# Electric Materialities and Interactive Technology

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## ABSTRACT
This paper offers new theoretical and design insights into interactive technology. By initially considering electric technology broadly, our work informs how HCI approaches a range of specific interactive or digital things and materials. Theoretically, we contribute a rigorous analysis of electric technology using the experiential lens of phenomenology. A major result is to characterize electric technology by three forms of materiality: the electric object, its electric materiality, and electric power. In terms of design, we present and analyze novel interactive form prototypes. Our theoretical contributions offer new insight into design artifacts, just as our novel design artifacts help reveal new theoretical insight.

### Author Keywords
Design theory; interaction design; electricity

### ACM Classification Keywords
H.5.m

## INTRODUCTION
HCI is concerned with a wide array of technologies, ranging from common electrical appliances to the latest electronic hardware and software. These technologies have been described as digital materials [31], interactive materials "without qualities" [20], computational composites [32] and generally as design materials [10,28]. Indicative of these works is a recent and substantial interest in HCI with understanding technology through a focus on "materiality". Concerns with interactive materials [e.g.,1,11,12,18,19,27,28] have been referred to as a "material move" [7] or "material turn" [29] in interaction design. A related cluster of work has investigated the material qualities of old and new technologies to inform HCI research, often focusing on differences between high-tech and traditional things [e.g.,8,30]. Instead of focusing on design materials, these works emphasize the materiality of technological things as they are used and incorporated into everyday contexts and practices. Outside of HCI, fields as diverse as new media studies, critical theory, philosophy and anthropology have looked at technologies from digital media [e.g.,21] to artifacts in general [e.g.,13,16]. However we note a lack of such theory that focuses on the materiality of interactive technologies and in a way that speaks to particular concerns of HCI.

However one might end up characterizing the technologies that HCI is primarily concerned with, there is a distinct element that precedes and underlies all such technologies: electricity. In order to advance theoretical understandings of the materiality of technological things, and the possibilities and limits of technology as a material in design, we begin with the basic notion of *electric technology*. One important theoretical result of our work is to characterize electric technology in terms of three forms of materiality: an *electric object*, its *electric materiality*, and *electric power*. To arrive at such new theoretical framings we draw on phenomenology, a form of inquiry that investigates subjective experience. The other main component of our approach involves "research through design" [e.g.,2,9,34]. In addition to analyzing *ordinary* electric technologies, we present and discuss new design prototypes that focus on an *uncommon* technology: bodily-powered electric technology.

While environmental sustainability has occupied a central position in prior energy and materiality research in HCI [e.g., 1,27]—including in our own work—here we largely sideline sustainability discussions. This move allows us to rigorously investigate electric technology independent of any one particular issue. However, concerns with sustainability and emerging energy systems [25] form an implicit backdrop for this work and an explicit point of engagement for future applications and extensions.

The contribution of this paper is threefold. First we develop new theoretical understandings of electric technology. Second, we concretely demonstrate how these understandings can inform design-oriented research. Third, we demonstrate how designing and building technology can "talk back" and inform theory. Following a discussion of methodology, the paper has 4 sections that correspond to (1) theoretical description, (2) design exploration, (3) design spaces/strategies and (4) general discussion.

## METHODOLOGY
Our approach involves doing both design and phenomenology. There three main reasons we have combined phenomenology and design. First, phenomenology helps us articulate and make sense of our


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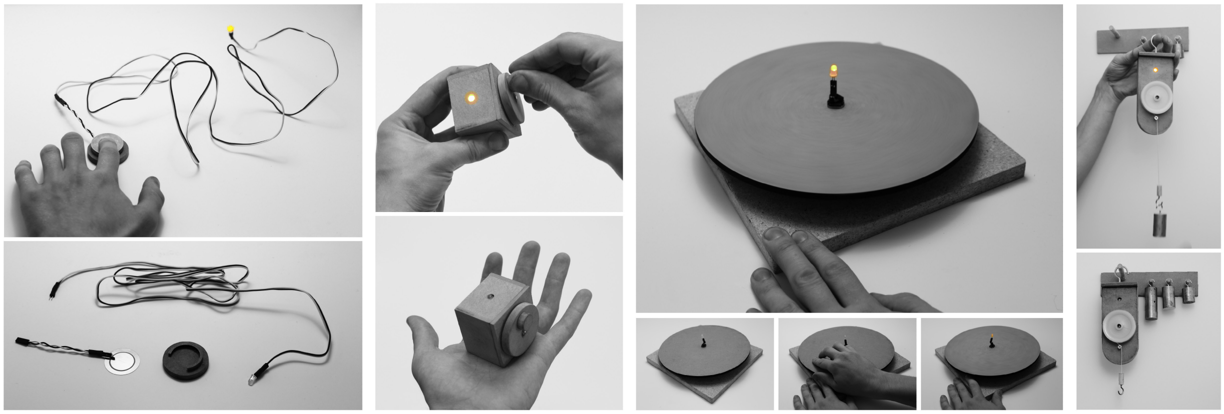

**Figure 1. Form studies in bodily-generated LED illumination: (Left to right) Tap LED, Crank LED, Spin LED and Drop LED. The interactions of tapping a surface, cranking a wheel, spinning a flywheel and dropping a weight generate electric power that illuminates an LED. (Note: Each prototype depicted is functional; a selective black and white filter has been applied to the images for emphasis.)**

design work. This includes particular designs as well as more general design spaces. While theory can be useful for inspiring and generating design—as we have found—it is its value in articulating and making sense of design artifacts that we propose as potentially more applicable and valuable for the HCI community. As others have argued [e.g., 2,9,34], we believe design research can stand on its own without relying on theory from other fields. Nonetheless, we find that such theory can play a vital role by articulating new insight about design outcomes and processes [c.f. 1,4,6,10,11,12,20,26,27,32]. One idea this suggests to us is a type of annotated portfolio [2,9] with *phenomenological annotations* or other theoretically-informed annotations.

