



From Research Prototype to Research Product

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ABSTRACT

Prototypes and prototyping have had a long and important history in the HCI community and have played a highly significant role in creating technology that is easier and more fulfilling to use. Yet, as focus in HCI is expanding to investigate complex matters of human relationships with technology over time in the intimate and contested contexts of everyday life, the notion of a ‘prototype’ may not be fully sufficient to support these kinds of inquiries. We propose the *research product* as an extension and evolution of the research prototype to support generative inquiries in this emerging research area. We articulate four interrelated qualities of research products—*inquiry-driven*, *finish*, *fit*, and *independent*—and draw on these qualities to describe and analyze five different yet related design research cases we have collectively conducted over the past six years. We conclude with a discussion of challenges and opportunities for crafting research products and the implications they suggest for future design-oriented HCI research.

Author Keywords

Interaction Design Research; Research Product; Design.

ACM Classification Keywords

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

INTRODUCTION

Prototypes have had a long and important history in the HCI community. Prototyping has proven to be productive in enabling HCI researchers to develop, refine, and test theories, concepts, and interactive systems in a human-centered fashion. The use of prototyping and prototypes to elicit feedback from people plays a highly significant role in pursuing the question of how new technologies can be created that are easier and more fulfilling to use.

However, the kinds of questions that HCI researchers are

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pursuing are expanding. The focus of a growing portion of the HCI community has moved beyond designing for efficient use to investigating complex matters of human-technology relations that often involve messy, intimate, and contested aspects of everyday life. These kinds of questions include: What roles could—or *should*—interactive technology play when we consider it as a long-term, evolving component of everyday life? How do technologies mediate between humans and their actions in the world? How do choices that go into the materials, form, and computation of interactive systems shape human relations to them? And, how do they change over time?

A core goal of this paper is to motivate and develop the notion that investigating these kinds of research questions can require a type of a research artifact different from a research prototype that we call a *research product*. The complexities and challenges in researching questions about human-technology relations in everyday life over time suggest that the notion of a ‘prototype’ within research may not be sufficient. Key to this distinction, and to the notion of a research product, is the relationship between the kinds of research questions being asked and the kinds of perspectives that needs to be generated by a design artifact in order to investigate these questions. In this paper we propose the research product as an extension and evolution of the research prototype to support investigations into distinct kinds of experiences, encounters, and relationships between humans and interactive technology.

While the fidelity of prototypes can range, they remain references to future products, systems, or services. In this way, prototypes are placeholders for *something else*; they are an instantiation of a future outcome [31]. Within HCI research, a prototype may be the manifestation or bare bones testing of a theoretical concept not to be judged for its actuality or present state, but rather its potential [52]. Prototypes are also often assumed to be a point on a trajectory toward a fully realized commercial product used to test specified needs or unmet requirements. In either case, new knowledge and insights are produced through the use of research prototypes and it is not our aim to criticize or undermine these efforts. Rather, our goal is to extend the capacity for developing new knowledge through the making of design artifacts for research.

The concept of a research product emphasizes the nature of the engagement that people have with an artifact predicated on *what it is* as opposed to what it *might become*. It is this core distinction that led us to use the term ‘research product’ in reference to the final and actual nature of the artifact. This is in contrast to a ‘research prototype’ that refers to a final concept but the artifact itself may be transitional or in-progress. We believe the term ‘research product’ emphasizes the actuality of the design artifact helping to overcome the limitations of prototypes when investigating complex matters of human-technology relations over time, which is of growing interest in the HCI community. Importantly, we do not use the term ‘product’ to suggest these kinds of artifacts are intended to be commercial products, or produced at commercial scale and volume.

Another goal of this paper is to articulate the concept of *research product* through the practices of research through design. We analyze design cases that stretched over six years of practice across three research groups that then led to the retrospective articulation of the concept of research product. We situate the research product as a design concept that is crafted, inherently messy, and achieved through balancing overlapping and competing design qualities that come together (or fail to coalesce) in the completion of making the artifact. We are not the only researchers to practice this kind of research and several important prior research examples have existed for some time and new examples continue to emerge (e.g., [1, 8, 16, 17, 22, 38]). Importantly, research products are not a theoretically derived notion that is rationalized as complete. Like prototypes, the concept of a research product is generative; findings from each of our design cases generated new insights that framed future design research inquiries. An overarching goal of this paper is to open up the notion of the research product, so that this particular kind of research can be further taken up and refined by the HCI community.

In what follows we describe the qualities of a research product to be *inquiry-driven, finish, fit, and independent*. We draw on these qualities to describe and analyze five different yet related design research cases of our own that exhibited varying levels of success at achieving the qualities of a research product. We first detail key theoretical motivations and our design decisions for each case. We then unpack how these design artifacts were encountered in the field and the extent to which they successfully operated as research products. We conclude with a discussion aimed at mobilizing our work in future HCI research, focusing specifically on the challenges and opportunities in the crafting of research products.

BACKGROUND AND RELATED WORK

Related work falls into two areas: the roles of prototyping and prototypes in HCI; and research on human-technology relations in HCI influential to our design research cases.

