# "I Feel Like This is a Bad Thing": Investigating Disassembly in Action for Novices

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## ABSTRACT
Materials are dynamic—they can be shaped and changed. Often however, our tools and technologies appear to fix materials in place. Disassembly is one practice that provides openings to explore and understand the dynamic nature of material. In this research, we investigate possibilities that emerge from disassembly. Specifically, we studied how novices disassembled a common digital artifact—desktop printers. We worked with 21 young people and family members across two evening workshops at a middle school. We report on the workshop interactions, categories of actions of disassembly, and four in-depth vignettes showcasing disassembly in action. In the discussion, we reflect on disassembly and permission, sustainability, the joy of disassembling, and design considerations in support of disassembly. Our contributions include: (1) extending existing theoretical framings about artifacts and materials; (2) an empirical study documenting the process by which novices disassemble; and (3) preliminary design and policy considerations that enable disassembly.

### Author Keywords
Materials; design principles; design theory; disassembly; empowerment; making; novices; play; unmaking.

### CSS Concepts
• **Human-centered computing~HCI theory, concepts and models**; https://dl.acm.org/ccs/ccs_flat.cfm

## INTRODUCTION
The materials that make up artifacts are dynamic. They can be shaped and reshaped; adapted and re-purposed. Often however, our tools and technologies appear to fix materials into place. Disassembly—the practice of taking something apart—is one way to explore and understand artifacts and the materials which compose them. Disassembly affords opportunities for different engagements and relationships with technical artifacts and provokes thinking on sustainability, interaction, and design.


*CHI 2020, April 25–30, 2020, Honolulu, HI, USA.*

ACM ISBN 978-1-4503-6708-0/20/04...$15.00.
DOI: https://doi.org/10.1145/3313831.3376337

Consider the inventory of artifacts in a room. What are their exterior surfaces like? Are they smooth to the touch? Are any screws visible? Is there an obvious way to open any of them? These artifacts, likely wrapped in plastic, metal, and glass enclosures, condition a particular understanding of technical systems. Specifically, of how they are to be *used*. *How* artifacts work and *what* they are made of however, is typically less salient. As Weiser write, "[G]ood tools enhance invisibility" [60:7]. This emphasis creates conditions where the material reality of technical artifacts can "vanish into the background" [61:19]. Complex internal assemblies are carefully sealed in smooth black boxes—closed off mysteries, to be used, not understood.

Winograd and Flores [63] remind us that "in designing tools, we are designing ways of being" [p. xi]—Friedman and Hendry [18] that we should imagine what sorts of worlds we want to live in as we design and build technologies. What ways of being are afforded to us in a world of black boxes? And what other ways of being might be possible? Disassembly is one practice for opening black boxes. It invites those disassembling to consider how the materials in an artifact have been shaped and how they might be further shaped in the future. Our hope in investigating disassembly is to imagine a world of technology that is open, malleable, and fluid, rich in opportunities for play, exploration, and creativity. It is to consider disassembly as a practice enabling the exploration of the dynamic materials of interactive systems.

Who disassembles? Engineers, technical students, toddlers, carpenters, salvagers, electricians, and Lego builders all do. In this exploratory study, we focused on a group of non-professionals, specifically young people and their families. We chose this group because they are both familiar with common digital artifacts, and yet do not have specialized technical training, arriving at disassembly as novices.

Focusing on disassembly with novices such as young people and their families invites at least two questions. First, how do novices practice disassembly? Second, how might disassembly be accounted for in the design of artifacts? In this research, we present an exploratory study of *disassembly in action*. Specifically, we studied how young people and their family members practiced disassembling an everyday technology—a common desktop printer. Twenty-one participants disassembled printers across two 2-hour workshops held at a middle school in the Pacific Northwest of the U.S. We report on the workshop interactions, describe overarching categories of actions that occurred during disassembly, and present in-depth vignettes to showcase disassembly in context. We make three contributions: (1) we expand existing theory on the dynamic nature of materials in interactive systems; (2) we empirically document how novices disassemble; and (3) we provide preliminary design and policy considerations in support of disassembly.

## CONCEPTUALIZING AND SITUATING DISASSEMBLY

Disassembly is the action of taking something a part—opening an artifact and breaking it down into its component materials. Circuit bending, bricolage, and salvage; de-synthesis and reverse engineering; and do-it-yourself and repair communities are traditions that share an interest in opening, exploring, and understanding artifacts, but differ in context (e.g., where and how artifacts are opened and disassembled) and intention (e.g., to what end). We discuss each concept briefly below.

### Circuit Bending, Bricolage, Salvage: Folk Methodologies

Folk methodologies refer to actions that "recall historical practices of reuse" that "don't easily fit" into narratives of digital culture while providing a counterpoint to "glossy high-tech" visions of technology [27:427]. We use this term to refer to practices, typically carried out by amateurs, working with technical artifacts, outside of traditional categories of expertise [27], which repurpose beyond their intended use. Examples of such practices include *circuit bending* [23, 27], *bricolage* [59], and *salvage* [14, 15].

*Circuit bending* entails "shorting out conventional electronic devices to reveal unexpected sound and music" where bending hardware results in "discovered circuit paths," and "chance wired instruments [that] take us to a new place" [23:97–98]. Ghazala describes circuit bending as a practice that transforms an artifact into "a friend and 'immediate' canvas like the painter's canvas: immediately there for anyone at all with brush in hand. Just walk up to it and paint" [23:99–100]. The immediacy and intuitive nature of paints invokes definitions of usability described in human centered design [46], ubiquitous computing [60, 61], educational creative computing [51, 52], and personal fabrication [4]. HCI researchers [20] have used Ghazala's approach to explore how circuit bending looks "beyond productivity" and embraces "the cultural and creative potentials of information technology" by asking young people to modify discarded electronics [p. 2].