Second, we find a general lack of theory that helps us make sense of both our own design work and the design of electric technology in general. Specifically we identify a lack of detailed phenomenological accounts of electric technology with a focus on materiality [c.f. 10,16,26]. Consequently we found a need to generate theory by building on prior work outside of HCI. More generally we believe HCI theory should seek to identify and address such theoretical gaps in research originating outside of our field.

Finally, our design work helps us advance our phenomenological inquiry. Designing and building novel electric things has highlighted gaps in our analysis and surfaced new theoretical insight. More generally, we believe that the exemplars created by design-oriented research can be used in *building theory*—regardless of whether the designers intended to inform theory or whether theory informed their design.

### Approaching electric technology phenomenologically

Phenomenology has been described as a "style of thinking which concentrates an intense examination on experience in its multifaceted, complex and essential forms" [15, p. 17]. Phenomenology has appeared across several areas of HCI research [e.g., 3,5,10,26,35], and coincides with the so-called "third wave" HCI shift toward "experience". Our inquiry will begin with a *phenomenological description* of experiential features of ordinary electric technology (ordinary in the sense of familiar and common to everyday practices). The phenomenological style adopted here is based closely on the work of Don Ihde [15,16,17] and in turn the foundational works of Edmund Husserl [14] and Martin Heidegger [13]. Our style of analysis is aligned with what Ihde describes as a Husserlian-style phenomenology of *presence* [15]. (Although our work also reflects a concern with *praxis* and the "background" of experience, following Heidegger as well as Ihde, again, in this regard.) A fundamental aspect of this approach is to "attend to the phenomena of experience as they appear" [17, p. 34]. This excludes attending to *explanations* of phenomena, including both scientific and everyday explanations. A related rule is to *describe rather than explain* the phenomena.

A phenomenology of electric technology is faced from the outset with a dilemma regarding electricity as both a scientific and everyday explanation. Initially we "put out of play" or *bracket*, in Husserlian terms, electricity as a concept. As we will see, things commonly identified as "electric" exhibit forms of *activeness*. Further, we come to encounter a *source* that enables this activeness, which we ordinarily refer to as "power" or "electricity". These phenomena, which appear within experience, are taken as more primary than explanations of electricity.

Another key feature of the approach is a *variational method* for investigating phenomena, first introduced by Husserl. This involves obtaining many *variations*, or examples, of phenomena to arrive at *invariant,* or *essential,* features of experience. A mathematician by training, Husserl favored the use of fantasy or *imaginative variations*. Ihde's approach favors the use of *perceptual variations*. The use of perceptual variations leads to an empirical phenomenology in the sense that it is grounded in actual observed and hence *fulfillable experience* [15]. Stylistically we use the written form "One can _____" to indicate an experience that has actually occurred for the authors. For example, "One can make these words appear on the computer screen."

### Design Form Explorations / Designed Variations

In the later sections of the paper we present prototypes that focus on bodily-powered electric generation (e.g., Figure 1). These have been refined and carefully selected from a much larger set of concepts and forms we have constructed with varying degrees of fidelity. The main goal of our prototypes is to explore specific interactive forms separated from specific applications, uses or practices [c.f. 3,11,19], rather than addressing more holistic concerns such as user needs and desires. Here we do not formally present the prototypes to others. While user studies are often considered the norm in HCI, a range of prior works have argued and demonstrated other methods of analyzing and reflecting on designs [e.g.,1,3,10,11,12,22, 27].

Here we present a phenomenologically-informed analysis of our prototypes. There are several reasons why have chosen this type of analysis. The primary purpose of our prototypes is to explore, identify and illustrate possibilities that we are able to confirm based on our own experiences. We do not make strong empirical claims about aspects such as routine use, appropriation, usefulness or desirability. We will be mainly concerned with understanding basic perceptual and interactive elements of bodily-powered electric technology. In this way, our work is similar to prior explorations of interactive design materials that do not rely on traditional user studies [e.g.,1,3,10,11].

While our analysis is based on our actual experience, it is not a strict phenomenology. Further, our use of *designed variations* straddle the space between perceptual variations and imaginative variations. Stylistically, we indicate analysis that is partly imaginative by putting it in the form "One may ___". For example, one may be able to read this paper on a bodily-powered display..." (although neither of the authors has actually done so).

## ORDINARY ELECTRIC TECHNOLOGY & EXPERIENCE

In this first part of our inquiry we analyze everyday experience of electric technologies yielding a set of thematic features. Our analysis in the present section will serve as a foundation for identifying, understanding and intentionally amplifying differences between ordinary and bodily-powered technologies.