Prototyping and prototypes

Prototypes can be defined as “*physical manifestations of ideas or concepts*” [40:9] or as “*representations of a design made before final artifacts exist*” [6:424]. Prototyping and prototypes in HCI and interaction design play multiple roles ranging from open-ended explorations to provoking critical reflections and testing or validating hypotheses [52]. Houde and Hill [25] were among the first to emphasize the importance of the questions the prototype asks and hence what the prototype *prototypes* through its different dimensions (e.g., role, look, and feel, and implementation). Buchenau and Fulton Suri [6] motivated and unpacked *experience prototyping*, which aimed to bring multiple stakeholders together to “*gain first-hand appreciation of existing or future conditions through active engagement with prototypes*” [6:424]. Experience prototyping provided an approach that leveraged the practice of prototypes to explore and experience aspects of potential technological futures. It has since catalyzed a range of methods, techniques, and toolkits aimed at enabling HCI designers and researchers to prototype interactive systems in more rapid, sophisticated, and even speculative ways (e.g. [5, 7, 43]).

Following these seminal works, there was an increasing emphasis on the ways prototypes and prototyping operate as carriers of reflection and argumentation. Galey and Rueckler [15] articulate how knowledge is embedded within a prototype and how this can advance knowledge production about the world. They also position the act of design as a critical inquiry in itself. The idea that artifacts embody knowledge that cannot be articulated otherwise is also explored by Stolterman and Wiberg [44] who argue for a concept-driven interaction design research approach.

Drawing on these works and many others, Lim, Stolterman and Tenenberg [31] present an in-depth investigation into the fundamental nature of prototypes. They articulate two key dimensions of prototypes in support of this argument. First, prototypes as *filters*—designers can purposefully leave out aspects of the design at a particular phase of the design process, while exploring radical variations of other qualities. Second, prototypes are purposely formed manifestations of design ideas—this manifestation enables project stakeholders to experience the idea, and designers themselves to reflectively engage in a conversation with the design idea, as famously articulated by Schön [41]. Relatedly, Boer and Donovan [3] articulate the notion of *provotypes*—provocative prototypes that “*embody tensions surrounding an area of interest, in order to support collaborative analysis of that area and to collaboratively explore design possibilities*” [3:389]. Central to the notion of provotypes is the analytical and generative role they play in bringing a project’s multiple stakeholders together around critical issues bound to the design goal.

Our aim is to build on and extend the important role of prototyping in HCI. However, as interest in designing for contexts of everyday life is increasing in the HCI community, new modes of investigating through the

crafting of artifacts are required. Next we briefly review works in the HCI community that are beginning to ask theoretical and philosophical questions about the nature of technology in everyday life, what forms it ought to take, and how it mediates human actions in the world.

Everyday life and human-technology relations in HCI

As focus has expanded beyond the workplace to the complex, messy contexts of everyday life, the HCI community has continued to grapple with a range of new concerns, issues, and research questions [2,21]. Many works have developed new approaches to better take into account the ways in which interactive systems become entangled in people's lives (e.g., [9,13,17,33,42]). A strand of HCI research has investigated design strategies for creating technology that more fluidly be transformed and situated to people's everyday practices. Wakkary & Maestri [51] describe this process as *design-in-use*; here, the notion of 'design' is comprised of people shaping their worlds in an ongoing fashion to better address their unique needs. This work builds on the previous studies by Taylor and Swan [45] and Tolmie et al. [46] who respectively looked at how technologies ought to be designed as resources to support the complex and creative ways people socially organize their homes and articulated the need to make technologies as unremarkable as domestic routines themselves.

The need to support self-determined uses of technology reflected in the sample of works above is emblematic of a broader shift toward investigating the ways technology mediates between humans and their actions in everyday life. Drawing on works in philosophy of technology from Borgmann [4], Ihde [27], and Verbeek [47,48], Fallman [12] advocates for the design of computational objects that are more open to people forming relations to them that reach beyond explicit purposes or utility. This imperative is well articulated through the slow technology design philosophy [20] and Mazé & Redström's [32] subsequent assertion that crafting computational objects for everyday life requires researchers "*to investigate what it means to design a relationship with a computational thing that will last and develop over*" [32:11]. Issues surrounding how more enduring forms of technologies could be designed have steadily gained purchase in the HCI community (e.g., [14,18,19,26,28,36,39]).

Collectively, these works make clear the need for new strategies to critically investigate human-technology relations and how they are mediated through actions and experiences over time. We contribute to this work by articulating how *research products* offer a productive design-oriented approach to support rich investigations into this growing area of HCI research.

QUALITIES OF A RESEARCH PRODUCT

Our conceptualization of the research product emerged through the ongoing design, deployment, and analysis of design artifacts. Importantly the qualities of a research product we articulate here are not *a priori*. This involved joint bi-weekly meetings over the course of more than a

year to discuss and retrospectively analyze our design research projects. Thus, this paper provides a space to consider our common research from a higher-level perspective to articulate an initial set of interrelated qualities of a research product. For readability we briefly describe each quality upfront to preface our subsequent reporting and analysis. The qualities include:

Inquiry driven: a research product aims to drive a research inquiry through the making and experience of a design artifact. Research products are designed to ask particular research questions about potential alternative futures. In this way, they embody theoretical stances on a design issue or set of issues.