Similarly, *bricolage*, the practice of constructing artifacts from a diverse range of available materials, has been used to explore and inform interaction design [59]. Specifically, how bricoleurs (e.g., amateurs) work with the materials they have on hand (e.g., without the tools and knowledge of trade professionals) to create artifacts in a local (e.g., their homes or workshops) and constrained contexts (e.g., the optimal tools and materials may not be readily available) [59]. Vallgårda and Fernaeus argue bricolage's attention to cultural and material context provides a useful approach for designers to apply to design practices [59]. Haque and Somali-Fischer's work [25] demonstrates how bricolage practices using everyday electronic devices support prototyping interactive systems.

Salvage or harvesting the waste materials from other constructive processes for new artifacts has also been explored as a means for engaging with technologies. For example, Dew et al. [14, 15] centered their investigation on waste materials from digital fabrication processes (e.g., scrap material and trimmings from 3D printers), and develop tools and processes that transform waste streams into resources (e.g., re-spooled wire). Similar to prior research in HCI on textiles and electronics [9, 49], Dew et al. demonstrate how building tools and theory [15] in HCI expands users conceptions of available materials.

Similar to previous research in HCI on woodworking [13] and Wabi-Sabi philosophy [58], the aforementioned folk methodologies treat everyday artifacts as materials. These approaches position artifacts as existing before and beyond their current compositions, and recognize the impermanence and imperfections of technical systems. Our research extends this body of work, offering disassembly as another practice that treats materials as dynamic—one that expands the notion of material flow found in the literature [29,30] to include not only discarded artifacts, but also *in artifacts* as they are currently presented.

### De-synthesis in HCI

Previous research in HCI has studied different forms of disassembly (e.g., unmaking, un-crafting, making apart) [42–45]. These terms, taken together refer to processes of de-synthesis, and have been used to advance design and design knowledge. For example, Murer et al. [45] report on taking apart an unfamiliar device as an explorative design practice that contributes to the design process. Studies of de-synthesis are intended to position designers to learn from the outcome of disassembly (e.g., the knowledge of the resulting materials) and to inform and support design practices (e.g., sketching). De-synthesis differs from practices such as reverse engineering [10] and product dissection [64] in that they are typically associated with engineering education. Similarly, design for disassembly is a term often used in manufacturing to consider product lifecycles, specifically how they might be broken down or remanufactured in industrial settings [7, 26, 66].

Our conception of disassembly expands on the existing literature on de-synthesis in at least two ways: First, we shift attention to the *process* of disassembly, rather than the *outcome* of disassembly. Second, we expand who practices disassembly beyond designers and engineers to include non-technical audiences.

### Do-It-Yourself & Repair Communities

Disassembly and de-synthesis intersect with work in HCI on do-it-yourself (DIY) and repair communities as broadly both focus on non-experts (e.g., non-designers or non-engineers) creating with technology [3]. Research on DIY communities (e.g., makers and crafters) has focused on different communities of making [2, 19, 55]; where making takes place and who counts as a maker [17, 37, 53, 54]; and making as a platform for empowerment [38, 57]. Likewise, investigation in repair considers the life of a technical artifact beyond the design space [31, 32, 54] and opens investigations into the different groups that continue to work and create with technologies in unplanned ways [33]. Our conceptualization of disassembly differs from repair in its interest in breaking down existing artifacts (discarded or not) rather than restoring them.

## METHOD

To gain insight into how non-experts disassemble common technologies, we employed a case study methodology [41]. The case study is what Yin [65] refers to as a revelatory case; that is, we investigate a social phenomenon that has previously been inaccessible to researchers. In our work, we study novices in their nascent disassembly work together, which can be difficult to motivate and organize for families with busy schedules [53]. Specifically, our case study examines two workshops around disassembling desktop printers which we hosted for youth and their families at a local middle school in the Pacific Northwest of the U.S. in March 2019.

### Family Science Nights

We conducted the two disassembly workshops with young people and family members as part of on-going *Family Science Nights* (FSNs). The FSN meetings are monthly events for young people and their families to meet, have dinner, and perform a science or technology-based activity together. FSNs are part of a larger research program studying how neighborhoods engage together in STEM learning [1]. Past FSNs have included sewing wearable and soft circuits, designing physical computing interfaces with Makey Makey boards, and baking cookies with different leavening agents. Families are recruited by the FSN team with the help of partner organizations. Different students and families attend each session, there are no requirements for regular attendance, and each event typically runs for about two hours in the evening.

### Disassembly Artifact: The Desktop Printer

Desktop printers offer a compelling case for disassembly. Since their development in the 1970s, desktop printers have become nearly ubiquitous in homes, schools, and offices in the global North [28]. A quick online search turns up printers for sale for as little as $25 USD. Despite their prevalence and low cost, printers are, for the most part, invisible. Most common desktop printers are black seamless boxes, unseen in the background until they breakdown.

For each workshop, numerous disassembly stations (see Figure 1) were set up containing the following: (1) a common desktop inkjet printer acquired from a local thrift store; (2) an electronics screwdriver kit containing small bits; (3) a larger screwdriver kit containing standard screwdrivers; and (4) magnetic trays to collect screws and small metal pieces. In addition to the disassembly stations, toolboxes containing other screwdrivers and assorted pliers were available. Gloves and eye protection were provided to participants. No tools were available to smash or cut the printers (e.g., no saws, scissors, hammers, or utility knives).