### Electric Objects, Materialities and Sources of Power

Let us begin by taking account of the electric things that surround us. Within our ordinary experience (although only within the last century) electricity and electric technology have become familiar notions. As I walk into a room or down the street I can readily identify a diverse range of everyday material objects as "electric"—the laptop computer, the radio, the ceiling fan, the streetlight, and so on. What is it that distinguishes these from other objects?

The laptop, the radio, the ceiling fan and the streetlight are, to begin with, objects. These objects present themselves to as stable material objects and as useful, usable everyday things. However, these objects are each distinguished in that they become *activated* or *enlivened.* The radio sounds, the ceiling fan moves around, the streetlight illuminates and the laptop presents a multiplicity of moving and moveable media forms (music, video, text, voice, etc.). When these objects become activated, they present and make available material forms that were not previously present and available. When they are *deactivated* they hold the possibility of making these forms present and available.

The materialities they make available are in each case *active*: the ceiling fan moves, the light glows, the radio sounds and the laptop changes its imagery. However, this active materiality can exhibit different "distances" from the electric object. When looking at the spinning ceiling fan, one can see the fan's materiality that was once stationary as now active and moving. One can experience it as *activated materiality*. With a lamp, one can experience the illumination as *emanating from* the object. The illumination of the lamp can also be experienced as being *apart from* one's direct experience of the lamp—for example, when using its light to read.

The *activeness* of this materiality has a distinct temporality. The ceiling fan begins to spin when the wall switch is flipped and comes to a stop when it is switched off. The radio can similarly be controlled. The electronic music player can further be paused and later resumed. Even hallway safety lighting that is "always on" in the apartment building at some point ceases to be active—during a power outage, or when the bulb burns out. And even the momentary activeness of the television remote control has a distinct temporality both in its constant readiness to control the television and in its instantaneity of switching.

The activeness of this materiality is furthermore highly *controllable*. I can control the activeness of many everyday things around me. Those that are not directly within one's immediate control can still be experienced as capable of being controlled (e.g., the city streetlights have been programmed by "the city"). In each case, these forms can be *activated* and *deactivated*. And they can be reactivated again and again. One need only flip a switch to re-illuminate the light or make the fan spin at a regular, consistent speed.

There is a diverse range of *activated forms*: the mechanical movements of the ceiling fan, the sounds of the radio, the moving and illuminated imagery of the computer screen. (Although some are apparently absent: One does not activate smells or tastes in the same way.) There are also degrees and varieties of activeness. For example, a laptop may be actively downloading a file but without giving signs of activity. One can also identify or predict forms of activeness based on familiar forms. For example, one recognizes the activate-able display screen, even when it is inactive. One recognizes any object with a power cord or battery as activate-able.

It is this activeness that allows electric things to be used. It is only when active that one can utilize the illumination of the electric lamp, the moving and moveable graphic elements on the computer screen, and the cool breeze of the fan. However, this active materiality and usability can become *unavailable*. This occasionally yet familiarly occurs when one is unable to find a power outlet or a battery "dies". In this situation, the object can be encountered as unable to be activated. This inability to be activated can be attributed to a lack of power. It is in this way that electricity as electricity is typically encountered—as a source of power, as a thing that activates. *It is here, in its absence, that one most directly encounter* ***electricity as an entity****; and it is because of this entity one knows the radio, the laptop, the streetlight, and the ceiling fan as electric things.*

To summarize, we have identified several important ways in which electric technology can be experienced: the electric object, the electrified object, the electric materiality the object, the de-electrified object, the unable-to-be-electrified object, and the source that electrifies. More succinctly, it useful to characterize electric technology in terms of three forms of materiality:

(1) An **electric object** (a stable, physical object)
(2) The plural **electric materiality** of that object
(3) The sources that electrify (**electric power**)

In the remainder if this section we discuss additional thematic features of ordinary electric technology.

### Outlets and Batteries: Tethering and Replenishing

The availability of ordinary electric materiality depends on connecting to a source of electric power. There are two basic ways this occurs. The first is through the power cord, power plug and power outlet (a connection to a larger system: a power grid). We refer to this as *tethering*, since it requires that an electric object be tied to a particular source. Electric objects are ordinarily tethered through a flexible cord or an inflexible fixture (e.g., a street light, ceiling fan). The second way of connecting to a power source is with a *battery*. An electric object can be tethered to a stand-alone battery, but typically it has an integrated battery. Batteries allow electric technologies to be electrified while *untethered.* However, a battery must periodically be *replenished* by tethering it, or else replacing it.

Tethering and replenishing are general and familiar features of ordinary experience. They are easily taken-for-granted, yet they have some important implications. Tethering and replenishing imply that an ordinary electric technology must, at least on occasion, be physically connected to something other than itself—either a power outlet (and a larger power grid) or a new battery (and a larger manufacturing system). This has two notable effects.

First, tethering and replenishing shape the temporal and spatial contexts in which electric materiality can be activated. Put another way, they give definition to *electrifiable space*. If a device is tethered, electrifiable space is limited to within proximity of a power outlet. If a device can be battery-powered, then this substantially expands electrifiable space. However, a battery-powered device must still periodically be tethered or replaced. The expanded electrifiable space that batteries create can disappear; it has temporal limits. The possibility of a device "dying" consequently can shape one's interactions with it.