Finish: a research product is designed such that the nature of the engagement that people have with it is predicated on *what it is* as opposed to what it *might become*. It emphasizes the actuality of the design artifact. This quality of finish is bound to the artifact's resolution and clarity in terms of its design and subsequent perception in use.

Fit: the aim of a research product is to be lived-with and experienced in an everyday fashion over time. Under these conditions, the nuanced dimensions of human experience can emerge. In our cases, we leveraged fit to investigate research questions related to human-technology relations, everyday practices, and temporality. Fit requires the artifact to balance the delicate threshold between being neither too familiar nor too strange.

Independent: a research product operates effectively when it is freely deployable in the field for an extended duration. This means that from technical, material, and design perspectives an artifact can be lived with for a long duration in everyday conditions without the intervention of a researcher.

DESIGN RESEARCH CASES

In this section we draw on the qualities of a research product outlined above to analyze five design research cases. These include the hook [53], table-non-table [49], technology heirlooms [34], photobox [37], and discovery driven prototypes [30]. We selected these cases based on our intimate knowledge of their making and deployments. In each case, the artifacts were not considered as prototypes; there was no intention of making a next version and participants were expected to encounter the artifacts as is and not as what they might become. While all of our examples are in some form tangible systems, research products clearly could operate as solely digital applications.

The hook and the table-non-table

These two design cases are presented together as the hook informed the subsequent table-non-table project by evolving our thinking on what everyday design artifacts are.

The hook: a first attempt

The hook was inspired by previous findings from our empirical studies of *everyday design* [11,50,51], where we observed how people creatively adapt and repurpose common artifacts to fit their evolving needs in the home.

Our goal was to move beyond fieldwork findings to create a design artifact that could operate as a resource for everyday design over time. We wanted to investigate how this goal could be achieved through making a simple technology with a clear functionality yet open-ended purpose. The hook is a 16 cm tall cordless light with a hook built as part of its form. It is comprised of two tilt switches and three LEDs, powered by a 3V battery. The LEDs positioned at the center of the bulb shine through the 3 mm thick ABS 3D printed shell. A different color LED shines depending on the orientation of the hook (see figure 1). On three sides of the hook, flat surfaces have been designed to enable it to rest in these positions (triggering the LED to turn on and remain lit until tilted in a different orientation). The exterior shell was sanded until smooth to remove any lines, crevasses, or ridges left by the 3D printer. Five members of the Everyday Design Studio lived with the hook and deployed it in 5 households for periods ranging from several days to several months. Each participant maintained a micro-blog, kept a photo diary, and took part in a post hoc semi-structured interview.

The success of the hook was mixed. We initially witnessed members engaging in explorations with it that were functional, aesthetic, and playful. However, over time it became a forlorn object within the households. Theoretically, the hook seemed to have respected everyday designers' competences by being simple and requiring only basic manipulations to engage with its computational behavior. Below we analyze the hook's research product qualities as a lens to unpack factors shaping these outcomes.

The hook was *inquiry driven*; its design explicitly aimed to explore questions including: What forms, materials, and design strategies enable a design artifact to be taken up into everyday practice? How can a design artifact viably balance reflection and interaction to catalyze this relationship in unique, self-determined ways? What are the roles of crafting and materials in terms of enabling lived-with qualities to emerge with computational artifacts?

The degree to which the hook had a sufficient quality of *finish* was less clear. We sanded down the ABS material to remove its connection to 3D printing as much as possible; it

was otherwise left unfinished. Reflections from participants often emphasized suggestions for fine-tuning the shape of the hook, showing it was perceived more as a prototype. 3D printed plastic is currently a dominant prototyping material and therefore may have limited the extent to which the hook was able to achieve a high quality of finish.

We believe the 3D printed material and to a lesser degree the form negatively impacted the hook's *fit* quality. The sanded and translucent ABS plastic does not resemble any other materials (or fabrication method) in the home and may have made the object too strange. The shape also does not reference other everyday things in the home, potentially making it more difficult for people to resourcefully situate it within their everyday material and social environments.

The *independent* quality of the hook was successful. The overall simplicity of the form and implementation meant that we could reliably leave it behind for months without any issues including battery power.

The table-non-table: lessons learned

While the hook was not as successful as we had hoped, the process of crafting it and observing it deployed in different households enabled us to reflect on our own practices and articulate more productive ways to orient future research. It clarified why a sensitivity to 'real' materials was crucial for our research inquiry in domestic environments. These insights shaped our next design effort: the table-non-table [49]. The table-non-table is a slowly moving stack of paper supported by a motorized aluminum chassis (see figure 1). The paper is common stock; each sheet measures 44.5 cm by 57 cm with a square die cut in the middle to allow it to stack around a solid aluminum square post that holds the sheets in place. There are close to 1000 stacked sheets of paper per table-non-table, which rest on the chassis about one half-inch from the floor. The movement of the table is in short durations (5-12 seconds) that occur once during a longer period of time (a random selection between 20 to 110 minutes). The table-non-table lived with two households for three and five months, and two other households for six and three weeks respectively. Additionally, we lived with it ourselves for many weeks prior to deployment to fine-tune the frequency and duration of its movement.