### Participants

The disassembly workshops were conducted at a middle school in the Pacific Northwest of the United States with a diverse student body. The school has a high percentage (71%) of students receiving Free and Reduced-price Meals (FARMs), 23% of the students are English-language learners, and 18% have an Individualized Education Program. In terms of ethnicity, as of the 2017-2018 school year, the student body was 43% Latino, 22% Asian, 13% Black, and 11% White.

In total, we recruited 21 total participants in ten family groups across the two workshops: 17 middle school aged (~11-13 years old) young people (3 female, and 14 male), and 4 adult family members (3 female, and 1 male). The first workshop included 14 young people and 3 adults spread across seven family groups; the second workshop included 3 young people and 1 adult spread across 3 family groups. To ensure privacy, we did not collect demographic data from participants. We refer to participants by pseudonyms. Data from the two workshops were combined for analysis.

**Figure 1. A disassembly station.**

### Facilitators

Facilitators for the first workshop were comprised of four undergraduate students, three graduate students, and one professor, and for the second workshop of two undergraduate students, one graduate student, and one professor. During the workshop, facilitators assumed a participant observer role [28]. Like the participants, all but one of the facilitators were novices in disassembling printers. To mitigate this inexperience, all facilitators disassembled a printer prior to the workshops with the same tools used by participants. Facilitators' primary aim was to keep the disassembly activity going. Specifically, facilitators: (1) set up the room with printers, tools, and other materials; (2) set up the video recording equipment and ensured the video recording worked throughout the workshop; (3) provided meals and welcomed and oriented families to the disassembly activity; (4) answered questions; and (5) offered general support. As participant observers, facilitators sometimes helped with the disassembly process itself, especially when directed by participants to do so.

### Workshop Structure

At the beginning of each FSN, disassembly stations including printers were laid out across several tables. Each table contained two to three stations with enough space for youth, families, and facilitators to work.

We provided the youth and their families with a specific disassembly prompt: "*We are going to take these printers apart, there is only going to be one rule as we take these printers apart, and that is going to be that* ***you cannot break anything****. If you are completely stuck, a break has to be approved by a facilitator.*" Apart from this initial prompt, participants were left to structure their own disassembly activities as they wished—with the tools they wished, in the sequence they wished, at the pace they wished, and with the partners they wished. Participants had the entire two hours to disassemble their printers.

### Video Capture

We used four cameras with attached microphones to record workshop activities. Three cameras faced the tables where groups worked. The fourth camera was directed toward a large tangible display suspended on a stand in the front of the room [1], which in real time displayed interactive photos taken by participants at the workshop. The cameras were fixed in their respective positions. Facilitators monitored the cameras and when needed adjusted the camera angle to ensure the disassembly activity remained in the frame.

### Analysis

The video recordings across the two workshops resulted in approximately 8.5 hours of footage. To manage this volume of data, we divided the footage into 17 clips, each averaging about 29.5 minutes in length. Clips only included the workshop activities, not other activities like set up or clean up. In analyzing the video data, we examined the disassembly sessions at two levels. We sought first to understand the broad range of actions that participants employed as they engaged in their disassembly process (Level 1). Second, we focused in on a closer, more detailed analysis of vignettes that showcased important moments from the disassembly workshop (Level 2). Because this study was exploratory in nature, we employed an inductive process for analysis [11].

#### *Level 1: Categories of Disassembly in Action*

The entire dataset of 8.5 hours of video was used to generate and develop a set of categories that characterize disassembly actions. To begin, each of the 17 clips was reviewed by two researchers: the first researcher wrote a detailed memo describing the activities the clip. That memo and clip was then reviewed by a second researcher who added any key details or content missed by the first researcher. Once memos for all 17 clips were completed, the memo and content of each clip was discussed in a team meeting. Next, the memos were used to generate an initial set of categories that described the disassembly actions observed in the workshop. To test these initial coding categories, the categories were applied to roughly a quarter of the data (four clips; 24% of the video data). Based on this initial application of the coding categories, the coding scheme was refined. The refined coding categories were then applied to a portion of each of the four clips used for developing the categories. Based on this second application of the coding categories, further refinements were made to the coding scheme and the scheme was finalized. Lastly, the finalized category scheme was applied to the entire dataset. The presence or absence of each category of action at the most granular description of action in the coding scheme was recorded for each of the ten youth and family groups (e.g., if the group engaged at least once in the action it was coded as "present," otherwise it was coding as "absent").

#### *Level 2: Vignettes*

Complementing the broad but discrete categories of disassembly in action (Level 1), the vignettes highlight how actions can come together in disassembly to create meaningful moments and opportunities for participants, as well as point to unique qualities and challenges of disassembly. Following a process similar to Beneteau et al. [5], we intentionally selected vignettes to illustrate key moments and insights from the practice of disassembly. Specifically, to select the four vignettes, we returned to the data and memos to identify video snippets that pointed toward a significant moment in disassembly. Each researcher nominated one or two snippets as a potential vignette. During a meeting, researchers described their proposed vignettes, explained why each was significant, and justified the start and stop times. This process resulted in ten possible vignettes. Further discussion focused on the clarity, significance, and exemplary quality of each proposed vignette, ultimately settling on four (reported in the results below). Other proposed vignettes were set aside based on similarity (e.g., overlapping content), length (e.g., too long), and recording quality (e.g., difficult to hear dialogue or difficult to see actions). We then analyzed the four selected vignettes in greater detail using techniques from interaction analysis [12, 34, 56]. In our analyses we examined the interactions among the participants, their language choices, and their actions [34]. Each clip was presented by a member of the research team and then discussed to ensure there was agreement in the interpretation of the clips.

