicate the passing of some other phenomenon [16, 29]. Recent work in HCI and Ubicomp has separately looked at breakage and wear through the problems of obsolescence and digital inheritance they introduce into everyday production and consumption practices. Among ceramic artifacts, in particular, Zoran and Buechley [36] have described processes of fabrication that celebrate broken assemblages by highlighting marks of breakage in the repair and reassembly of clay artifacts. Within the domain of online activities, Schütte [30] PatinaMap software notably explored the creation and impact of digital "wear" by visualizing online usage data with the goal of promoting users' awareness of remote interaction. Research on the relationship between heirloom status and digital technology, for example, has suggested the importance of supporting multiple representations and roles around family archiving [24, 25] and design opportunities around digital loss [1]. Other HCI research has turned to craft and hacking practices to examine the role of distributed online applications in facilitating the taking-apart, customization, and reuse of broken or discarded parts [5], as when online blogs merge with IKEA's "As Is" department to create lego-like re-configurations of mass-

produced furniture, otherwise termed IKEA hacking [28]. Considering the diversity of domains that breakage crosses—both online and off—breakage is worth taking a second look. Taken together, these insights suggest that digital technology may be designed to support different modes of sustainable practice beyond functional appropriation. They also suggest a gap in the literature around breakage and wear as a resource for interaction design and a source for technological innovation.

New materialist scholarship in cultural anthropology, science and technology studies, and philosophy continues to broaden and sharpen these perspectives by offering alternative ideas of attrition. Signs of breakage and wear have the capacity to tell their own stories [4, 20, 22, 33, 35], as it is not the "style" or "oeuvre" of an artist that connects an artist's work to a viewer's interpretation. Rather interpretations come about through patterns of interaction or, in Grame Were's words, the "state of potential flux between its various forms and media, and its location in time and space" [35]. Our focus on breakage was particularly informed by what Barad (2007) has termed a diffractive methodology: "a critical practice of engagement, not a distance-learning practice of reflecting from afar" (ibid: p.90). Such a perspective acknowledges how different kinds of material afford very different ways of knowing through their entangled interactions—or "intra-actions" (2007: 33).

Within the specific context of ceramics, Japanese folklore has celebrated a long history of appreciation for broken and mended objects. In sixteenth century Japan, for instance, it was said that a clumsy page dropped and broke a beloved tea bowl named Tsutsui Zutsu that belonged to the strict military ruler Toyotomi Hideyoshi. While everyone froze fearing Hideyoshi's quick temper, one of the guests made up a quick comic poem tying in elements from the bowl's name, a famous literary work, and the five pieces it broke into, using wit and word play to turn an accident into an amusing moment. Everyone laughed including Hideyoshi and the mended bowl lived on to be cherished for generations. It now holds the governmental designation of Important Cultural Property in Japan [18].

Though this instance of breakage could have resulted in the bowl being discarded and forgotten like so many other broken objects, thanks to the poet's clever imagination and compelling use of language, the bowl was given new life. Rather than repairing the bowl to look as it once did, attention was drawn to the cracks by filling them with gold lacquer, a repair practice known as *kintsugi*. In this manner, the imperfections and lines in this once pristine bowl became an inextricable part of the bowl's newly attained value.

The Japanese tea ceremony master and national figurehead Sen no Rikyu (1522–1591) drew attention to broken ceramics on numerous occasions. On one such occasion, he marveled at a broken and repaired ceramic jar, exclaiming,

Fig. 2 The backside of the plate is coated with silicone. Once the material dries, it becomes firm but still pliable, allowing the ceramic surface to crack yet remain intact

"Now it is magnificent" [18]. He explained that his appreciation for broken and repaired ceramics stemmed not only from aesthetics but also from a philosophical understanding of what the objects themselves represented.

These mended ceramics embody the passage of time; they represent the unpredictability of our own existence through the traces left behind, as reflected in the aesthetics of wabi sabi [19]. The object itself conveys simultaneously an "eternally present moment" (the moment of breakage captured by the lines) and the continuation of its life after that moment as made possible by repair. However, repair cannot be the final step; after it is made whole again, it is the visual impression paired with the poetic interpretation that brings to light the object's emotional expression and potential for elevated value. The story of the tea bowl and jar not only illustrate the significance of the act of breaking, they also serve as inspiration for the development of the methodology described in this paper.

3 Methodology

In a piece called "do break" by Peter van der Jagt and Frank Tjepkema of Droog Design, a ceramic vase can be thrown against the wall. Its surface shatters while keeping its form remains intact due to a rubber-coated interior. The artifact is used to activate a paradoxical experience: the provocation of longevity through breakage or, put another way, "vestiges of aggression" [26]. Inspired by this piece, Broken Probes were designed to use the act of breaking to prompt critical reflection on intentional acts of breakage, not unlike Garfinkel's [7] breeching experiments, wherein experiments purposefully broke social norms to study how participants might respond and restore common understandings. By manipulating the social impetus for breaking, we explored the kinds of work that emerged from participants' reflections on the cracked surface of the vase. Notably, the artifact called attention to

breakage due to the visibility of its traces, reminiscent of discussions of the otherwise "invisibility" of infrastructure by Star and others [32]. It was through these events that we found participants reflect on—and radically reconfigure—their material interactions. While we suggest our methodology can yield insights about the notion of breakage more broadly, it is particularly relevant to proficient storytellers who are able to render these narratives meaningful through both material and discursive forms of inquiry and expression.