Figure 1. The hook; hook tilted in three orientations with blue, green and yellow lights. The table-non-table.

The table-non-table was computational yet many of the ways participants related to it mirrored manipulations more commonly associated with non-digital things. Its flat surface opened it up to being drawn on, at times in unknowing ways as other objects were stacked on top and it slowly became just another thing in the background of domestic life. It readily formed ensembles with other artifacts in the homes and engagements with participants were reflective, interactive, and in many instances incidental. We expand on these experiences in [49].

The table-non-table achieved a level of acceptance within everyday life that well exceeded the reception of the hook. It was an *inquiry driven* in that it explored the same questions as the hook.

The quality of *finish* of the table-non-table gained much from the experience of the hook. The choice of materials, paper and aluminum, and the level of finish between the water jet cut aluminum and the machine die-cut paper made clear the commitment of the artifact as a finished object. Even the frequency and length of the movement of the artifact was iterated upon to the point that we felt it had clarity of purpose between being frequent enough to be noticed yet not too frequent as to call attention to itself. Responses of our participants made it clear that they encountered it *as is* rather than what it might become.

The *fit* quality of the table-non-table was similar to the quality of *finish* in that the materials and form helped it easily establish relations among the things and people surrounding it. It mapped to everyday competences well in the way that the paper was simply stacked on the aluminum chassis. As a material, paper lent itself to all the typical activities of drawing, writing, cutting, tearing, etc. The form of the table-non-table meant it could be featured as something novel or retreat into the background as small surface for putting things on or even sitting on.

The *independent* quality of the table-non-table was quite successful for its simplicity. It was simply plugged in and could be moved anywhere in the home in proximity to an electric plug. It was subject to some wear since it was at times moved, disassembled, sat upon and so on.

Technology Heirlooms and Photobox

We present another pairing of cases that illustrates an evolution in thinking through attempts to make research products. The Technology Heirlooms informed the Photobox project in ways that advanced our understanding of how to approach investigating radically new ways for manifesting digital content in everyday life over time.

The Technology Heirlooms: Actuality Challenged

The Technology Heirlooms project was in part inspired by prior works examining the character of material heirlooms and their capacity to find a long-term place in people's everyday lives [10,23,28,29,35,36]. People today accumulate vast archives of digital content that offer rich potential resources for reflecting on personal and familial histories. However, accelerating rates of digital content generation and the ephemeral lifespans of most domestic

technologies seemed to be at odds with supporting meaningful enduring experiences with one's sentimental digital materials. We drew on *slow technology* [20] as theoretical framing for our research inquiry because it offered a lens for conceptualizing how long-term relationships might unfold among people and computational things. Our goal was to investigate how personal digital content could be embodied in design artifacts in ways that might support a wider range of experiences from rich interactions to simply living with one's digital archive in meaningful ways over time.

We designed three Technology Heirloom artifacts (see figure 2); all were encased in European Oak veneer with material affordances enabling them to be opened up or put away. The *Digital Slide Viewer* packages a family's digital photographs in the form of an analog slide viewer. Acrylic slides correspond to specific photo albums. A wooden case packages the viewer and 20 slides. When a slide is inserted, the photos in the corresponding album become viewable on a 100x100 pixel display embedded in the viewer; photos can be serially explored by tilting the viewer left or right.

Timecard enables families to construct digital content from multiple family members along a chronological timeline. Family members can add digital content (e.g., text, images) to Timecard via an online service used to transfer content to the device and attribute specific dates and annotations. Timecard's case includes hinged doors with a touch screen displaying the timeline interface is embedded behind them.

Backup Box is an embodied digital store of a lifetime of Tweets posted to Twitter.com. Through a WIFI connection, it copies messages from the Internet to a self-contained hard drive. The form consists of a box with a removable lid; when opened, a user interface for navigating the archive is displayed on a touch screen. We brought the Technology Heirlooms to 8 UK households [34] and asked family members to use the devices; we conducted interviews to probe into their experiences and perceptions.

The Technology Heirlooms were *inquiry driven*. While more specific questions were tied to each artifact, the overarching questions we aimed to investigate included: How would these artifacts support or complicate family members' practices of remembering the past? To what extent would they become integrated into family members' everyday lives? Would the devices mediate experiences with sentimental digital content in slower, yet rich ways as experiences with them unfolded over time?

The quality of *finish* of the Technology Heirlooms were achieved largely through the choice of materials, form, and crafting quality. Each design artifact strongly referenced common heirloom objects in the home or in the participants' pasts. However, their overall quality of finish was partly undermined by the role of data within the Technology Heirlooms. In each case, the artifacts required personal data of the participants to function in actuality. Yet, it proved too laborious for participants to assemble their own collections for each artifact. Ultimately, we

decided to populate the devices with stock digital content from a research team member's own archive that captured years of personal and family experiences. As a consequence, close attention by the research team was required to guide the discussion among household members to speculate more generally on a potential future in which they had lived with and perhaps even been bequeathed the Technology Heirlooms.

