Investigating Composite Relation with a Data-Physicalized Thing through the Deployment of the WavData Lamp

Ce Zhong
Cheriton School of Computer Science
University of Waterloo
Waterloo, Ontario, Canada
kczhong@uwaterloo.ca

Xiang Li
Cheriton School of Computer Science
University of Waterloo
Waterloo, Ontario, Canada
x247li@uwaterloo.ca

Xizi Wang
Cheriton School of Computer Science
University of Waterloo
Waterloo, Ontario, Canada
l84wang@uwaterloo.ca

Junwei Sun
Huawei Human Machine Interaction Lab
Markham, Ontario, Canada
junwei.sun@huawei.com

Jian Zhao
Cheriton School of Computer Science
University of Waterloo
Waterloo, Ontario, Canada
jianzhao@uwaterloo.ca

Abstract

This paper reports on a field study of the WavData Lamp: an interactive lamp that can physically visualize people's music listening data by changing light colors and outstretching its form enclosure. We deployed five WavData Lamps to five participants' homes for two months to investigate their composite relation with a data-physicalized thing. Findings reveal that their music-listening norms were determined by the instantiated materiality of the Lamp in the early days. With a tilted form enclosure, the WavData Lamp successfully engendered rich actions and meanings of the cohabiting participants and their family members. In the end, the participants described their experiences of entangling with and living with the Lamp as a form of collaboration. Reflecting on these empirical insights explicitly extends the intrinsic meaning of the composite relation and offers rich implications to promote further HCI explorations and practices.

CCS Concepts

• **Human-centered computing → Empirical studies in interaction design**.

Keywords

Data physicalization, Composite relation, Technological things, Artificial intelligence, Research through design

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1 Introduction

The field of Human-Computer Interaction (HCI) has an ongoing interest in blending diverse data into people's everyday lives [53, 68, 84]. For instance, researchers have been initiated to visualize people's personal information on digital screens to enhance their awareness of everyday routines in situated contexts [7]. With the development of novel artificial intelligence (AI) algorithms, they have begun designing novel predictive features by processing everyday data stored on the cloud. For example, Prospector, a web-based interface with an embedded AI model, can predict diabetes trends by processing personal medical record data [38]. To facilitate knowledge production in HCI, researchers have recently been encouraged to blend information visualization into design [4].

As an emerging research field, prior work has proposed the term data physicalization to describe designed material forms "whose geometry or material properties encode data" [33, p.3228]. Physically visualized data can blend into people's everyday lives in more engaging and intuitive ways. Conducting empirical studies of these technologies suggests that interacting with them can engender meaningful experiences, such as self-reflection, from a human-centered perspective [8]. Yet, little has been initiated to explore entangled relations with a data-physicalized thing [13]. Here, the term entanglement refers to the intertwined and mutual relations between human beings and technological things [82]. To facilitate investigations in this direction, HCI researchers have been suggested to adopt the Research through Design (RtD) approach [91] to synthesize *"diverse considerations for constructing and evaluating research artifacts [data physicalization] in the real world"* [4, p.14]. Additionally, Frauenberger has advocated for grounding entanglement theories in the discourses of human-thing relations [13], such as postphenomenology [71].

The composite relation, as a form of human-technology relations derived from postphenomenology, might contribute to explorations in this direction [70]. Typically, this notion emphasizes the combined intentionality of humans and things, highlighting that *"human beings can never be understood in isolation from the reality in which they live"* [70, p.388]. Indeed, they can experience the reality of their situated context of everyday through intimate entanglements with technological things, such as a data-physicalized thing.