3.1 Living object interviews

The motivation for the Broken Probes project came, in part, from a series of informal interviews with interaction design colleagues. Each interviewee was presented with six artifacts and asked: If this object were a person, what kind of person would it be? Would it be male or female? How old would it be? What would its name be? And would it have any personality quirks? The goal was to get participants to think about the values ascribed to artifacts in relation to their form. We asked each person to speak about the qualities of an object as a way of eliciting a focused storyline. However, in practice, stories arose for some artifacts easier than for others. Consider how interviewees described two of these artifacts: a flat sheet of white paper and a crumpled sheet of white paper (Fig. 3).

Flat sheet:

"Steph, is a new born baby boy that is rather quiet and doesn't cry much."
"The secretary who is dependable and makes the office run but is quiet and overlooked. She's not married, leads a quiet life and wears old fashioned suits in neutral tones."
"… a nice guy who everyone likes, but is rather boring."

Crumpled sheet:

"Jessica, is in her 50 s and has experienced violence in her life. She sees the beauty in small things, but has difficulty overcoming her past."
"Jo, a 28 year old male who doesn't have his life together. However because he's smart and funny, he's not a lost cause."
"Samantha, 20 year old female who has experienced recent heartache just getting out of her first relationship."

Descriptions of the flat sheet of paper emphasized ideas of purity and openness. The stories surrounding the crumpled sheet stressed conflict, turmoil, survival, and struggle. The artifacts were seen to behave differently depending on the worn nature of their form.

Within this interview we also asked interviewees the same questions about an iPhone as a point of comparison. While many had difficulty creating stories for the blank piece of paper, people found it far more difficult to tell a story about the iPhone. As one explained, it was "definitely easier to personify things that have creases because they seem like wrinkles, like human skin, as it gets older starts to get wrinkly and gets more blemishes and scars marks." Most people could not begin to give the iPhone a personality let alone a full backstory. It was viewed as "cold," "logical," and "not very emotional." These comments suggest an ambivalence toward the immaculate quality of many digital devices. They also raise questions about what it means to introduce breakage and wear: would interviewees respond differently if they were presented with shattered iPhone screens or working phones running active or defunct applications (e.g., Facebook, Instant messenger, Instagram)? What would an iPhone designed to evoke empathy in its owner look like? As we will soon discover in our Broken Probes, making the form and act of degradation perceptible may enable and encourage certain forms of creative reuse.

3.2 Crafting broken probes

From the Living Object interviews, the notion of wear emerged as a useful lens with which to recognize the diversity of signification processes around everyday objects. To examine breakage anew, we borrow from the whimsy of Droog Design (exemplified in "do break"), the aesthetic focus and provocative spirit of Gaver's cultural probes [8], the interpretive approaches to design for interpretation and reflection (see [31], and the historic traditions of mended tea ceremony ceramics. In particular, we work our way from the stories of artifact personalities to moments of degradation and self-reflection. Using interviews, ceramic vessels, and a mobile phone application, we established a methodology that unfolds in four parts (Fig. 4).

3.2.1 The break

In part one of the process, participants received one of the prepared ceramic objects. They were asked to hit the non-coated ceramic side with a hammer as many times as they wished until they were satisfied with the amount of cracking (Fig. 4b). The silicone coating held the piece together during the breaking process allowing the broken pieces to retain their original form.

3.2.2 The paint

In part two of the process, participants were asked to paint the surface with a blue acrylic paint and wipe the excess away with a rag (Fig. 4c). Surfaces where ceramic pieces had chipped away also took on the blue pigment creating a visual indicator of subtle irregularities. Through the act of