## RESULTS

We begin by reporting on the specific dynamics that manifest during the disassembly workshops. Then, we describe the categories of actions practiced in disassembly which we identified. Finally, we present four detailed vignettes that as a group highlight compelling moments from disassembly and demonstrate disassembly in context.

### Workshop Dynamics

Disassembly in the context of a Family Science Night is a dynamic and interactive process. In addition to the young people and adults reacting with excitement at the prospect of disassembling printers, they were in a familiar space with family and friends. Participants were comfortable moving about the room, at times leaving their workstations to check in on others' progress, share results, enjoy snacks, and socialize.

In turn, the facilitators had to respond to the workshops' active environment. Video cameras needed to be adjusted to keep participants in the frame. Tools and supplies spread throughout the workshop as participants engaged with the activity. Smaller participant groups tended to require more active facilitator involvement. And in one instance a larger family group (five members) split into two groups (a group of two and a group of three), which required adding another printer (from a reserve supply) and redistributing tools.

### Level 1: Categories of Disassembly in Action

In the course of their disassembly work, participants engaged in a range of activities. We identified four overarching categories of action: *physical, social, epistemic*, and *affective*.

**Physical.** When participants are using their hands and bodies to practice disassembly, either directly or with tools, they are taking physical actions. The actions included *hitting* (1 of 10 groups), *probing* (10 of 10 groups), *prying* (10 of 10 groups), *unplugging* (10 of 10 groups), and *unscrewing* (10 of 10 groups). In a constrained disassembly session like the one described in this paper (e.g., breaking parts was not allowed unless absolutely necessary), participants were often searching for different ways into the printer by picking up, handling, and turning the printer (*probing*); using screwdrivers and their hands to separate seams (*prying*); and removing screws either with tools or by hand (*unscrewing*). Many consumer electronics are held together with screws, glue, and tabs, and using actions to remove and undo these connections are the essential physical actions of disassembly.

**Social.** Participants demonstrated social actions: asking questions, brainstorming together, and sharing results as they disassembled. Social actions involved *asking* (5 of 10 groups), *showing* (8 of 10 groups), or *telling* (9 of 10 groups). For example, a participant would *ask* what to do next (e.g., when they do not know how to proceed), how to remove a part (e.g., after having identified an internal component, but being unable to remove it), or ask for permission to take an action (e.g., whether they can disconnect certain pieces inside the printer or not). Participants might *show* an exciting result (e.g., a difficult screw finally removed), how to use a tool (e.g., using a flexible screwdriver extension), what to do next (e.g., pointing out the location of previously unnoticed tabs), or how to do something (e.g., demonstrating how a screwdriver bit fits a specific tool). To *show* required a participant getting another's attention to present an outcome of a disassembly action. Finally, participants might *tell* a result (e.g., "Oh the screw is out!") or a next step (e.g., "We have to get this screw out first"). These actions took place among participants, among participants and facilitators, and among facilitators. Through social actions, participants build a shared experience and understanding of disassembly.

**Epistemic.** As participants and facilitators worked together to disassemble the printers, they expressed and built knowledge. Epistemic actions included *naming* (10 of 10 groups), such as stating what a part (e.g., "These are the chips"), a tool (e.g., "Could you pass me the screwdriver?"), or a material is (e.g., "look at all this metal"), or is believed to be. Epistemic actions also included *describing* (10 of 10 groups), stating how something works inside the printer (e.g., "This [piece of plastic] is connected here"), a problem (e.g., "We can't get this screw loose"), a future next step (e.g., "We have to get this part out first"); or not knowing (e.g., "I don't know"). Epistemic actions describe emergent reflection, knowledge and understandings that develop during disassembly.

**Affective.** Disassembly is not necessarily an easy or intuitive process, resulting in visible expressions of affect. For example, *pleasure* (e.g., celebrations after having successfully removed a part) (10 of 10 groups) or *frustration* (e.g., many attempted actions without any visible result) (5 of 10 groups). These states were made visible by different gestures and speech (e.g., group celebrations and exclamations after successful physical actions). Frustration might occur when individuals either could not act (e.g., there are no visible screw left to remove, but the printer stays together), when other actions are not successful (e.g., a screw cannot be removed), or when actions do not yield the expected result (e.g., a screw is removed successfully, but the pieces it joined together do not come out). Frustration manifested in sighs, groans, or statements to others. Affective actions provide clues to the inner worlds of participants as they practice disassembly.

### Level 2: Vignettes

The four in-depth vignettes presented here highlight key moments in a disassembly process. As a group, they offer insight into how novices practice disassembly, demonstrate how different disassembly actions are enabled or inhibited, and lay a foundation for considering how to design for disassembly. For each vignette, we provide an overview, followed by a transcript with descriptions of the associated actions, and then a brief reflection on the events.

#### *Emerging Possibilities*

Warren works with his mom (Keri) on a printer. They have been working for over an hour, and they have removed many of the printer's parts. The table is full of large pieces of plastic, as well as tools, small components, and assemblies from inside of the printer. Keri removes screws from a panel she has detached from the front of the printer. She has just handed Warren a printed circuit board with buttons on it, which he examines. A facilitator (F1) asks about the buttons.