The *fit* qualities with the Technology Heirlooms are similar to their quality of *finish*. The design decisions of form, materials, and functionality were purposely designed to fit within the homes and especially relate to past and present heirlooms. Yet, the issues of data and the need to imagine a lived-with experience inhibited the fullness of fit needed for a research product in this context.

The *independent* quality of the Technology Heirlooms was similarly compromised. While unintentional, the Technology Heirlooms acted more as prototypes [3]; they were able to provoke and elicit imagined relationships with the intervention with guidance of the researchers. Ultimately, we were able to speculatively and conceptually explore our research questions, but not empirically through actual engagements.

Photobox: lessons learned

The Technology Heirlooms set an ambitious aim for investigating the long-term place of digital content in people's everyday lives and key lessons learned catalyzed decisions in our next design research effort. We needed to develop a design artifact that would leverage people's own existing and easily accessible digital archives content. We also needed to move away from using LCD screens; they tended to draw participants into fixating on particular interface elements and, perhaps more importantly, evoked symbolic associations with contemporary consumer technology (i.e. touchscreens) that we aimed to radically depart from. These decisions were brought into the crafting of artifact and inquiry in our next case, the Photobox.

The Photobox is a WIFI connected domestic technology embodied in the form of a well-worn antique chest that prints four or five randomly selected photos from the owner's Flickr collection at random intervals each month. We decided to use a chest to keep with a design that had to be opened up and closed when interacted with, and a printer

to negate the need to use a display or interface. The printer was secured to a small opening in the panel to allow a photo to drop onto the central platform of the chest. We chose to randomly surface Flickr photos to slowly grow anticipation around the Photobox and also to subvert the need for an interface. The Photobox did not require nor demand any attention from its owner to continue enacting its behavior. Three nearly identical Photoboxes were crafted and implemented, and eventually deployed for fourteen months in three households respectively [37].

The Photobox triggered a trajectory of reactions from initial frustration to attachment and acceptance. It was *inquiry driven* in that it investigated the same overarching questions as the Technology Heirlooms, but with added precision of generating actual long-term, lived-with experiences.

It achieved a quality of *finish* that greatly surpassed the Technology Heirlooms. Photobox was highly resolved in terms of materials and form, and one member of the design team lived it with for four months prior to deployment to fine-tune its behavior. We avoided it becoming ignored by printing too seldom or becoming commonplace (or overwhelming) from printing too often. Not only was Photobox treated as a distinct, actual thing, it also prompted household members to consider their relation to other local domestic technologies.

Photobox similarly exhibited a high degree of *fit*. Over time it (and the printed photos) became embedded within complex ensembles of domestic spaces, things, people, rituals, and routines. The form of the chest combined with the relatively slow behavior enabled it to fade in and out of perceptual view, and become a fixture in domestic life.

The *independent* quality of Photobox was successful. It was plugged in and could be moved anywhere in proximity to an electric outlet. We could remotely restart Photobox via its WIFI connection in the case of unexpected technical problems. Bi-monthly researchers had to visit households to reload the printer; this provided a productive period to gauge participants' experiences with Photobox over fourteen months without having to formally intervene.

Discovery-driven Prototypes

Discovery-Driven Prototyping (DDP) [30] is a design research approach that emphasizes generating design



Figure 2. The Technology Heirlooms (from left to right): Digital Slide Viewer, Timecard, and Backup Box. The Photobox.

artifacts without prescribing how people should use them in order to push people to discover new opportunities of how technology can be situated within their own lives in uniquely creative and self-determined ways. DDP is inspired by prior works on the benefits of leveraging uncertainty in design [13, 29] to enable users themselves to discover and manifest their own ideas with the discovery driven prototypes (DDPs) in their everyday lives. While the kinds of questions DDPs aim to investigate require them to be research products with no self-reference to a future thing, we originally used the term “prototypes” to emphasize the generative, exploratory behavior we aimed to manifest in people engaging with them.

We designed three DDPs artifacts (see Figure 3) that aimed to balance clarity in function with unpredictability in intended purpose to catalyze open-ended, creative, explorations among household members. The *Aeng-aeng-yee* (a Korean onomatopoeia for ‘loud noise’) is a music-playing light-sensing timer comprised of a speaker, two photo sensors, and a potentiometer. Using the dial, a time limit can be set; after it expires and it subsequently senses light, it will play a loud popular Korean folk song. The *Deol-deol-yee* (a Korean word expressing ‘vibration’) is a pair of wirelessly connected objects that can send signals by toggling the white button on top of them. When one receives a signal from the other, it vibrates and blinks an LED. The Tong (the Korean word for ‘jar’) is a set of four jar-shaped sound recorders. At the bottom of each jar, there is a button that when pressed will record a sound for a maximum of 20 seconds; only one recording can be saved. If the cap is opened, the recorded sound plays on loop until it closes again. Similar to the Photobox and the Hook, we lived with the DDPs in our studio and homes as they were developed to make sure they struck a seemingly appropriate boundary between clarity or unpredictability. We deployed all three DDPs simultaneously with three different families for one week each respectively [30]. We collected their diary recordings of new usage ideas they created while using our DDPs and we interviewed the families to understand their effects.