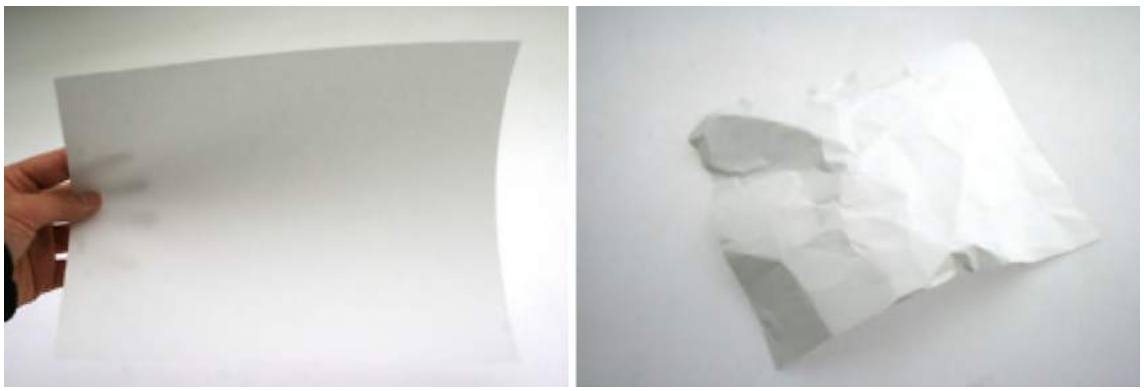

Fig. 3 Two artifacts presented in living object interviews: plain sheet of paper (*left*); crumpled sheet of paper (*right*)

Fig. 4 (*Left to right*) **a** liquid rubber-coated ceramic cup; **b** the break; **c** the paint; **d** the story

painting, the participants not only highlighted the cracks but also became aware of the form and location of the cracks (Fig. 4c).

3.2.3 The story

In part three of the process, participants were asked to look at the cracks in the surface of the object and create a story based on the cracks. Then, they had to interpret and associate the cracks with digital images. These images could be personal photos, images taken for this project, images gathered from the Internet or other sources, images of written words, or images of previously created work. The images were then digitally tagged to the object using visual recognition technology (Fig. 4d). The application Aurasma for the iPhone was used to associate digital images to locations on the broken artifacts.[1] To create a tag, the participant points the viewfinder at the crack and surrounding area being careful to avoid deep shadows or glare. After capturing the image, the participant is prompted to choose an image from their phone to associate with the crack (participants had to preload desired images onto their phones). The image is then placed over the crack according to how the participant wishes to orient it. Once this tag is created, one can use the application to scan the object and recognize tagged cracks. Once a crack is recognized, the image appears and viewers can see the image in more detail by moving the phone physically closer to the object. The process took place over two or more interview sessions with time in between for the participant to work on the project independently. Participants took anywhere from 3 days to 2 weeks to complete their stories, sometimes rescheduling interview appointments to give themselves more time with their artifact (Fig. 5).

3.2.4 The share

After the participants finished creating their stories and tagging their images, they were asked to share them with the first author and talk about their experience with the project. The sharing of the stories was done verbally, through photos shown on the iPhone or computer screens, and by pointing to the object itself.

The concept of broken probes developed from this appreciation of shape, texture, and patterning as a key aspect of wear. In keeping with the tea ceremony tradition of choosing aesthetic philosophers and poets to interpret the visual appearance of mended ceramics to elevate general understanding and appreciation of the pieces, we

[1] The application uses computer vision techniques detailed on the Aurasma website: www.aurasma.com/.

Fig. 5 Gold liquid rubber applied to the interior of the broken artifacts

recruited six participants who identified as storytellers across various disciplines, including filmmaking, acting, design, writing, and photography. Each probe began with a white ceramic plate or cup with no markings. Purchased at a discount supplier, these pieces were chosen for their low monetary value, their brand anonymity, and their seeming lack of distinctive aesthetic qualities. The pieces were then coated on one side (the inside of the cups, and the front or the back of the plates) with a silicone primer (to promote adhesion of silicone to ceramic) and then food grade silicone. This technique was developed to enable the plates to be cracked while remaining in tact and, thus, usable (at least in theory). The process also left a gold or greenish glaze-like surface that is rubbery to the touch. In the following section, we describe how our participants used this process to produce a specific set of relationships with the ideas and processes of breakage (Fig. 6).

3.3 Findings

Just after the artifact is hit by the hammer, participants discussed the object as having little or no value often because they felt they had destroyed its functionality. Even though the artifacts were theoretically still usable (they could retain water, display food), participants felt the object could no longer be used as a regular plate or vessel and could be discarded with little thought. This was the response we anticipated in following with general wisdom: broken objects are often discarded because they are believed to have little or no value and are not worth the amount of time, effort, or money necessary to repair them. Yet, after the cracks were painted, the artifact was seen as "more of an artistic object" (P6) or "an art piece" (P4). It was not obvious to the participant what the story would be, so participants often began their work by looking through the artifacts close at hand (their digital photos and the ceramic object). While browsing their digital files, cell phones, and family archives, varying content suggested different social, historical, and material associations. At each step, participants were manipulating the objects, and the participants themselves were also undergoing varying stages of transformation. The following three examples illustrate a few ways in which such transformations took place.