To facilitate HCI explorations on the composite relation, researchers have been encouraged to focus on notions of non-neutrality, mutual shaping, and shared intentionality [64]. Given this, in this paper, we ask: **RQ1) How can the composite relation in terms of these conceptual experiences be sustained in everyday settings by closely attending to a particular data-physicalized thing?** As researchers have developed diverse higher-level concepts, such as reality and intentionality, to promote discussions on the composite relation and things [70], we also want to explore **RQ2) What opportunities might be revealed by critically reflecting on the empirical findings related to these notions?**

To answer these questions, we conducted a 2-month field study of a WavData Lamp, a data-physicalized thing that can predict people's music listening habits by changing light colors and outstretching material form. Specifically, it can emit four different ambient colors as the prediction of the peak music listening period in the next 24 hours; it can also predict the length of a user's music listening time during the same period with a maximum stretching length of 10 cm. The WavData Lamp is highlighted with a tilted-form enclosure, which can occasionally fall with the actuation of an embedded rack-and-pinion mechanism. The prediction behavior occurs at 6 pm each day, during which the WavData Lamp emits subtle sounds for 20 seconds as an indication. A Raspberry Pi 5 embedded within the WavData Lamp can process a user's music listening data derived from Spotify API with a deliberately designed AI algorithm. In addition, it can be powered by plugging its adapter into a socket with no switch control. These qualities reveal that the WavData Lamp has a particular form of materiality that can sustain intertwined relations between the thread of processing stored data handled by the embedded Raspberry Pi 5 and the thread of the music listening by users [82]. We call the WavData Lamp a technological thing as it has intentionality in assembling the cohabiting human beings and other things in the situated context of everyday [72].

Five music listeners with more than two years of Spotify experience were recruited as participants for this field study (Fig.1). To investigate the composite relation with the WavData Lamp, we delivered the Lamp with informed consent forms, user manuals, and gift cards to their homes at the start of the study. We then conducted four interviews with each participant during the deployment period via Zoom to understand how they became intimately entangled with the WavData Lamp. The findings suggest that the design of the WavData Lamp subtly determined their music listening norms in transforming their conventional habits of using Spotify. As the WavData Lamp can occasionally fall, music listeners and their family members who cohabited with it performed diverse actions and developed rich meanings in their everyday routines. By the end of the field study, they had developed different senses of collaboration with a data-physicalized thing in their everyday routines.

This study makes three contributions to the HCI community: First, it extends ongoing empirical studies on data-physicalization by generating rich *entanglement insights* through the field deployment of the WavData Lamp in everyday settings. Second, it enriches the intrinsic meaning of the composite relation by elaborating on notions of *predictive possibilities, cat intentionality, and uncertainty.* Third, it provides *rich implications* to advance future HCI explorations and practices on technological things.

2 Literature Review

The background of this study is composed of three sections: empirical studies on data physicalization, composite relation, as well as technological things, materiality, and HCI.

2.1 Empirical studies on data physicalization

Over the past decade, HCI researchers have shown a growing interest in reshaping data interactions from visualization to physicalization [4, 25, 33, 84, 89]. As a cross-disciplinary research field, some researchers are exploring the use of emitted digital light as a visual variable to physically encode data [19, 27, 40, 62, 83]. For instance, the illuminated light on the Power-Aware Cord embodies real-time electricity usage data [22]. Others have used movement as a key factor to physically represent the processed data [48, 69, 80]. The Nowwhere project is one example that utilizes the position and force of a Computer Numerical Control (CNC) mechanism to translate real-time search queries into a dynamic physical landscape, encoding data as physical erosion patterns on a block of foam [1]. With these novel installations, early work has conducted user experiments to evaluate the predesigned interactivity, validity, and usability of physically visualized data in laboratory settings [10, 24, 46, 65]. Yet, the HCI community *"lacks empirical studies as a major element of the research agenda for data physicalization"* [33, p.3229].

To tackle this issue, previous research has conducted diverse user experiments with data-physicalized systems in public spaces. For example, conducting a comparative study of data physicalized installations in a working context suggests that the scale of physicalized material forms plays a pivotal role in communicating the meanings of experiences [45]. Additionally, inviting participants to interact with the CairnFORM in a public place enhanced their attractiveness of the renewable energy data [10]. Furthermore, deploying the Torrent at concert halls promoted the embodied performances of involved musicians [59].

Inspired by these studies, a growing body of later work has begun to blend physically visualized data into people's everyday lives. Most of the research was interested in exploring users' reflective potentials through the design of novel interactive systems to physicalize different kinds of data [26, 41, 42, 67]. For example, as Lina can physically visualize running data by changing its form shape, people who lived with it at home reflected and anticipated their running behaviors [47]. Additionally, HCI researchers have designed novel data-physicalized installations to improve people's emotional awareness, such as the Motiis [57]. These studies reveal that physically visualized data can engender meaningful interactions and experiences [27, 36, 49]. With the shift toward the entanglement HCI [13], this paper aims to extend ongoing empirical studies on data physicalization by deploying a data-physicalized thing in everyday settings.