DDPs are *inquiry driven* artifacts as their design aimed to investigate questions including: What kinds of design strategies of forms, interactions and material qualities in DDPs might enable people to discover new use for technology in their everyday lives? In what ways do people generate new use space of the technology manifested by

DDPs in their actual living situations?

All the DDPs were made to have a quality of *finish* in their look and feel. Although we made them with 3D printing, we carefully polished and colored them. We intentionally used a glossy paint so that the material looked of a higher quality than plastic. The clarity and simplicity of the forms were also an important part of achieving a high quality of *finish*.

The *fit* quality was extremely critical for DDPs as they are designed to be malleable and flexible to fit to people’s everyday practices. Due to their ambiguity in purpose, they enabled people to think freely and flexibly about what they can be used for. In a sense, the DDPs were incomplete because they did not define any kind of use or purpose by virtue of their design. They became complete when people creatively determined their appropriate use at a certain moment to fulfill an emergent desire. One person’s use of a DDP can transform into a very different one with another person depending on where its fit manifested.

DDPs were also all made to be *independent*. Specifically for this, the strategy of how to power them was critical as they needed to be portable and stand-alone to be put to use anywhere in home. For Aeng-aeng-yee, we installed an on-off button so it could persist without needing to charge the battery over the deployment period. For Deol-deol-yee, we used a 9V rechargeable battery and crafted the design to be easy to disassemble for charging when needed. The 3V coin cell battery in Tong easily lasted throughout each study.

ENCOUNTERS WITH RESEARCH PRODUCTS

We have drawn on an interrelated set of research product qualities to analyze decisions in our design cases that shaped their various levels of success. On a high level, our design cases are united by similar shared sets of concerns aimed at exploring research questions bound to how human-technology relations emerge and shift over time in everyday life. Next, we draw on a sample of encounters study participants had with our design artifacts to illustrate the type of phenomena and relationships that research products can help reveal and make visible. We present only a small portion of previous findings to focus particularly on the research product qualities (additional study-specific findings can be found in [30,34,37,49,53]). Specifically, we draw on themes in our field studies related to: (i) long-term relations, (ii) everyday practices, and (iii) open-ended creativity.



Figure 3. Three DDPs: music-playing light-sensing timer, wireless communicable objects, and jar-shaped sound recorders.

Mediating the potential for long-term relations

While they had different theoretical motivations, the table-non-table and Photobox were closely united in their aims to investigate a longer-term place for technology in the home. They both were manifested in forms that are not typically associated with contemporary consumer technology—a table and a chest—and they did not demand nor require the attention of their owners to enact their computational behavior. The unfamiliar forms and lack of control that both design artifacts exhibited initially produced tensions. Yet, as the table-non-table and Photobox were accepted within the temporal rhythms of everyday life, participants commonly made direct comparisons between them and other domestic technological artifacts. For example, one participant speculates on the potential longevity of Photobox in comparison to devices in her living room: “*the GameCube itself doesn’t matter that much. There’s no value in it aside from playing games. ... Sometimes, sitting in here, I’ll be thinking [Photobox] is unusual around these systems. ... Like, it being there can be inviting, I can look in it. ... or sit on the couch, think about what already [printed] or what could [be] printed. ... The point is that it’s not used in the same way like the [GameCube]. It can’t be. ... it feels like it can settle in down there. The other stuff around it, feels like they’ll be gone sooner than later.*” These discussions at times led participants to consider the nature of their relation to Photobox: “*It’s like it’s operating on a whole different dimension of time. ... It’s in for the long haul. It’s not a momentary blip in my life before it’s off to... well wherever these [digital] things go.*”

Similar instances also surfaced with the table-non-table as participants reflected on its enduring potential. A primary example of this emerged when a participant described how the table-non-table performed many different roles in her family over time, which ranged from her children using it as a platform to sit or stand on, to it spontaneously catalyzing family activities to make drawings together during downtime after noticing its movement. Here, she reflects on how these kinds of activities led to a distinctly different kind of relation compared to other devices: “*I’d say it’s very different from other technology. ... It’s build to last. It will be around, it feels like it. Once we understood its function and what it can do for us, it feels like it’ll never become obsolete.*” This statement is exemplary at capturing how members of other households reflected on the table-

non-table’s potential for endurance compared to other devices perceived to be highly vulnerable to obsolescence.

Collectively, these instances help demonstrate how the table-non-table and Photobox functioned as research products. They operated largely independent of our need to intervene and had a high quality of finish that enabled them to achieve a level of fit within households that resulted in ongoing engagements. As experiences with these design artifacts accumulated, they prompted participants to consider their own relations to other technologies and their potential presence (or absence) in domestic life in the future. In this way, the Photobox and table-non-table emerged as successful platforms for exploring deeper research questions about the viability of our design strategies to mediate and nurture longer-term relations among people and everyday computational artifacts.