3.4 "Some little string": entanglements of time, geography, and medium

P5 is a photographer who uses analog cameras to capture imagery and digital technology to scan, edit, and print her photographs. She is hesitant to adopt new technology, finding that sometimes it "distance[s] us from our true selves and those we care for." Yet, like other participants, P5 pulled readily from her digital archive while participating in the Broken Probes project. In the below excerpt from the fieldnotes, her story develops as sequence of places and times traced through a mix of media:

> The participant views the cracks on the plate as representative of geographical locations all leading to the final destination, California, in the center. The images are tagged to the plate in a non-linear way but

Fig. 6 Our broken probes were generic pieces of tableware painted with silicone. When cracked, they became uniquely marked vessels with which their owners could associate digital annotations. Traces of physical breakage indexed material histories as well as digitally recorded personal stories, prompting self-reflection and reminiscence

> the story unfolds through a colorful progression of images illustrating movement, which includes her illustrations, text and photography. The first two illustrations are of Pittsburg and its bridges, which represent possible ways to leave the city. There is an illustration of a motel sign in blackness, a woman lying on concrete next to a body of water, and a deer's dead body in a creek covered with autumn leaves. The following two photographs represent the time and place where she decided to move to California. These images include horizon lines in motion; photos shot from the inside of a moving car. The final image—a warm sunset on a beach with the word "hello" written upside down in the sand—is a portrait of herself about her move to California.

At the time of the interview, P5 was faced with a decision about whether or not to move away from California to attend graduate school. By annotating her plate with images of her artwork, P5 first used the aesthetic form of the cracks as an analogy for temporal and geographic change (see Fig. 7e). The long cracks leading to the center of the plate anchored images of the bridges in Pittsburg leading the way to her current location, California, represented by the large central crack. Beyond connecting spatiotemporal imagery from her past, P5 saw a relation between two disconnected artistic mediums: photography and illustration. What once felt distinct prior to this project (geography and time, illustration and photography) was now interwoven with the broken plate. As she explained, "*I'm always trying to find some little string that might connect them because otherwise people always say 'oh, you should keep it separate' and it just feels strange to keep it separate*." She used the project to connect multiple (convergent) traces of her past. With this plate, she found a "little string" with which to tie together parts of her past (Fig. 8).

3.5 Mixing metaphors: revisiting the shape of a family archive

P4, an improv actor who described himself as "kind of techie," saw the cracks on his cup representative of a "family tree." Rather than using recent images gathered on the phone, P4 decided to use digitalized family photos—physical photos of his family across several generations that he had recently scanned.

> The beginning of the tree sits at the top of the cup and associated family photos work their way down the cup and around. With the cup upside-down, the images progress from photos his great grandparents as a newly married couple, to the participant as a baby at the bottom. The oldest photographs are black and white and faded, the photos taken in the 1930s and 1940s have a familiar soft glow, and the more recent photos are in full color. Couples are aging, children are appearing, and adolescents are growing up.

As the above excerpt illustrates, the cup traces the history of the participant's family over the course of four generations and their emigration from the Philippines to the United States. Even though the images are scanned, the older photographs are visibly worn: several depict dust, scratches, and pen marks. The last few photos, by contrast, are virtually scratch-free (Fig. 9).

Yet the shape of the artifact also played a role in how the participant interpreted the digital annotations: if the images were viewed backwards through the generations, they would be viewed in a counter-clockwise direction around the cup. P4 drew a parallel between the counter-clockwise motion and the idea of traveling backwards through time: "I thought of a clock, kind of circular," he explained while reexamining the tagged artifact. Each photo embodied the passage of time through the familial continuity the photos illustrated and the marks of wear indexed. The distinct composition of different media altered the form and meaning of the artifact to produce something new: a hybrid artifact that reflected both a clock and a family tree.

3.6 "Fill in the blank": using one vessel to find another

P3 began his project by looking through the photos stored on his phone. In the process, he noticed a reoccurring theme: the presence of a cup, bottle, or glass. As a filmmaker, he was relatively familiar with cinematic imagery and quickly drew a connection between the drinks in his photos and the Broken Probe vessel with which he was working. In the next excerpt, we get a better sense of how this attention to visual symbolism unfolded:

> This participant chose a series of seven photographs from his life over the past 6 months. The images were taken at the high and low points of his life where he found himself with a beverage, mostly alcoholic, in hand. A photo of a large wine glass taken on a trip to celebrate his sister's engagement, a can of beer taken during his sister's fiancée's bachelor party, a bottle of soju taken before he drank the entire thing by himself, an iced coffee at a café taken while waiting for date that was an hour late, a large bottle of Jack Daniel's in an empty apartment, a Kir Royal in a champagne flute taken during the day at work, and a bottle of beer in a backyard taken while he was helping his friend move. All of the images were taken on his phone in a similar style with the drink at the center of the image and the environment visible behind. There are no people in the photos only occasionally the