Second, tethering and replenishing are two important ways in which electric things are distinguished from non-electric things. Plugging in to an electric power outlet and replacing batteries are clearly unique to electric things. But more significantly this form of dependency separates electric technology and electric materiality from many other everyday things. Books, bicycles, knives, reading glasses, tables and host of other everyday things can be used without the same type of routine dependency (although we omit a lengthier analysis more firmly locating differences in this form of dependency). This suggests that electric things that do not require tethering or replacing batteries may exist in ways more similar to traditional and other non-electric things, such as books and manual tools [c.f. 8,30]. Indeed, tethering and replenishing are not invariant, or essential, aspects of electric technology and electric materiality. While ordinary electric technologies are tethered or battery powered, it is technologically possible to activate electric technology by other sources, such as the sun; the human body (e.g., motion, blood sugar); ambient sound, heat, vibration; and wireless power technologies.

### Electric Power as External to Self, Object and Context

While electricity tends to fall into the background of everyday experience, it nonetheless does routinely albeit infrequently present itself. Pierce and Paulos note several ways in which electricity can be become present [26]. While the notion of "external power" is commonly used in engineering, here we phenomenologically locate two ways in which the "externality" of electricity can be encountered: (1) as external to oneself and electric objects and (2) as external to the context of use and immediate environment.

Ordinary electric power can be experienced as external to oneself, to the electric object, and one's interaction with this object. One typically cannot generate a source of power to activate electric materiality. This is unlike the ways in which one can make a ball active by throwing it, or make a bicycle active by riding it, thus setting or keeping it in motion with one's body. One cannot transfer his or her bodily power to an electric object in order to electrify (activate) it. One also cannot *store-up* power as with the mechanical wristwatch that is wound. The appearance of ordinary power as external to oneself and to the object is not directly evident during use. But this externality does become evident when one is without an outlet or the battery "dies". In this situation one finds that he or she cannot power the device oneself.

Ordinary electric power can also be experienced as external to one's immediate environment and the context of use. A source of power typically cannot be located or generated within the room or building that one occupies. Often one further cannot see the technologies that generate power (an exception would be seeing a power plant in the distance). Again, this is not typically apparent when using an electrified object. However, when there is a power outage, then one can experience this externality. One can realize the source of power is not "here" but rather comes from "away".

However, these "externalities" are also not invariant features of electric technology. For example, the source of power for solar-powered calculators is typically not experienced as originating outside of the immediate environment. Rather, a source of power can be experienced as originating from the sunlight or from electric lighting in the room. If a source of power is encountered for a "self-winding" quartz electronic watch, this source may be experienced as originating "within" the device and the interaction between one's body and the watch. These examples suggest how one's relationship to the electric object, electric materiality and electric power can change depending on where a source of power is variously located or attributed. For example, solar-powered calculators and quartz watches may be seen as "perpetually activate-able" devices, since they do not require tethering or conscious replenishing. As such, an electric object that is less reliant on "external power" may exist more similarly to traditional technologies such as book, bicycles, and furniture.

### Electric-Interactions

In this final section of our descriptive analysis of ordinary electric technology we focus on forms of interaction. We identify 4 basic types of electric-interaction: *plugging-in*, *switching-on*, *staying-on* and *directing-about*.

#### *Staying-on*

Typically, the activeness of electric objects can *stay on*. For example, the electric light stays illuminated. Someone may turn it off, or the bulb may fail, or it may lose power during a power outage, but typically it reliably and consistently stays illuminated. It remains active. The radio also remains active, although its sound varies, expectedly, over time. One can *step back* and *step away* from the radio and the electric lamp while each continues to be active. One can recognize a general form of staying-on with many electric things: the light is "on", the phone is "on", the laptop is "on". One can also note particular staying-ons: the laptop screen, the word processor, the text I am composing.

The mobile phone also stays on although it may not give signs of an active presence. One treats his or her mobile phone as active and recognizes it as "being on", yet it gives no signs of activity. It is not illuminated, sounding or vibrating, or even noticeably emitting heat. Yet it may suddenly become active and begin to illuminate, sound and vibrate when receiving a call. This staying-on is not a continuing to be perceivably active but rather a working in the background. This can be understood as an *inactive activeness*. More generally this is an example of a *background relation*, a "present absence" of technology [16]. We have thus identified two types of staying-on: staying-on as a continuing to be perceptually active and staying-on as continuing to be inactively active, in the background. We also noted a *general staying-on* and *particular staying-ons*.

#### *Directing-about*

The activeness of electric objects can variously be *directed-about*. For example, one can alter the illumination of a lamp by dimming or brightening it. Similarly one can adjust the radio volume or the speed of the ceiling fan. One can direct-about the activeness of the electric materiality. One can also, in the present moment, direct-about future activity. The alarm clock can be set to become active at a certain time. It is this form of directing-about that Hallnäs and Redström point toward when they write: "What characterises computational technology as a design material, then, are the temporal structures that are generated when programs are executed." [11, p.106].

One can also direct-about inactive activeness. One can put a mobile phone in a "silent mode" by pressing a physical button on the side of the object yet without activating an electric materiality that one can directly perceive. However, such interactions are uncommon. The careful use of feedback (often through LEDs) is employed in most interactive technologies specifically to avoid confusion that may arise when activating an inactive activeness.