> F1: [*Walking over to the table*] What's that?
> Keri: The buttons, the actual buttons! [*Keri holds up the rubber buttons that cover the buttons connected to the printed circuit board.*]
> Warren: Look what I got. [*Holding the circuit board with the button switches.*]

F1: Do you want to take that home?
Warren: Hear the clicking though, feel it?
F1: Yeah, the tactile-ness, it actually has to feel good enough, they have to engineer that too.
F1: [*Picks up a small DC motor that Keri and Warren had removed from a printer*] This is cool, I wonder if I can get this working too.
Warren: Yeah! You could like […]
[*F1, Keri, Warren, and another facilitator, F2, all talk at once.*]
Keri: You put one to positive and one to negative and it will go.
F2: Yeah that's why I'm collecting all the motors because [*another facilitator*] said let's maybe save those.
F1: Yeah let's save those.
Warren: [*Still holding the circuit board and pressing the buttons*] I wonder … We could actually use it to make something else.
F1: Yes, that's what our idea is, could you break it down and someday maybe make something else out of it.
Warren: Oh! Like a robot or […] or something.
F1: Yeah.
Keri: Different circuits!

As the vignette begins, Keri has just handed Warren the printed circuit board (PCB) with the buttons on it. He is excited to show the buttons to a facilitator, and he is intrigued by the way the buttons feel and click ("Hear the clicking? Feel it?"). While Keri holds the soft plastic covering for the keypad buttons—what Warren might normally recognize as buttons ("The buttons, the actual buttons"), Warren is beginning to develop an understanding that the materials they remove from the printer have context and meaning. Specifically, that they might have an unfamiliar shape or appearance but have a common familiar function (the soft button covers versus the small momentary switches on the PCB).

Warren's growing understanding of the buttons leads to an exchange where F1 proposes the idea that materials have an origin story ("They are engineered this way"). The buttons are the result of intentional human action, they have come from *somewhere*, and they are designed by *someone.* This statement begins to map history, intention, and meaning onto materials.

Warren's exploration shifts the group's understanding of materials from the printer. Specifically, that they are not static, and that they might be available as something else. We see this dynamic possibility as the conversation shifts based on F1's question about the small DC motor ("I wonder if I can get this working?"). Warren immediately begins brainstorming about how to make it work ("Yeah! You could like…") and Keri describes how to make it spin ("You put one to positive and one to negative"). Realizing that the motors can be made to spin independently from their prior arrangement in the printer, Warren begins to see an unfolding world of opportunities ("We could actually use it to make something else […] Like a robot"). He recognizes a piece removed from the printer (e.g., a motor) might be deployed somehow somewhere else, beyond the printer. Similar to how Dew et al.'s work on salvage reimagines waste streams as materials for fabrication [15], Warren and Keri's interactions reveal the inner worlds of material artifacts and reconsiders the possibilities therein.

### *Inhibited and Enabled*

Blake and Giovanni (two youths) work side-by-side on the same table, about 45 minutes into the workshop, each trying to disassemble his own printer. They have nearly identical desktop sized portable photo printers. Blake, having recently removed a large piece from the top, works inside of his printer steadily without pause. Giovanni has not yet been able to open his printer. He tries using several screwdrivers to pry off the handle of his printer, while Blake uses a screwdriver to remove screws from the top of his printer.

Blake: [*Removing a large piece from the top of the printer*] Oh wow.
[*Blake tilts the printer forward, towards Giovanni, revealing green printed circuit boards inside of the printer. He looks over at Giovanni with his eyes wide.*]
Giovanni: [It's] the motherboard of it.
Blake: I want to take a picture of it. [*Blake uses his cell phone to take a picture*].
[*Giovanni continues working on the printer, trying hard to pry the side handle off, without success*.]
Blake: [*To Giovanni*] Do you need help?
Giovanni: No, I'm good.
Blake: [*Picking up a screwdriver and returning to the printer*] This is going to take forever, there are so many screws.
[*Giovanni continues to try to poke and pry the printer with the same screwdriver. Giovanni picks up a larger screwdriver and stands as he repositions the printer. Pressing very hard, he tries to pry off the printer handle again without success. Giovanni gets up to get a drink while Blake continues to remove screws from the interior of the printer. Blake recognizes that he needs a different screwdriver and reaches for it.*]
Blake: Where's the big one? [*Reaches for a large screwdriver and removes the screw.*]

To see the two interactions unfolding side-by-side is striking. Blake and Giovanni are close in age, have access to the same tools, and have near identical printers, yet their experiences are widely divergent. Though Giovanni understands what physical actions he needs to take to disassemble the printer (e.g., unscrewing and prying), he cannot enact his apparent intentions. In contrast, Blake works effectively next to him. Giovanni's difficulties with physical actions, do not prevent him from engaging with the larger workshop, however. He responds to Blake's excitement about removing a part and performs an epistemic action when he identifies it ("the motherboard"). Still, Giovanni struggles with his own machine. Blake seems to sense Giovanni's difficulties with his printer and offers to help, but Giovanni declines.

Once Giovanni declines Blake's offer of assistance, Blake returns to his printer and identifies a clear next step ("there are so many screws"). He understands the screws inside hold other parts in place, and that these will need to be removed. At the same table, Giovanni cycles through different sized screwdrivers and continues to try to pry off pieces without success. Giovanni does not have a specific part he is trying to remove. Instead, he tries to use a variety of screwdrivers on different areas of the printer, searching for openings, but without a clear plan. Meanwhile, Blake also cycles through screwdrivers ("Where's the big one?"). His tool use however is intentional. He seems to see a path forward through his printer and to know which tools can support his work.

Giovanni and Blake's divergent experiences with their printers highlight how artifacts can afford (or fail to) disassembly. Giovanni's experience recalls Hertz's treatment of the black box [27], where the interior of the artifact is the domain of the expert. Artifacts are *not* designed for material exploration, and disassembly is not necessarily an intuitive or easy practice.

### *Playfulness in Disassembly*

Devon, Robert, and Alexis (all young people) stand over the printer and work on disassembling the pieces (Figure 2). The printer is on its side, and they cluster around it. Devon is very jovial and jokes with the others, pointing out something one of the others has done.