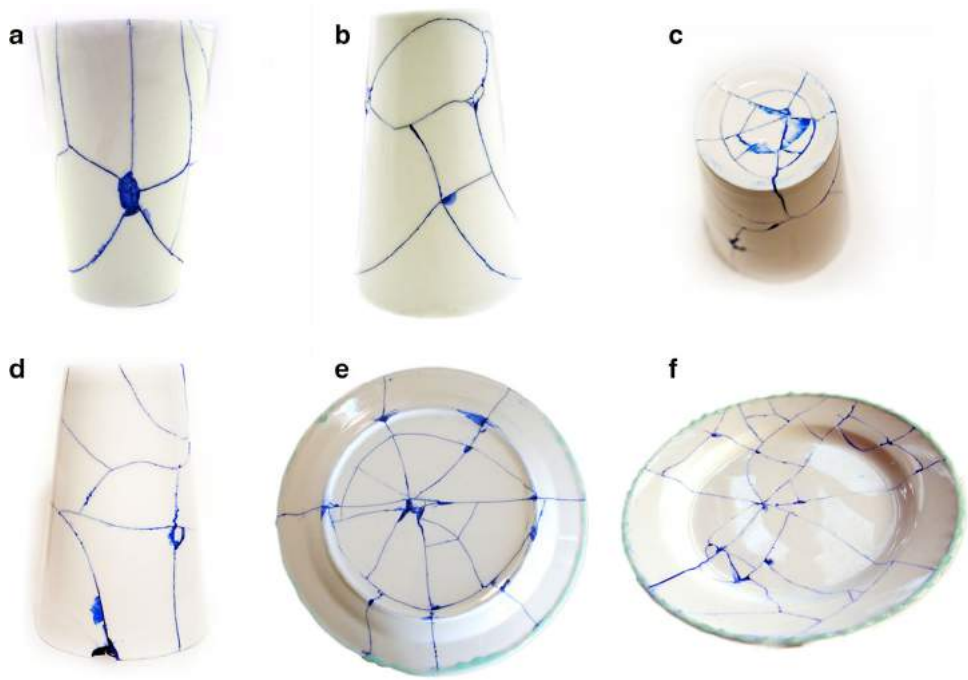

Fig. 7 **a** P1's quotations: P1 associated photographs off the internet and screenshots of quotations to different cracks; **b** P2's haiku: P2 extracted passages from a series of haikus he wrote over the previous year and associated them with parts of the broken vessel; **c** P3's beverages: P3 saw his broken cup as a representation of other cups he had used to drink out of in recent months and associated it with images of his drinks and their circumstances; **d** P4's family tree: P4 decided to associate digitized family photographs clockwise around the cup with cracks so that the images could be viewed backward through the generations; **e** P5's transitions: by annotating her plate with images of her artwork, P5 used the cracks as an analog for temporal and geographic change; **f** P6's connections to men: P6 *viewed* her plate as an analog for her fractured past with men, and the silicon as her role keeping the various pieces together

participant's hand and one time the hand of another individual.

This participant saw the Broken Probe cup as a representation of the other cups he had used to drink out of in recent months. The images were not just about the drink, they were also about the circumstances leading up to and following that drink. What is striking is the diversity of moments and the range of affective responses that the cup thematically provoked for him. His emotions transitioned from happiness for his sister's engagement, to extreme sadness that might push him to excessively drink alone, to moments of anticipation waiting for a date to arrive, to relaxation spending time outdoors during the day. The project highlighted forgotten moments and offered an opportunity to communicate, and perhaps warn himself about, tendencies he might not want to see, such as his reoccurring taste for alcohol. He used the cup to reflect on his emotional patterns around routine alcohol consumption.

4 Discussion

Like *Do Break*, the artifacts shattered in our Broken Probes remained usable as vessels after breakage. By enabling people to associate stories with the objects, they became something more: self-portraits, family trees, and aspirations. They were given a new life. Generative relationships with the ceramic objects developed out of the memories and narratives they evoked for each person. Memories of transition and stories of a troubled past were less concerned with the object itself (e.g., its provenance or personal value) as the evidence and experience of breakage. Not only the visual appearance of the cracks, but their development in relation to the vessel and the person came to influence the character of each story.

While it is unclear whether presenting participants with other evocative broken forms, such as an abstract painting or image of shattered glass, might have reached the same ends, the act of breaking itself became significant. Before hitting the object, participants discussed feeling anxious, nervous, or excited. After hitting the object, they described the breakage as cathartic, invigorating, or uncanny—"almost like having your hand held by yourself, by your other hand," one explained. Additionally, by asking participants to associate photos with locations on the cracked ceramic objects rather than any artifact, their experience of the photos became particular to the cracks. As we will discuss, it was through these unique circumstances and associations that Broken Probes provided some useful