The *directing* in the directing-about can originate from several sources: *I* can direct-about (I turn on light), *others* can direct-about (someone calls me and makes my phone ring, someone has programmed the street lights to go on at a certain time), *the device* can direct itself (the robotic vacuum acts on its own, the ATM makes requests, my alarm clock wakes me up), and *the environment* or *other things* can direct-about (my laptop screen automatically dims when the ambient light changes, the smoke detector is activated by smoke from the oven, a wireless router causes my laptop to try to connect). This source of direction is *multistable* with respect to use, context, and culture in the sense discussed by Ihde [16]. The ringing of the phone can be constituted as a person calling me, as my leaving the phone on (*I* forgot to turn it off), as a non-human other calling me (an automated voice message), or as the device itself ringing (*it* is bothering me). In passing, we note that the source of directing is related to perceptions of agency among human and non-human things (e.g., [33]).

#### *Switching-on and plugging-in*

There are many different ways of directing-about (adjusting brightness, transmitting data wirelessly, setting an alarm to sound in the future). Two basic and ubiquitous modes of directing-about are *switching-on* and *switching-off*. Many everyday electric technologies have a general mode of being switched-on and switched-off. Specific forms or degrees of being switched-on and -off also occur (e.g., powering off a laptop versus putting it in a low-power state so one can quickly activate it). When switching something off one can make it *stay-off*. Two other ubiquitous forms of interaction are connecting and disconnecting from a source of power. By plugging in the electric lamp one enables the possibilities for switching-on, staying-on, and directing-about; by unplugging it one can prevent these possibilities.

### General implications and future analysis

Based on our analysis of electric-interactions we highlight two general points. First, staying-on is a familiar yet crucial aspect of most ordinary electric-interactions. A steady and consistent staying-on is the condition of possibility for many forms of directing-about. In passing, we note that instances of each of Ihde's 4 general human-technology relations [16] are often dependent on staying-on if the technology is electric. For example, if the technology does not continue to stay-on, then one cannot create holes *through* one's use the electric drill (an embodiment relation), read an article *with* the computer screen (a hermeneutic relation), relate *to* the otherness of the alarm clock upon waking (an alterity relation) or possess the feeling of security that one's alarm clock will sound at certain time (a background relation). As we will see, a host of interaction design challenges—as well as opportunities—emerge when electric technologies do not utilize external power from tethering or batteries. With bodily-powered technologies, for example, the forms of staying-on change drastically.

Second, directing-about/staying-on is precisely the juncture in our analysis where we begin to characterize interactions that are distinctly "electronic", "digital", "computational" and "interactive". Directing-about and staying-on are future points of departure for investigating various forms of electric-interaction and electric materialities. For example, future extensions of our analysis could investigate how "control", "transitions" and "states" in "computational composites" [31] emerge phenomenologically as forms of directing-about and staying-on. Similarly, future work could look at the various directing-abouts and staying-ons of accelerometers, RFID and wireless sensor networks as a design material [31].

## Transition: From Ordinary to Uncommon Technologies

While our analysis may be valuable for explaining current interactions with electric technology, or as a foundation for critiquing technology, in the remainder of this paper we will focus on its value in expanding, refining, articulating and generally helping to make sense of a design space. Our approach will be to locate and intentionally amplify differences between ordinary and less common technologies. While such differences are evident across a range of new and emerging technologies, here we focus on bodily-powered electric technologies. In part, this is because it represents extreme variations, thus surfacing additional insight into ordinary technology. Bodily-powered generation also suggest interesting albeit relatively limited applications—from useful to provocative [e.g.,1,24,25,34].

## BODILY-POWERED ELECTRIC TECHNOLOGY

Ordinary electric technologies are electrified via the plug and the outlet or the battery. However, electric technologies need not only be powered in this way. In the following sections we focus on one alternative: bodily-powered electric technology. Commonplace examples are rare, though two examples are hand-crank flashlights and dynamo powered bicycle lights. Generally we describe bodily-powered electric technology as consisting of: (1) A *bodily-powered electric object,* which involves an integrated mechanism for electrifying the device. (2) The object's *bodily-generated electric materiality.* (3) The *bodily-generated electric power* that electrifies the object, generated through an interaction between one's body and the power-generating mechanism.

Here we focus specifically on bodily-powered generation—as bodily-kinetic-generation—rather than human-powered electric technology more generally (thus excluding electric generation from human sound, heat, and metabolic energy) [24]. Importantly, we additionally focus on technologies that do not allow bodily-generated electric power to be *stored-up* using a battery or capacitor. Pierce and Paulos have previously introduced human-powered microgeneration [24], yet do not carefully articulate a distinction between directly powering and storing-up energy. Villar and Hodges notion of "interaction powered" electronics more clearly locates this distinction [34]. We further note there is a range of interesting variations in between, such as short-term mechanical storage with a flywheel or electric capacitors. We will look at such possibilities in the next section. Prior to this we extend our previous discussion by outlining three general ways in which bodily-powered technology differ from ordinary, externally powered technology. These will serve as themes of departure for our design studies.

*1. Never without power (yet never externally powered).* A bodily-powered electric technology can be activated without being tethered or without a battery. As such, it can *be* an electric object without possessing a power plug or a space to connect a battery (i.e., without possessing the possibilities for externally powering). It can also be mobile yet not "die" like a battery powered device in the sense that there is a source of power available via one's interaction it.