Varying adoptions into everyday practice

The Technology Heirlooms represented a substantial effort to craft design artifacts that could potentially support a wide range of everyday practices—from reflecting on the past, to constructing new family histories, to their maintenance and safekeeping over time, to being packed away with other cherished objects to be revisited in the future. Our design choices in form and materials that enabled the Technology Heirlooms to be easily opened up or put away resonated strongly with participants. Across households, members initiated explorations of where they would want to put the different devices, and described the unique, typically idiosyncratic, meanings and social practices that motivated these decisions. These instances often prompted *in situ* speculations on the potential value of having an aesthetic embodiment of their cherished digital content that could easily be manipulated and resituated to various social audiences, domestic places, and activities. However, our use of stock data complicated the overall finish and independent qualities of the Technology Heirlooms. We were not able to generate the actual encounters needed to carry the research questions inquiring into how radically different forms of technology might become embedded in everyday practices over time.

In contrast, the table-non-table became situated to various emergent actions and practices. For example, in several cases when participants noticed the table-non-table’s movement, it was relocated to a different place in the home



Figure 4. Encounters with research products (from left to right): The photobox in relation to other domestic technologies. The unpacking of the table-non-table. The aesthetic explorations of the hook. The Deol-deol-yeo creatively paired with the seatbelt.

in attempts to reveal different understandings of the artifact in this new configuration of their everyday setting. Such emergent reconfigurations even extended to non-human household members. One participant reported that her cat appeared to treat a heater appliance next to the table-non-table in a similar fashion as if similarly constituted objects were now actuated with movement. In another household, the table-non-table's movement triggered their cat to attack the artifact, displacing several sheets of paper around the living room. This instance provoked household members to incorporate the paper sheets into their annual practice of making paper snowflake Christmas decorations. As each study progressed, it was common for participants to unpack the sheets of paper and actively investigate the aluminum frame, internal components, and its movement. In one case, participants reduced the artifact to the aluminum chassis and studied its movement with time-lapse photography (see figure 4). In this way, people, pets and their material environments were reconfigured in an ongoing manner as the table-non-table emerged in household's existing practices and catalyzed new actions over time.

These case examples help illustrate key factors that can shape the extent to which a research product becomes integrated into people's everyday practices and catalyzes new practices. Despite exhibiting a high quality of finish in terms of form and materials, the ways in which the Technology Heirlooms manifested digital content complicated their overall viability of finding a place in people's everyday lives. Next, we turn to encounters with the hook and DDPs to further unpack how key design choices shaped the extent they were engaged with over time and were able to carry and inquire into their respective research questions.

Mediating open-ended creative actions

The DDP and the hook design cases aimed to investigate how technology could mediate experiences of open-ended everyday creativity through crafting and deploying design artifacts that could be manipulated in simple ways that would produce minimal output (e.g., tilting the hook to trigger an LED to blink, or pressing a button on the Deol-deol-yeo to trigger a vibration on the other it is paired with). Yet, they produced starkly different results.

In most cases, participants explored the hook's shape and function in the first few days they had, but these actions quickly faded. Experimentations (see figure 4) often revolved around aesthetic connection to the hook, either to its colors or shape (e.g., taking long exposure photos of the colors or finding other domestic objects that complemented its shape), or they emphasized functional aspects of the hook (e.g., using it as a quasi-functioning nightstand light). These explorations show that the hook was drawn on either as a purely aesthetic object, which its unfinished materials fell short of supporting. Or, as a functional object, which it could not entirely live up to. These instances provided interesting starting points for new practices around the hook, but most were one offs and not repeated later.

In contrast, the DPPs catalyzed open-ended, ongoing creative actions by participants that were widely unexpected by the research team. These ranged extensively from the Aeng-aeng-yeo being heavy enough for a 4-year old child to hold for a while as the noisy song played; her aunt intended it to be a punishment for her bad behavior. The Deol-deol-yeo's vibration was leveraged as a resource for self-massage techniques on a participant's body. In another instance on of the two Deol-deol-yeo was attached to a safety belt of a husband while he is driving so that his wife who is sitting next to him can wake him up if he feels sleepy while long driving (see figure 4). Many other instances of creative actions were mediated by the DPPs that included, a tool for measuring the wellbeing of houseplants, a remote alarm clock, a medium for capturing secret messages and even a pedagogical resource for remembering English words.

Together, these instances illustrate that despite adopting relatively similar design approaches in crafting technically simple design artifacts, the DPPs were able to successfully operate as research products by achieving high qualities of finish and fit, and remaining independent. Yet, the hook was unable to reaching a similar status among participants; its aesthetics and functionality prevented it from attaining a high enough degree of finish or fitting within people's creative uses and re-uses of it to generate the kind of perspective needed to explore its potential role as a resource for everyday design over time.