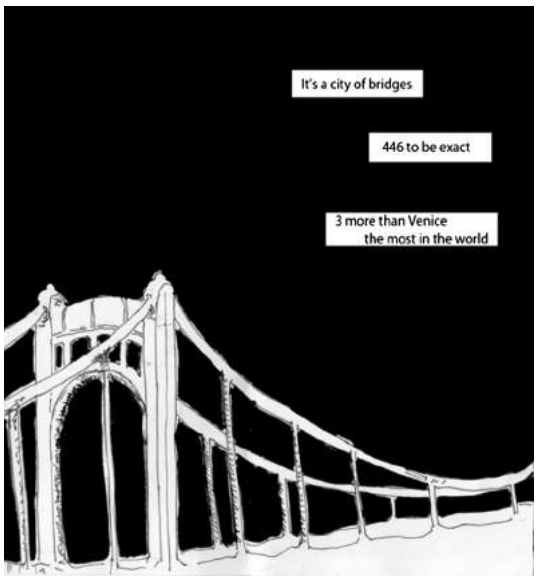

Fig. 8 The first three images are illustrations where the majority of the image is *black*, which feel static and heavy. The next two images have *color* but the tones are subdued earth tones that feel melancholy and contemplative. They both include solitary unmoving figures (a woman, a dead deer) next to or in moving bodies of water, so there is movement but the main subject remains motionless. The next two images have brighter colors and feel like the photographer is in full motion. The last image is the warmest and the brightest with an open sky and golden waves; it feels content and resolved. Without words or the format of a linear story the participant was able to indicate the story's progression and how she was feeling, through *color tone* and movement

Fig. 9 The cracks became a family tree signifying the passage of time and ancestry

insights into broken objects—how they may be repurposed and renewed—and about people's relationship to those artifacts during and after breakage.

4.1 Figure and ground

A first theme that emerged across participants was the flexible relation between the cracks and the white space in between. Much like Gestalt theorists' concern for figure and ground, participants swapped the ceramic fracture and surrounding white space interchangeably: white objects described by lines, or line drawings lingering in white space. A similar transition developed in the act of breakage: the process was interpreted as the solidification of cracked ceramics or the degradation of a solid form. These interpretations of fracture suggest that aesthetical, practical, and ethical concerns may develop in a few different ways.

4.1.1 Perception: form of breakage

When seen visually, the cracks were often interpreted as illustrations with which to connect personal anecdotes. For example, P2 saw lightening in the cracks and tagged a photo of a lightening storm that set the stage for a somber haikus; P6 saw a crack shaped like South Africa and linked a photo to represent an ex-boyfriend from that country. P2 connected a photograph of two people's intersecting shadows with two cracks near but not touching each other. Though the shadows merged together in the photo, P2 saw the people casting those shadows as leading separate lives. In letting the cracks remain separate, he reinforced that their paths may never cross again.

Others used the white space in between. For P4, the large area of his cup that had no cracks represented the void and feelings of loss that his newly widowed grandmother experienced at the time. Further, we saw how the tactility and form of the vessel inspired P4 to draw a connection between the round shape of the vessel and the passage of time, connecting a crack near the top with a photograph of his grandmother with her three children. The opportunity arises for designers to look into how aspects of an object's design may be open at many levels yet specific to a particular person's interpretation.

4.1.2 Comprehension: object of breakage

Three participants interpreted the object as a whole and saw the entire object as the representation of a vessel. As we saw, P3 saw his cup as representative of other drinking vessels, and P4 connected the cup with his family, which has had difficulties remaining intact. P6 viewed her plate as a metaphor for her fractured past relationships, but also viewed herself as the silicone that keeps all of those various pieces together. How might a cell phone not only represent itself, but also all of the phone calls it has made or received? How could it come more to life?

4.1.3 Contemplation: act of breakage

For some participants, the acts of breakage associated with the plate or cup became powerful metaphors for the kind of story they wanted to tell. While P2 and P6 revisited broken relationships, P4 and P5 found change, and movement. The idea of breakage evoked memories of challenge and transition that seemed to shape how the participants talked about themselves. The object made certain interpretations intimately available to the participant.

Rather than viewing the objects as broken remains, they approached the object as representative of a transformative act. As we may recall from the Japanese tea ceremony, "[i]t is not simply any mended object that increases in its appreciation but for Rikyu, it is the gap between the vanity of pristine appearance and the fractured manifestation of mortal fate which deepens its appeal" [18]. The breaking of the artifact transforms a pristine anonymous object into one that is "mortal" as we humans are, and because it has shown vulnerability and resilience, it is that much more open to intimacy and personalization. This suggests that we consider how to design objects that can undergo gross transformation in ways that reflect how their owners continually change as well, e.g., shifting the anonymity of the iPhone into expanded features revealed or understood through use.

Our findings suggest an opportunity for users to interact with our breaking and wear of the digital medium. In our Object Personality interviews, participants said the iPhone "doesn't seem human" because, among other things, it was "smooth" and "polished." Perhaps it is harder to personify and empathize with objects that remain unchanged because marks, blemishes, and wrinkles are qualities we associate with being human. In revealing the degradation of software, we might to identify breakage and wear as central human concerns that help us reconsider the moral choices embedded in design environments.