2.2 Composite relation

Introduced by Verbeek, the theory of the composite relation typically describes the combined intentionality between human beings and technological things [70]. Here, *human intentionality* refers to the mental states of human beings directed toward something or affairs, such as perceptions, beliefs, and hopes [31]. One example of

Figure 1: Sophia's cat Coco noticed the WavData Lamp placed next to a cat water fountain on the floor in her living room.

understanding this notion is the sense of relaxation derived from the experience of using an ambient lamp. As a postphenomenological concept, it is important to note that the term intentionality has a different meaning from the notion of *intention* as the latter refers to the goal or plan we have in action [64], like the behavior of turning on a lamp for reading. Additionally, the notion of *technological intentionality* describes "specific ways in which specific technological things can be directed at specific aspects of reality" [70, p.392]. Ihde introduced one notable example of this concept. That is, sound recorders can detect background noises that humans may neglect while both of them have sound intentionality [29, 30].

Alternatively, as the composite relation is extended from the mediated relation, particularly the hermeneutic relation, it can reflect the experience of interpreting the represented and constructed reality generated by a technological thing. Here, represented reality can be understood as the intentionality of a thermometer in detecting temperature. Such a form of the composite relation "consists of making accessible to the human eye an artificially expanded form of human intentionality" [70, p.394]. The constructive reality, as another form of the composite relation, describes the generated new reality that "can only exist for human intentionality when it is complemented with technological intentionality" [70, p.394]. One example is a visual image of a star taken by a radio telescope that is originally invisible to human eyes. Taken together, "the composition of human intentionality and technological intentionality is directed at making accessible ways in which technologies "experience" the world" [70, p.393]. For example, the world of Morse Things can be understood as "connecting with other things on a computational network" [72, p.393].

To facilitate HCI inquiries into the composite relation with novel technological things, researchers have developed concepts of *non-neutrality*, *mutual shaping*, and *shared intentionalities* [64]. Non-neutrality describes how technologies can stabilize or destabilize people's conventional norms as well as "influences, restricts, leads, inclines, or controls us" [72, p.142]. It also emphasizes the trade-offs of things in amplifying an extended sight. For example, "reading glasses make seeing far difficult and supplemental oxygen systems make it difficult to speak by covering your face" [72, p.104]. Mutual shaping describes how meanings and actions are co-shaped by a purposefully designed technological thing and cohabiting (non)human beings. The key to engaging the composite relation is unpacking the notion of shared intentionality, which refers to people's sense of collaborating or coordinating with technological intentionality, like a designer's sense of collaborating with a counterfactual 3D printer to generate a physical model. Inspired by these concepts, the main goal of our study is to investigate the composite relation with a data-physicalized thing in terms of non-neutrality, mutual shaping, and shared intentionalities. With the collected empirical data, we also aim to extend ongoing discussions on related concepts of the composite relation, such as reality and intentionality.

2.3 Technological things, materiality, and HCI

With the emergence of intelligent things, such as data-physicalized things, researchers are shifting their focus to investigate the mutual, transformative, and interconnected relations with purposefully designed technological things in the context of so-called entanglement HCI [13]. To this end, Freudenberg suggested "to abandon user-centered design" as (non)human needs are not the overarching goal of interacting with technological things [13, p.19]. Rather, (non)human beings, such as music listeners and their pets, might be entangled with technological things to make sense of their perceptions, existence, and belongings rather than achieving functional and utilitarian intentions. To facilitate knowledge production in this research domain, he claimed that grounding entanglement theories, such as postphenomenology [61], in design-oriented studies can enrich existing understandings of human-thing relations.