> Devon: [*laughing*] Did that disconnect? This is the one that… you know the Xbox…? [*laughing and looking at Alexis*]
> Robert: Oh look! More stuff came out!
> Devon: Oh shoot! [*Devon jostles something*]
> Robert: Devon!
> Devon: Oh shoot! I'm sorry, I'm sorry!
> F1: [*A facilitator enters to help remove a part*] So this is a little pull, you can just yank that out… [*sounds of realization from the boys*] like from the white piece right here. That clips right…
> Robert: Exploring […] is real [*Robert hands something from inside of the printer to Devon*]
> Devon: Look, this is 50 bucks right here
> Robert: [*Laughing*] The heck D, you trying to sell this?
> F1: There's… people do part these down and resell.
> Robert: [*Working inside the printer*] This moves a little bit.
> Devon: Yeah yeah yeah, it's pretty loose, I would say so. Looks like a USB cable type of vibe [*putting on an "academic adult" voice*]. I would say it's more like an external HD type of… very sophisticated… oh yeah… [*Alexis says something kind of affirmative, but it's hard to hear*] call it more like a […] vibe […].
> Robert: [*exasperated*] Oh my God, Devon.

The three young people are enjoying disassembly, in particular Devon, who laughs and jokes throughout. The three participants show fascination as they remove parts ("More stuff came out!"). Though they worry they are breaking the printer ("Oh shoot! I'm sorry,"), it does not stop their work. Their playful engagement creates openings for learning and social engagement as F1 interjects and explains how to undo a connector ("You just yank it out"). The boys react with interest and F1's advice helps the group complete a goal (removing a particular component that was giving them a hard time).

Two conversations then follow in rapid succession. First, Devon and Robert joke about selling parts from the printer. Their joking communicates an understanding that the printer materials have some sort of value outside of the arrangement of the printer. Devon then takes on the role of the expert. He assumes an "academic adult voice" and describes the materials he sees. In doing so, he explores what it is to be an authority in relation to an artifact—an opportunity that may not be readily available in his day-to-day life.

Disassembly can shift artifacts, from invisible black boxes, to sites of play and joy [57]. Play lets one imagine new relationships with technology. When Devon plays at being an expert, he explores a possible but unrealized relationship with artifacts.

**Figure 2. Devon at work and at play with Robert and Alexis.**

### *Permission to Disassemble*

Ahmed and his mom (Amelia) work together on a common desktop printer. Two facilitators sit with them, one (F1) works closely with Ahmed, while the other (F2) looks on. F1 has just helped Ahmed pry up the top of the printer, opening the top of the printer so they can work inside. F1 demonstrates to Ahmed how a particular internal piece can be removed, and points out similar pieces.

> Ahmed: So, we can break these off?
> F1: [*Points towards a part of the printer*] If you want to unlock that one over there.
> Ahmed: [*Looking for the part F1 suggests*] Uh it doesn't have one.
> [*Ahmed, Amelia, and F1 look closely at the printer to see what to do next. Ahmed finds a screw and picks up a screwdriver to point it out. Amelia points to the spot.*]
> Amelia: Yes. There you go.
> F1: Nice.

Ahmed: [*Ahmed pushes hard on the printer in order to reach the screw he would like to work on. There is a loud cracking sound and he hesitates*.] I had to.
F1: That's ok.
[*Ahmed continues removing screws.*]
Amelia: There are some more screws right there, and over there [*pointing to different parts of the printer*].
Ahmed: [*Unscrewing*] What happens if we unscrew something and uh, it falls apart?
F2: That's ok.
Amelia: We're just taking it apart.
F2: Don't worry so much about it.
Amelia: [*Laughing*] You'll mess it all up.
Ahmed: But **I feel like this is a bad thing**.
F1: No!
Ahmed: When I'm in school-
F1: Oh … don't want to break a normal function printer, but this is the exception.

Ahmed tries to follow the F1's suggestion ("So, we can break these off?"), but cannot remove the part. Instead, he finds a screw to remove instead. When he presses on the screw however, there is a loud cracking sound. This immediately gives Ahmed pause. He goes out of his way to explain his actions ("I had to"). He may be responding to a concern that he has broken the workshop rules (avoid breaking anything), but his next statement points to a concern beyond the rules of the workshop. He worries that after removing all the screws the printer will "fall apart." Both F2 and Amelia try to assure Ahmed that what he is doing is fine. Ahmed is trying to reconcile his normally implicit relationship with artifacts (that he should not take them apart) with the explicit actions he takes in the workshop. His thinking culminates in the unprompted declaration, *"I feel like this is a bad thing."*

Despite the assurances of the facilitators and his parent, Ahmed feels like he is a breaking some sort of rule. Though Amelia laughs ("you're going to mess it all up"), her reaction points to one possible source of Ahmed's apprehensions. The shape and design of artifacts communicate that they ought to remain as they are. To interact with them in another way challenges and disrupts this fixed state and perhaps should not to be allowed.

Unlike Vallgårda and Fernaeus' bricoleurs [59], Ahmed does not have a relationship with artifacts that allows him to view technology as readily available materials. Instead, Ahmed must navigate the tension between the workshop prompt (disassemble the printer) and his everyday relationship with the printer. Ahmed's final comment points toward one of the socio-cultural contexts in which this understanding is learned and cultivated ("When I'm in school"). Of course, Ahmed's school needs to keep printers together and functioning; limited budgets, a diverse set of users, and limited technical expertise contribute to a relationship that fixes technologies in place, to be treated with reverence and handled delicately. It constrains how Ahmed perceives what constitutes appropriate interactions with everyday technologies.