*2. Power originating within the context of interaction.* If the source of power is generated only via one's interaction with the technology and experienced as such, then one does not experience the power as external to the immediate context of use as can be the case with ordinary electric technology. Instead, one can experience this power as something able to be personally generated or created.

*3. Demanding/inviting bodily exertion and involvement.* If one must exert oneself bodily in order to power the technology, than one is not able to switch-on in order for the technology to stay-on as with ordinary electric technologies. Switching-on, staying-on and directing-about are instead directly dependent on bodily exertion.

## INTERACTIVE FORM STUDIES IN BODILY-GENERATION

We now begin our move from phenomenologically describing current electric technology toward designing new technologies, interactions and experiences. We begin with 4 form studies in hand-generated electroluminescence.

### Hand-generated LED-illumination

We focus on 4 form prototypes, each of which involves a single electrifiable element: a light-emitting diode (LED). Our functional form prototypes do not use batteries or capacitors to store-up power. Instead bodily-generated electricity is either directly materialized as light or else is momentarily stored up mechanically using a flywheel or the potential energy of a mass. The operation of each form prototype will become more apparent throughout our discussions, but we introduce each with a short description (see Figure 1, p. 2). **Tap LED** involves a piezo element to generate a momentary illumination via a tapping or pressing/depressing interaction (depending on the polarity). **Crank LED** involves a DC gear motor (100:1 ratio) to illuminate via a cranking or turning interaction. **Spin LED** involves a DC gear motor (30:1 ratio) to illuminate by spinning a disc, which acts as a flywheel. **Drop LED** involves a DC gear motor (100:1) connected to a pulley around which a string around which a hook is wound. Placing a weight on the hook causes the pulley to rotate and illuminate the LED. Each form prototype is constructed for easy disassembly into basic electrical/electronic components, power transmission components and housing/mounting components. This "transparency" highlights the lack of batteries, capacitors and power cords.

We present a focused selection of observations emerging from our form study exploration below.

*Each form study object mediates different forms of LED-illumination. Differences in temporal forms of illumination are especially pronounced.* The Drop LED materializes a sustained glow with a temporality defined by the length of the cord and the weight attached to it. The distance from the weight to the ground also creates a defined limit on the duration of the "drop glow". However, one can intervene with the falling weight by stopping it with one's hand, or pulling on the cord directly. When one spins the disc of the Spin LED, one generates a brightness that fades in concert with the slowing of the wheel. However, there is a pronounced speed at which the illumination suddenly ceases. One may also repeatability spin to generate a sustained glow. The Crank LED allows greater variation in the spatial and temporal form of illumination, allowing for continuous illumination at my discretion. Yet slight variations in brightness can be difficult to negate. A continuous glow is impossible with the Tap LED; a *blink* or *series of blinks* are the only fulfillable forms.

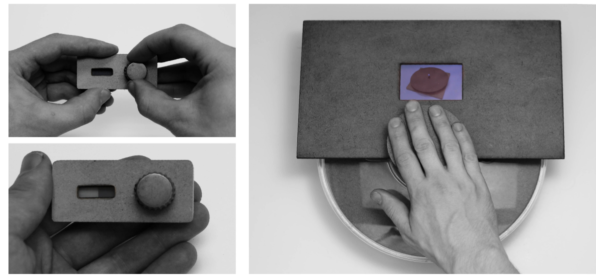

**Figure 2. Form studies in bodily-generated displays. Turning the dial /motor (left) adjusts the e-paper display bar. Pushing (right) drives a screw mechanism that spins a flywheel, activating an OLED display.**

Generalizing from these observations, we see that certain forms tend to emerge owing to the ways in which the form of generation mediates or affords certain forms of interaction. Some forms are facilitated and encouraged (e.g., a sustained glow from Dropping; a short, fading glow from Spinning), while other—possibly expected—forms are difficult or impossible to materialize (e.g., a sustained glow by Tapping, a rapid succession of blinks by Dropping).

*There is a direct relationship between the form of electric generation in terms of my bodily involvement and the form of LED-illumination one generates, though this relationship varies across the form studies.* In order for the Crank LED to become illuminated one must crank. One must exert oneself bodily, and moreover one must continue exerting myself in a way that is proportional to the illumination that is generated. Consider now the Drop LED. Again, one must exert oneself bodily in order to illuminate this object. In this case, one places a weight on the hook (and tugs on it) in order to set in motion to fall, generating a sustained and consistent glow. One may now stand back and watch the electrified object glow without one's direct involvement. However, one can still see, feel and hear the steady and continuous spinning of the gear motor and descending of the weight. After a short time, the weight reaches its limit and the LED ceases to glow. Finally, consider the Tap LED. The tapping or pressing motions that illuminate the LED are similar to the familiar and ubiquitous button-press interaction. However, in contrast to the button on a battery powered flashlight, tapping or pressing creates only a momentary illumination—a *blink*. There is no possibility here for a continuous, sustained glow.

Our form studies help us to see how and in what particular ways some forms of bodily-generation are better matched to certain forms of LED-illumination (and activation more generally) than to others. Tap, for example, is not well suited for a continual activation. Drop, on the other hand, is well suited for a sustained activation in which one may *step away*, yet is not well matched to a momentary activation.