Indeed, the HCI community has a nascent but growing body of work in investigating entangled relations with technological things through practices [12, 34, 60, 78, 90]. The deployment of the Prayer Companion suggested that it successfully assembled cloistered nuns and digital news through the lens of materiality [15]. Discussions about the values of fabricating multiple obscure 1C digital cameras revealed that designing an inhibitive interface can highlight the *counterfactuality* of technological things [58]. Another example is the field study of Morse Things, which highlights the importance of *ambivalence* in maintaining unknowing relations with technological things [77]. Recently, Wakkary has introduced diverse higher-level concepts to promote thing-centered discussions in HCI [72]. He introduced the term *assemblage* as one quality of things to describe the "heterogeneous elements that function together" [72, p.17]. For instance, an everyday designer, as part of an assemblage, can appropriate surrounding materials, tools, and resources in crafting or repairing gathered things [74, 79, 87]. In the form of assemblages, things belong to a collective agency or "the ensemble nature of action and the interconnections between persons and things" [5, p.37]. This paper aims to enrich the assemblage notion's intrinsic meaning by discussing the WavData Lamp's empirical findings.

Wakkary has encouraged designers and researchers to "keep in close proximity to the concreteness of things as matters of materiality" [72, p.118] to facilitate ongoing discourses with technological things. Indeed, as a theoretical framework, the Materiality of Interaction was suggested to frame the implementations of novel computational material forms [81, 82]. Specifically, this notion describes an ever-changing process between the threads of interactions and the threads of computing. It also highlights a transformative relationship that intertwines with purposefully designed technological things. Building on this framework, the instantiated materialities of these things can sustain entangled relations with cohabiting (non)human beings. Previously, HCI researchers have investigated how a particular form of materiality has successfully scaffolded the mediated relation with a shape-changing thing in their homes over 9 months [89]. In this paper, we assert that the WavData Lamp, as another form of materiality, can also sustain the composite relation with a data physicalized thing in the context of everyday.

Collectively, HCI researchers have surfaced the necessity to extend empirical studies on data physicalization from in-situ experiments to the mundane context of everyday. They were also encouraged to generate new and unknown entanglement insights through the lens of novel postphenomenological concepts. However, it remains unknown what empirical data about the composite relation can be engendered by purposefully instantiating the materiality of a data-physicalized thing. This paper aims to tackle this issue. Specifically, we want to explore how the experiences in terms of non-neutrality, mutual shaping, and shared intentionalities can be scaffolded through the deployment of the WavData Lamp. With the collected findings, we also intend to contribute valuable reflective insights to enrich the meaning of the composite relation and advance future HCI explorations and practices on technological things. In the following section, we will elaborate on the implementation of the WavData Lamp and how it can embody related HCI concepts as a particular form of materiality.

3 WavData Lamp: implementation and rationale

WavData Lamp is a data-physicalized thing that can predict a user's Spotify music-listening behaviors. Here, the term prediction refers to an embedded statistical learning algorithm of the WavData Lamp in anticipating people's music-listening behaviors in terms of time length and peak period in the next 24 hours. We add this feature to the WavData Lamp as it can highlight the intelligence of a particular data-physicalized thing that can sustain intimate entanglements in everyday settings [13]. It performs the prediction by outstretching its form enclosure and emitting digital light colors as two separate metrics. In particular, the WavData Lamp can outstretch its tilted form enclosure at 6 pm each day to predict a user's Spotify music-listening time length in the next 24 hours (Fig.2); It can also emit four different colors at 6 pm each day to predict a user's Spotify peak music listening period in the next 24 hours. The light colors vary from yellow to orange to blue to purple, representing the predicted peak music listening period in the morning (6 am to 12 pm), afternoon (12 pm to 6 pm), evening (6 pm to 12 am), and midnight (12 am to 6 am) respectively (Fig.3). Given this, we can call the WavData Lamp a data-physicalized thing because it can physically encode people's music-listening data stored in Spotify API [1]: the world's largest on-demand music streaming platform, which has successfully attracted 640 million active listeners with 252 million subscribers by 2024 [32].

The prediction feature of the WavData Lamp is scaffolded by an embedded AI algorithm named Auto-Regressive Integrated Moving Average (ARIMA): a statistical learning model that provides reliable predictions without requiring vast amounts of input data. Specifically, suppose a user's average music-listening time over the past three days is x% more or less than the historical average listening time. In that case, the height will increase or decrease by 0.5x% from the midpoint, resulting in a final height of 100mm * (50% ± 0.5x%). With this AI model, the WavData Lamp can make predictions by processing a user's music listening data from the Spotify API. We chose this platform because personal music listening data,

[1]Spotify is the world's largest on-demand music streaming platform. For more information, please go to: https://www.spotify.com/.