## DISCUSSION

Studying disassembly in action reveals a set of practices which can be described using four broad categories: physical, social, epistemic, and affective. The vignettes demonstrate disassembly in a situated context—young people and family members taking apart printers, and highlight moments demonstrating why and how disassembly can be a meaningful practice. Taken together (actions of disassembly and disassembly in context), we discuss several challenges and opportunities in disassembly. Specifically, we consider permission to disassemble, disassembly and sustainability in HCI, the playfulness of disassembling, and design opportunities to support disassembly.

### Permission to Disassemble

In the fourth vignette, why did Ahmed declare that disassembly felt like a "bad thing"? What relationships do novices have with technologies that would make disassembly taboo? The disassembly workshops were environments meant to encourage and enable disassembly, yet Ahmed still expressed sentiments as if they were doing something wrong. There are at least three factors that shape the relationship among non-experts, artifacts, and disassembly. First, the immediate *setting and context* (socio-cultural context) communicates to novices whether or not it is ok to open an artifact. Second, the relationship is further reinforced by the *policies* intended to define the appropriate use of a technology. Finally, the *physical design* of the artifacts themselves.

*Socio-cultural contexts* can communicate to non-experts how artifacts are to be engaged. For most people, three things can happen with a printer: printing (its intended use), maintenance (changing ink cartridges, loading paper), and disposal (after breakdown). Other actions (e.g., disassembly) are less available, in part, because the practices themselves are less visible. Consider Ahmed. He demonstrates a learned deference to objects, rather than a willful exploration, because he has either limited or no experience disassembling. Non-experts are less likely to encounter settings where disassembly is permitted or encouraged. The disassembly workshop (e.g., a space full of tools and facilitators) is intended to create replicable conditions to consider other actions and relationships with technology.

*Policies* also communicate how artifacts should be used. For example, warranties and terms of service formalize what it means to use technology appropriately. Many warranties inform users that opening a device voids the warranty [35, 36] as does removing security stickers placed across seams and over screws [50]. Similarly, 'Shrink Wrap' style licenses force users to accept terms of service for applications simply by opening packaging or logging into an interface [24].

The physical shape of artifacts encodes a message of closure. The printer, for example, is not designed to be undone. They do not afford opportunities to open them beyond controlled operations such as replacing ink cartridges. Many modern commonplace technologies are joined together with fine seams and offer little or no opportunity to begin opening it. Screws are hidden underneath stickers and rubber feet, or they are recessed in deep plastic cavities. Sometimes removing parts requires special tools for proprietary screws [62]. The artifacts present themselves as closed and final, and users are unable to enact the physical disassembly actions.

### Reuse and repurpose

Blevis [6] describes how the design of interactive systems obscures the physical and material reality of technical systems. Users interact with software, in turn, software is perceived of as the material of interaction designs, and this drives the premature obsolesce and invisibility of the hardware of technical systems [6, 8]. That data can sync easily across multiple platforms (e.g., a calendar across a computer, a mobile device, and a voice assistant) pushes the material elements of systems further to the background. This distance reinforces artifacts as objects to be used, not understood [27].

Disassembly provides a practice for revealing and considering the physical reality of technical systems. Consider Warren's experience with buttons and motors in the first vignette. For Warren, the practice of disassembly created openings to consider first, the material world of the artifact itself, and second, that this material world might actually be actionable. Warren's response invokes Dew et al., [15] and Ingold's [29] notion of materials in flow, able to shape and be shaped, rather than fixed into a form. For Warren, after removing the buttons and motor from the printer, they became reanimated.

When artifacts are perceived as materials, it can shift our relationship with systems away from use and disposal, toward possibility and action. Building on prior work which expands HCI to include the physical hardware on which computation is carried out [6], disassembly creates opportunities to enlarge thinking around what materials are available and to whom, for interaction. This invites consideration of the complex relationship between the physical and digital elements of technical systems, as well as interaction itself. Emphasizing disassembly contributes to a "shared responsibility" [47:56] anchored in the material and ecological limits in which technology is designed, created, and deployed.

### Playfulness of Disassembly

Playful experiences shift relationships with technology away from more pragmatic goal oriented experiences, toward open ended or ambiguous engagements with technical systems [21, 22]. They are experiences centered on internally motivated exploration. In this workshop, disassembly creates conditions for open-ended and ambiguous interactions with technical artifacts. The workshop asks participants to take a familiar artifact (a printer) and perform an unfamiliar practice (disassembly).

In the third vignette, Devon, Robert, and Alexis interact with their printer in a playful way. They begin to imagine different possibilities for the materials in the printer (e.g., selling the parts). In taking on an adult voice, Devon experiments with how it feels to be an expert. In the second vignette, Blake reacts with excitement to removing the motherboard. Likewise, in the first vignette, Warren and Keri respond enthusiastically to removing the buttons. Successfully removing a part was deeply satisfying for participants and were often accompanied by exclamations and celebrations. Disassembly transformed a mysterious artifact into a site of curiosity and play. Disassembly lends itself to a world where. as Paulos [47] writes, technologies can "sing of not just productivity and efficiency but of our love of curiosity, the joy of wonderment, and the freshness of the unknown" [p. 52]. Disassembly opens opportunities for "new thinking, curiosities, and beliefs" and invites "people to engage in otherwise socially unacceptable behaviors" [47:56], while creating conditions for what Duckworth [16] calls the "wonderful ideas" we develop as we explore new spaces.

### Design Opportunities

Disassembly is a practice that can help to rethink our relationship with technologies: it calls into question what technical systems permit; it highlights the relationship between technical systems, the natural world and material flows; and it creates conditions for play. The ability to access and work within the inner world of a technology could be considered a feature. How then might designers in HCI support and design for disassembly?