*Each form study object "stays-on" differently.* With the Crank LED, the illumination does not persist without one's direct bodily involvement. One must generate and sustain its illumination. With the Tap LED, illumination also requires one's direct bodily involvement, but there is no possibility of generating a sustained, uninterrupted glow. With the Drop LED, the LED may stay illuminated but only for duration of time defined by the length of the cord and the distance to the ground. Repeated illumination is further dependent on one re-raising and re-dropping the weight.

The Crank LED, Spin LED and Drop LED suggest a continuum of staying-on in terms of my bodily exertion and involvement. The Crank LED requires direct exertion to *constantly maintain* its activeness; the Spin LED allows one to exert and then *step back* while the LED continues to be illuminated; and the Drop LED allows one to further *step away* from the active LED. An LED light that uses a battery or outlet for power allows for an even more prolonged staying-on independent of my bodily involvement. The extreme ideal case in the trajectory is the Perpetually-Illuminated LED (similarly as impossible as the coveted perpetual motion machine).

### A Look at Bodily-powered Electric Visual Displays

We now briefly extend our explorations in LED illumination to more complicated electric displays. Here we consider two types of low-power display technologies: OLED and electronic paper (e-paper). Based on our prototypes discussed previously, it should be easier to now imagine variations such as a Drop OLED Display, Spin LCD Display and Tap E-Paper Display. We present two additional form prototypes, which introduce two new forms of generation: **Push-to-spin OLED Display** and **Turn E-Paper Display.** (See Figure 2 for a description of each). In contrast to our previous prototypes, these two form studies do not actually generate power to activate the displays. However, they do require an amount of bodily exertion comparable to the power requirements for each display. We restrict our discussion to two important areas.

#### *Display stability*

The temporal stability of the OLED-activated imagery is dependent on its continually being electrified. In contrast, the e-paper displays used in our prototypes do not require electrical power in order to remain visually stable. Electronic paper may thus have a "staying-on" that may not be experienced as an active staying-on. The directing-about that occurs is a momentary switching. Thus, momentary interactions such as Tap, Press, and Turn may activate a change in the display. In contrast, a bodily-powered OLED display must be continually powered to continue displaying. E-paper is a very unique electric technology owing to its display stability, relative to ordinary electric displays.

#### *Display involvement*

A primary function of visual electronic displays is to be seen and read. Reading a bodily powered display, however, requires bodily exertion to activate the display (e.g., Tapping, Dropping, Cranking). Consider three general ways this may be experienced. (1) Activating the display may be experienced as *effortful*. For example, pushing the OLED display may be tiring and distract one from my viewing imagery being displayed. (2) Activating the display may be experienced as *effortless*. For example, turning the knob on the Turn E-Paper Display may be experienced similar to many common everyday interactions with various electric switches and dials. One may forget, or never even realize, that one's bodily exertion is actively powering the directing-about of the display. (3) Activating the display may be experienced as *engaging*. The Push-to-Spin Display may be initially experienced as a fun surprise. If it is not experienced as effortful, the demand for bodily exertion may encourage one to engage with the video, rather than walking away. (The distinction between engagement and effort owes to Verbeek [33]. Here we introduce "effortless" as an additional form of involvement.)

## BODILY-GENERATION DESIGN SPACES/STRATEGIES

We now expand outward to reflect on our forms studies in relation to general structural differences between ordinary and bodily-powered electric technologies. We present three design spaces for bodily-powered technology.

### Expanding Electrifiable Space

Bodily-powered electric technologies may *enable new and less common contexts for electric-interactions to occur, for electric materialities to be activated, and for electric technologies to "live"*. An important implication of bodily-powered technology is the potential for activation independent from the power grid and other sources "external" to the interaction between a human body and the technology. While power grids and batteries have created expansive electrifiable space, consider several ways of further expanding: Bodily-powered technology may (1) *live apart from the grid* (e.g., a bodily-powered display is left at a remote location such as campsite or mountain summit to communicate with future visitors), (2) *live for when the grid is unavailable* (e.g., a hand-crank flashlight is kept in the automobile for emergencies), (3) *live "off the grid" within the grid* (e.g., an activist/artist places an electric intervention in a public urban space where it can be continually electrified without utilizing municipal power infrastructure), and (4) *live to fill in pockets of space not electrified by the grid* (e.g., a paper map at a bus stop is replaced with a hand-powered interactive e-paper map). Bodily-powered technology may also (5) *live more similarly alongside non-electric things.* For example, digital photos of high sentimental value might be uploaded to a hand-powered photo locket, which is kept in a wooden box alongside paper letters, film photographs and other sentimental possessions. Decades later the photo locket may be removed and the images immediately materialized without having to locate an outlet or battery. In this sense, the hand-powered digital photo locket may live more similarly alongside the paper letters and photographs—spatially and temporally.

### Engaging through Bodily Involvement

Bodily-powered electric technologies may *mediate new and less common forms of interaction through and with them*. If not experienced as effortful, they may be experienced as distinctly engaging. Bodily-powered technology is particularly interesting to explore in the context of "third-wave" HCI concerns such as slowness and reflection [e.g., 12,23]; intimacy, playful engagement, and provocation [e.g.,1]; and provenance, durability and heirloom qualities [23,30]. For example, consider the Crank Video prototype (Figure 3), one of several prototypes in a series we are currently developing around the theme of hand-captured and hand-instantiated digital media devices. Cranking in one direction allows for the recording of a digital video while cranking in the opposing direction plays back the video. The necessity for direct bodily involvement may, for example, help mediate a slower, more reflective capturing and viewing of video. Designed to connote sentimentality, the Crank Video prototype may mediate more engaging interactions through the act of hand-generating the displaying and capturing of video.