DISCUSSION: CRAFTING RESEARCH PRODUCTS

Throughout this paper we have emphasized that the research product is a design concept—it has emerged through ongoing practices of research through design. Similarly, prototypes are a design concept that developed from design practices and research. Central to both concepts is the crafting of artifacts. A core goal of this paper is to motivate and develop the concept of research products and to articulate how they help overcome limitations of prototypes to create perspectives that are necessary to inquire into the complex and situated matters of human (and non-human) relations to technology, everyday practices, and creative actions over time.

Next, we further discuss and reflect on unique aspects of crafting research products, illustrating that this concept can be seen as an extension of, yet distinct from, prototypes. Importantly, we do not present these aspects as fully realized principles, but rather as intermediate knowing [24] representative of our current and provisional knowledge that has developed through making research products. These aspects of crafting research products do point to several challenges and opportunities for mobilizing research products in future design-oriented HCI research.

An explicit aim of research products is to design for actuality—for participants to experience design artifacts *as is* rather than *what they might become*. The critical distinction is that the nature of the design decisions related to material, form, computation, and interaction are all governed by the artifact's ability to *carry* the research

question. For example, the choice of materials in the Photobox, such as the aged oak box with crafted brass hinges and paper photos collectively supported its acceptance in households. The nature of the materials helped establish a set of relationships to the artifact that were key to the research questions, such as timelessness, value, anticipation, and uniqueness. The ways in which materials, form, computation, and interaction coalesce in a research product directly shape the precision to which a research question (or set of questions) can be inquired into.

A key condition of research products is that the interrelated qualities of *inquiry-driven*, *fit*, *finish*, and *independent* need to be present at once in the design artifact. Our cases of the hook and Technology Heirlooms demonstrated the shortcomings of not having all of the qualities realized. Research product qualities are also not scalar. Qualities are not a measure of magnitude or to what degree along the continuum of finish, for example, a research product achieves. As we learned in the case of the hook, a research product is either experienced as an artifact with a high degree of finish or it is not. There is always room for refinement; however, it became clear that each quality must be achieved and be present simultaneously. This is a fundamental difference with prototypes where, a design researcher can choose to emphasize (or ‘filter out’ [31]) one aspect of the prototype at the expense of others, such as when a technical prototype is created to establish the technical possibilities with no regard for user experience [25]. In this way, prototype qualities are scalar. For example, a common strategy in prototyping is to iteratively advance the degree of finish and fidelity through a series of artifacts. This condition poses real challenges for designers of research products. Typically in design, questions of the use situation are asked through the prototyping process and the ‘answer’ is presented in a finished product. In designing a research product, there is the typical iteration and prototyping in trying to best formulate and carry research questions through an artifact. As a result, the finished research product depicts the design research team’s ‘best’ articulation of how to ask and pursue the research question at that given time.

Lastly, another unique aspect of crafting a research product is situating the artifact in a real—in our cases everyday—environment. Deployments are critical to the research investigations. It was through deployments that insights were revealed to our respective design research teams about the extent to which particular qualities of a research product were successfully achieved. For example, we desired to deploy the Technology Heirlooms, but the reality of integrating personal content into the research products was impractical and, when brought to households, they operated more as prototypes [3] than research products.

However, these kinds of instances can play critical roles in helping the design team develop judgment about how to frame a subsequent conceptual leap within complex, unstructured, and largely unknown design spaces. It was evident that what was learned in the field in terms of the

‘failures’ of the Technology Heirlooms and the hook informed design moves in subsequently successful projects. Additionally, in the cases of the Photobox, table-non-table, and DPPs, members of the design team lived with the research products themselves to fine tune aspects of their form, materials, computational behavior, and interactive characteristics prior to their deployments.

The inclusion of deployments in various forms as a part of making a research product does raise interesting methodological challenges. For example, it is unclear what best practices are for balancing the complexity of managing one’s own and others’ lived-with experiences to understand how particular design decisions shape the emergence (or absence) of particular research product qualities. Relatedly, crafting research products emphasizes the need for design researchers to develop and refine a sensibility for reflectively considering design decisions and how they shape the ways research questions are articulated, and carried through the artifact. This process may unfold in various ways for the design team through unpredictable configurations of crafting, personally living-with, and observing the research product among other humans (and non-humans), things, and environments over time.

CONCLUSION AND FUTURE DIRECTIONS

This paper has motivated and articulated the concept of research products as an extension to prototypes in HCI research. Our goal was to offer a generative approach for designers and researchers to investigate complex questions concerning human-technology relations, which we situated around design cases exploring long-term interaction, everyday practices, and open-ended creativity. Our analysis of five design cases led us to four qualities of the research product: *inquiry driven*, *fit*, *finish*, and *independent*. We detailed a sample of participants’ encounters with research products to further unpack how design decisions shape research product qualities and the viability of the artifact to investigate the research questions bound to it. Importantly, our aim is not to be prescriptive nor conclusive. We intended to provide an interrelated set of research product qualities to frame future generative work and open this concept up for further development. As the HCI community continues to explore the nature of interactive technology in everyday life, we hope the research product can be seen as a complementary framing for supporting these inquiries and, more broadly, the need to better recognize ways of practicing reflective forms of knowledge production.

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