4.2 Constraints for self-reflection

Beyond the aesthetics of breakage, participants' use of material constraints became a vehicle for introspection. Most participants began their projects by looking through materials they had on hand: digital photos stored on their phone or laptops (P3, P5), haikus written in a journal (P2), online photo albums (P1, P6), or newly scanned physical photos (P4). P2 extracted passages from a series of haikus written in his journal over the previous year. He then photographed his journal and associated the images with parts of the broken artifact. Moving from his phone to paper and back again, he saw his work as a combination of each of these media. While browsing through their archives, the process of recollection took on a specific material form. For example, in making his family tree, P4 discussed small details of the scans, pointed out family resemblances, and recounted stories as one might do with a photo album. But through their association with the ceramic cracks, the photos also conveyed feelings of grief and moments of change through their relationship with the ceramic cracks. Moments of remembrance became inseparable from the details of the medium. In our digital materials, we are rarely able to trace our usage. Have the memories changed? Does this allow more memories to come to light? How do these memories fit within a longer time frame of years, lifetimes, even generations? Here, we seek out opportunities to see how things have changed over time in the same way we might be able to trace the history of an old leather suitcase through physical use. Not having the ability to reflect on these changes makes the answers as well as the questions inaccessible.

The act of breakage unveiled additional constraints regarding the value of serendipity. Consider how two participants described their experience:

> I think by the nature of the fact that I didn't draw these [cracks], they were secondarily designed by me hitting a hammer so I had no control over the patterns they would make… you could interpret it a million ways. If you were able to draw your own lines, I hate when things are overly spelled out. And so I think it wouldn't be as interesting. (P3)

> There is something really lovely about the happenstance of breaking it. No one asks you to break anything and it's just a weird, nerve wracking release of tension. (P5)

Just as the probes themselves were pivotal to the type of stories participants told, participants found relief in limiting possibilities. Because there was no "right" way to break, participants tended to relinquish control while still claiming ownership. In the words of one participant:

> Breaking it was freeing and kind of felt like playing and so it was more of an opening to be a creative story teller rather than someone who was self-conscious about what kind of image they are going to portray. (P6)

There was an element of serendipity and happenstance to each moment of change. As P6 continued, "*I don't think I would have come up with the same thing at all if I wouldn't have had the plate to kind of be my guide*." This action could not be over-thought and was not reversible; there was no "undo" or "delete" button; once it was done, it was done. By attending to orders of change around irreversible arrangements, design might account for the kinds of constraints afforded by fluctuating layers of

metaphor and material. We can start to imagine how this type of careful, emergent interaction could translate across mediums—designing whole artifacts and their ecosystems rather than simply interfaces, and giving form to computers [giving form to computers].

A final constraint in this process was what our participants did *not* get out of the Broken Probes. In trying to use the technology we put forward, participants revealed an awkwardness that arose from the mismatch between the richness of their stories and their inability to get the technology to work consistently. Images were sometimes too small or did not appear on demand. This complicated the storyteller's ability to tell their story. The digital component lagged far behind the other individual elements: the act of breaking, the constructive process of painting, and interpretive process of storytelling. Nonetheless, these elements paired with digital association revealed a different form of mark making—one that allowed participants to use broken artifacts to think differently about their own social worlds: their past experiences and possible futures.

5 Toward worn media: embracing degradation in IT design

Our interest in sentimental attachment and endurance drew from our deeply held beliefs about the ecological benefits of reuse. Correspondingly, our choice of non-descript white vessels and minimally tinted cracks borrowed from our modernist design sensibilities. In selecting the Aurasma application for annotation with digital imagery, we further refined and reinstated specific claims about the nature of technology—how the technology might help people extend their concerns for breakage beyond the artifact and into their wider social relations. All in all, our studies helped us rethink the conventional opposition of breakage with innovation, novelty, and progress. We began to introduce new sorts of politics and research through the work of IT design. As such, we framed aspects of Jackson's formulation of *broken world thinking* [15] in conversation with critical and speculative design approaches [8, 12, 31]. This meeting of humanities research and design practice is further elaborated in [Structures, Forms, and Stuff]. It is through these and other conversations within design and technology studies that we ground our interest in *worn media*.

The genre of worn media describes the kinds of computational material we saw participants identify and critically engage through acts of breakage. It includes the image of connected shadows cast by people who might never connect again, the photo assemblages of reoccurring relations that may lead to tumultuous ends (with men, alcohol, etc.), and the portraits connected to emptiness in response to familial loss. While the Object Personality interviewees improvised stories based on pre-specified forms, Broken Probes participants produced broken narratives alongside broken processes, leaving visible residue in the digital realm. While [hybrid crafting] might call this "hybrid crafting," [interaction through design]'s material-centered lens renders this media more unusual: the material constrains of the ceramic coating, the aesthetic and qualitative details of the cracks, composition and meaning of the whole artifact, and perceivable texture of the interwoven digital images. At the heart of these narratives was a kind of wear, and worn media, that contrasts with mainstream conceptions of digital technology as a means to novelty and cultural advancement. In closing, we wish to highlight three attributes of worn media that emerged from our interventions: incompleteness, impermanence, and imperfection.