### Forging Relationships to Electric Technology

Bodily-powered electric technologies may *mediate new and less common relationships to electric technology itself (including the electric object, its electric materialities, and the source of power)*. For example, consider again the Crank Video (Figure 3). One may relate to this electric object as more durable since it can be activated independent of outlets or batteries. One may also relate to the device as unique and special, as standing apart from ordinary battery/outlet powered things. Similarly, the bodily-powered aspects of the device may also affect one's relationship to the digital media (both the active video and its inactive electric storage). For example, one may relate to the video as special owing to the way it is generated.

## SUMMARY OF DESIGN INSIGHTS AND IMPLICATIONS

Our form prototypes concretely highlight a range of interesting and useful forms of bodily-generation including Tap, Crank, Spin, Drop, Push-to-Spin and Turn. We further presented display stability and display involvement as two important considerations. E-paper was highlighted as a unique electric technology owing to its display stability (a no-power "staying-on") and activation (a low-power directing-about that is possible with momentary interactions such as Tap, Press and Turn.) Effortful, effortless and engaging surfaced as three important types of involvement especially pertinent to electric displays, but also more generally to the intrinsic exertion characteristic of all bodily-powered electric technology. We then articulated three design spaces/strategies: bodily-generation may be used to expand electrified space, engage through bodily involvement, and forging new relationships to electric technology. The Crank Video was offered as an example of a hand-captured and hand-instantiated digital media device related to a number of "third wave HCI" themes. As this example suggests*, it is the "limitations" of bodily-powered electric technologies—relative to ordinary ones—whose exploitation and amplification afford the greatest design possibilities.*

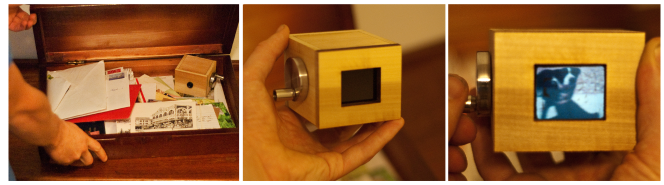

**Figure 3. Crank Video. Video is captured and displayed by turning a finger-crank power generator.**

## DISCUSSION, CONCLUSIONS AND FUTURE WORK

In closing we reflect on our work and present two key areas for future extensions and applications.

*Other technologies / specific research areas.* Bodily-generation is an interesting yet relatively limited area in terms of its potential to replace current, everyday electric things. While its "limitations" can be positive features (e.g., it can be exploited as a unique and special type of technology), there are many other applicable, relevant and timely technologies to consider. One prominent example is solar power. While we have not conducted in-depth phenomenological analysis or form studies for photovoltaic generation, our work offers insight. For example, mobile devices that passively harvest solar power might be experienced as electric things that "never die" or "won't die". These suggest different relationships to the object (e.g., possibly more lasting and durable) as well as new attributions of agency (consider domestic robots that do not require tethering or batteries). While our discussions have been relatively agnostic to specific research agendas, we note that our work may be of particular value to a variety of application domains (e.g., electronic music) and broader issues (e.g., environmental sustainability).

*Advancing HCI theory/reflection.* Our work is of particular relevance to research concerned with both understanding the materiality of useful, everyday technologies, and the possibilities and limitations of electric technologies as design materials. A specific research question that we here emphasize has to do with locating similarities and differences among technologies [e.g.,8,30,32]. Phenomenologically, we propose two differences to account for. The first is ordinary or typical differences. A clear example of an ordinary difference is that electric things have batteries and power cords, whereas non-electric things do not. However, as we have noted, this is not an invariant or essential difference. Hence, a second category is "essential" differences. Locating and explaining essential differences—which in practice involve *approximations* thereof—can help us grapple with questions such as why e-books are different than paper bound books. In terms of design, such differences can indicate essential limits of technology. For example, our work suggests dimensions in which electronic text can *never be like* paper books (the electric materiality is unstable and active relative to ink on paper; it has an "impermanence" owing to its possibilities for being directing-about and deactivated; paper books are not dependent on sources of electric power).

We also argue that research through design can (and does) create exemplars that may be useful in locating important similarities and differences among technologies. For example, consider the well-cited Power Aware Cord, which visualizes the electricity flowing through it [1]. Our Crank LED and the Power Aware Cord both "visualize" the electricity being used, but represent key differences. For example, the "amount" of power is primarily *seen and read with* The Power Aware cord, whereas it is unavoidably *felt and embodied through* the Crank LED. And together, these examples suggest that usable electricity, in contrast to wood fuel or gasoline, is essentially imperceptible to "naked", non-technologically-mediated human perception [16]; electricity cannot stand apart, on its own, as *an object*.

Based on this discussion, we close with two considerations. First, HCI theory can benefit from taking into account and explaining uncommon and extreme design variations. Second, research through design should perhaps be allowed even more freedom to create novel, interesting, even radical exemplars that do not strictly require validation in terms of usefulness and desirability to "users".

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