First, designers might consider the artifact itself and the different levels a design might **account for disassembly**. Designers might start at the surface level of the artifact—the construction of the exterior shell. For example, they might consider what screws are used to construct an artifact (e.g., proprietary or standard screws) and how accessible they are (e.g., hidden or in sight). Similarly, external assemblies might use snap together systems rather than internal tabs to hold cases together. The instructions for disassembly could be built into the artifact itself (e.g., instructions for disassembly embedded into the system). Considerations for disassembly may also extend into the interior of a system. Internal assemblies (e.g., sensors, motor carriages) might be designed as modular (much like the interior of many smart phones), making them easy to remove, replace, or repurpose. HCI researchers might also investigate how to interface with these internal materials once removed from the artifact. Designers could also reconsider the policy environment: warranties could be rethought so as not to punish users for being interested in exploring the interior of their artifacts.

Second, rather than focusing on the artifact itself, designers could direct their attention to the tools, practice, and environments **enabling disassembly**. Enabling disassembly means creating resources to support opening artifacts and accessing the materials within. The categories of actions describing disassembly point to possible design interventions; tools and platforms to support the physical, social, epistemic, and affective actions. For example, physical tools can support the opening of tightly closed technologies (e.g., iFixit's, a repair manual repository, smartphone specific tools [67]). Designs could also support the use of these tools (e.g., how to use tools for specific applications). Interventions could support social actions of disassembly (e.g., card sets highlighting different construction techniques such as seams, tabs, or recessed screws to help users like Giovanni, who are unable to act), as well as epistemic actions (e.g., a catalogue of materials and parts one might encounter during a disassembly practice). Social actions might be supported by a platform for users to share their disassembly experiences.

Finally, positioning disassembly as a practice that reveals materials as dynamic and in process, invites designers to turn their attention to the **results of disassembly**, and to the potential opportunities that might unfold in each material. Designers might create interfaces or designs to enable non-experts to access and use the capabilities in materials. This represents for example, the difference between an extracted motor being controlled and spun, and it serving as a paperweight. Though there is not anything inherently wrong with either application, accounting for materials in disassembly implies making either opportunity available. Though there are kits and platforms available to introduce controlling electronics to novices (e.g., Arduino, Makecode, RaspberryPi, to name a few), making the materials artifacts are made of useable may require further support than is available in an off-the-shelf kit. What novice users might do with the metals, plastics, and electronics components, and how they might do it is open for exploration.

### Limitations of the Study

The workshop environment was highly dynamic and camera angles were limited, so it might be possible to glean even more insight in future work with more cameras and recorders. Further, a more controlled environment with less noise or smaller groups would enable finer grained micro-analysis. Participants were constrained by the tools available to them in the workshop. Despite the limited tools, many of participants were still able to successfully and completely disassemble their printers. Though the data is rich and dense, the workshops would have benefited from having more participants.

### Future Work

We hypothesize that the elemental actions of disassembly identified in this research with novices are of a more general and abstract character. Thus, we would expect to see them in disassembly activities across widely different contexts with widely different populations (e.g., skilled engineers, versus farmers in rural areas). In contrast, the vignettes point to how these elements manifest situated in a particular culture and context. Future work could study disassembly in action with these different groups.

Future work might also focus on the varied ways in which the categories of disassembly actions manifest with novices, as well as longer-term explorations of how novices develop their skills in disassembly (and so grow beyond novice-hood). This work was focused on printers, further research might explore different physical artifacts with varying levels of computation embedded into them (e.g., remote controls or smartphones), or even consider digital artifacts (e.g., software).

Finally, future work might ask how far can amateurs or non-experts go, really? It may appear to be quite a leap to expect non-experts to be able to engage and interact with the materials within technological artifacts. This gap though, does not preclude non-experts from practicing disassembly. Previously, HCI researchers have created and studied designs that widen who is able to build and create with tools traditionally limited to experts. For example, non-experts have built electronics [40], digital fabrication tools [48], and even cell phones [39].

## CONCLUSION

In this work, we have presented an investigation of the material opportunities that emerge from disassembly. To do so, we studied how novices, in this case young people and family members, disassemble an everyday technical artifact—the desktop printer. We offer three contributions: (1) expanding existing theoretical work on materials in interactive systems; (2) an empirical study of disassembly in action; and (3) design considerations to support disassembly.

To disassemble is to open artifacts, and in doing so, to explore the materials that make up the artifact's inner worlds. Disassembly helps reveal that these materials are not fixed in place, but rather, they are dynamic—that they are continuously reshaped and reformed, that they existed before and will exist beyond their current arrangement, and that they are available for further repurposing and reuse. Disassembly invites novices (and all users) to consider artifacts as open canvases, empowering users to play an active role in creating and shaping the technical systems that saturate the world in which they live. To design for disassembly is to continue to look beyond productivity and efficiency toward possibility and ambiguity, and asks what people might do with an artifact, rather than directing people toward singular uses. It opens artifacts to new levels of understanding—how an artifact works rather than how to work it. Disassembly invites us to imagine a world where the materials which make up our technical artifacts are sites of play and creation, as inviting and available as paints, markers, or clay.

## ACKNOWLEDGMENTS

We thank the young people, parents, and facilitators who played an integral role in the project. We also thank the reviewers for their insightful and helpful feedback. We acknowledge June Ahn and Tamara Clegg for their development of Science Everywhere. This material is based upon work supported by the NSF under Grant No. 1441523. Any opinions, findings, and conclusions expressed in this material are those of the author(s) and do not necessarily reflect the view of the National Science Foundation.

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