5.1 The incompleteness of worn media

One feature of the probes we found useful for considering the longevity of the digital artifacts was their ability to expose the incompleteness of their form. In contrast to a finished product, the cracked surfaces of the vessels had stories left to tell. The cracks narrated particular kinds of relations that enabled participants to interpret the artifact and make it personal. As one participant said in reference to the approachable nature of the form, "I feel like it has a story just inherently. The thing about this by itself is that, I feel like it had a story and then when I assign photos to it, I'm personalizing it. I mean that's basically it, I'm making it more personal to me." By exposing something about how that object or interface was used, designers might leave space for the user to feel their story is "inherent" to the completion of that product. As we incorporate an increasing number of devices and media into our everyday practices, the openness and incompleteness of each element may engender new paths for digital inscription.

5.2 The imperfection of worn media

Purposeful imperfections fostered unique interactions that, in turn, lead to personal associations with the object. For P3, the object enabled him to warn himself about some self-destructive tendencies; for P2, it enabled him to recount an old relationship and work through some possibly latent emotions and feelings of loss; and for P5, it helped her come to terms with a large decision that had been weighing on her mind. Things that are perfect seem all the same, but things that are imperfect can be imperfect in an infinite number of ways. In each case, the object becomes a means for coming to terms with the many fascinating ways in which we are all imperfect.

5.3 The impermanence of worn media

Recalling the story of the Japanese tea ceremony master Sen no Rikyu, the pristine bowl held no intrinsic value for him. Yet, once broken and repaired, the same bowl became "magnificent" for Sen no Rikyu [18]. The breaking of the object freed it from a state of apparent permanence. It could be viewed as something that no longer conveyed what Kopplin [18] called "vanity," but was now able to depict the embodiment of time. This view resonates with new materialist notions of agentic matter wherein materials are in constant flux [2, 10]. The bowl became not only a vessel, but also a potentiality: a "manifestation of mortal fate" [18].

Participants similarly experienced transformations through the narrative possibilities the cracks presented. P5 understood that her interpretation of this plate was one that reflected her current state of mind and that in the future the plate would allow room for reinterpretation to reflect changes in her relationships. P4 spoke of revisiting her plate sometime in the future and finding something completely different in it with perhaps a different geographic location at the center. The object is reinterpretable and the links to the images are digital; therefore, the associations do not have to remain permanent, allowing the object to reflect the changes undergone in that person. Instead of presenting the unchanging, perfect product as the ideal, we can design to highlight the changes and evolution over time allowing that impermanence to be what brings value to the interaction, object, or experience.

In the past, we were able to simply look at a printed photo and recognize through creases, wear, and dust how much it was held and viewed; we could then interpret how beloved the subject of the photo was or the habits of the photo's owner. Currently, in viewing personal digital photos, there is nothing that evokes the same level of interpretation or possibility for emotional connection. The sense of permanence around impermanence suggests that the paradox of degradation has resonance among digital materials. We might discover new opportunities for emotional endurance when digital files (whether file formats or digital annotations) transpire and dissolve. Every interaction with that object, digital or otherwise, results in a layer of *wear* that does not necessarily change the object's functionality but often changes how that object is experienced or understood.

6 Conclusion

This article has made two central contributions to materials-focused ubiquitous computing in and through everyday practice. First, it offered Broken Probes as a methodology with which to examine the possibilities and responsibilities that intentional acts of breakage introduce for people. The probes enabled us to explore specific issues around material and interpretation. Second, we identified the qualities of imperfection, impermanence, and incompleteness as prescient themes with which to design for worn media. Participants moved between the cracks digitally, symbolically, and practically. Some found figures in the white "in between" spaces (P6's image of South Africa or P3's pauses); others used the breakage to inspire creative curation and critical reflection (P4's tree branches or P3's wine glass). In each case, the probes exposed different patterns of breakage and reuse, enabling participants to look to the pieces as a whole rather than as discrete and disjointed parts.

Returning to the suitcase at the beginning of this article, we can see that what has sustained its emotional resonance was not its slick and pristine form but how marks of use, wear, decay connect with personal memories and shared histories. Whether we deal with software architectures, digital bits, or metal and wood, materials may be understood based on how their differences and distinctions form and transform over time. By reframing breakage as the pivotal interaction with an object, we challenged participants to find value in transformations they might have previously ignored or overlooked. We saw how the introduction of stories changed and challenged people's conventional relationships with, and interactions around emotional endurance. In imbuing breakage with emotional value, we found that the inevitable degradation and changes that occur to a product might be designed to add value to the product over time for the end user, or even become the reason for a user's engagement with the product in the first place. In getting people to break and tell (digital) stories around otherwise pristine and generic tableware, we broadened the kinds of research, design, and politics make possible with ubiquitous computing techniques.

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