Figure 2: From left to right: the WavData Lamp can linearly outstretch its form enclosure from 0 mm to 100 mm to predict a user's music listening time length in the next 24 hours while it may fall over 75 mm due to its tilted form enclosure (sketched image).

such as demographic information, have been successfully utilized to design data-physicalized things [39] and have been adopted as a material for designing novel interactive technologies, such as slow technology [50, 51, 54].

To instantiate the materiality of the WavData Lamp, we purposefully designed the output interface with its input module being the music-listening data derived from Spotify API (Fig.4). Our experiments aimed to test alternative electronics to explore possible light and actuator materials of the WavData Lamp. For the ambient light, we initially experimented with a Neopixel Ring with 32 LEDs as it offers a hollow space for installing the rack and pinion mechanism. The challenge was that there was no supported Raspberry Pi 5 library at the time of our experiments. A Neopixel matrix was also tested as it can emit diverse ambient colors with a 5V power supply. While it was successfully powered, such a matrix was not suitable for the mechanism. Additionally, we programmed with a DotStar strip with 40 LEDs that were flexible for different form designs. In terms of the actuator, a 28BYJ48 stepper motor was tested, because it can be powered by the Raspberry Pi 5 and has been successfully applied to design novel technological things [90]. In the end, the stepper motor and DotStar strip were selected as the output electronics of the WavData Lamp (Fig.5).

Additionally, we used a piezo buzzer named PS 1240 to create a subtle sound while the WavData Lamp is performing predictions at 6 pm each day (Fig.6), during which the buzzer can make a contentious beep sound for around 20 seconds. Our intention of doing this was inspired by how the sound made by Morse Things successfully enhanced the interconnections between things and humans [77]. Given the goal of the study, designing such a feature for the WavData Lamp might cultivate music listeners to interpret their entangled relations and experiences [16, 23]. Further, our motivation for setting up the prediction time at 6 pm was inspired by the Message Ritual Lamp, an AI-powered lamp that generates poetics at 7 am each morning by processing transcripts received from the past 24 hours [60].

The WavData Lamp was also deliberately designed with qualities of open-endedness and lived-with to sustain situated inquiries on the composite relation [52, 73]. Here, open-endedness emphasizes how a purposefully designed technological thing can serve as a resource for supporting situated inquiries on new and unknown entanglement relations. Lived-with describes how a highly finished computational thing can sustain deployment inquiries in everyday settings rather than laboratory experiments. To embody the notion of open-endedness, we crafted a heptagonal form with uneven sides to cultivate novel entanglements with a data-physicalized thing. In attending to the lived-with quality, we intentionally minimized the input interface to enhance the manifestation of the data-physicalized material form. Further, we smoothed the surface of the 3D printed form enclosure to diffuse the emitted digital light as well as enhance its actuality.

In addition, the WavData Lamp is highlighted by a counterfactual feature: it can occasionally fall depending on the actuation height of a tilted form enclosure [58, 77] (Fig.2). This feature was informed by the notion of material speculation: adopting unfamiliarization as a design strategy to make familiar strange as a way to inform critical inquiry on the proposed research questions [75]. Technically, the tilted form has a 70-degree inclination to the horizontal surface where the WavData Lamp is placed. Specifically, it can fall to the ground by itself after it rises for more than 75% of the max actuation length (i.e., 75 mm). It can also fall when it loses balance through the engagements of cohabiting (non)human beings or other things. While the WavData Lamp might fall to the ground, the embedded mechanism can still push up and retract the form enclosure to continue performing predictions.

These endeavors demonstrate how we instantiated the materiality of the WavData Lamp. That is, it manifests a concrete form of materiality through the threads of predicting music listening habits by changing light colors and outstretching the form enclosure. It also instantiates a particular form of materiality when a user is listening to music at a given moment. Therefore, the WavData Lamp is always in an ever-changing process "both in relation to its user

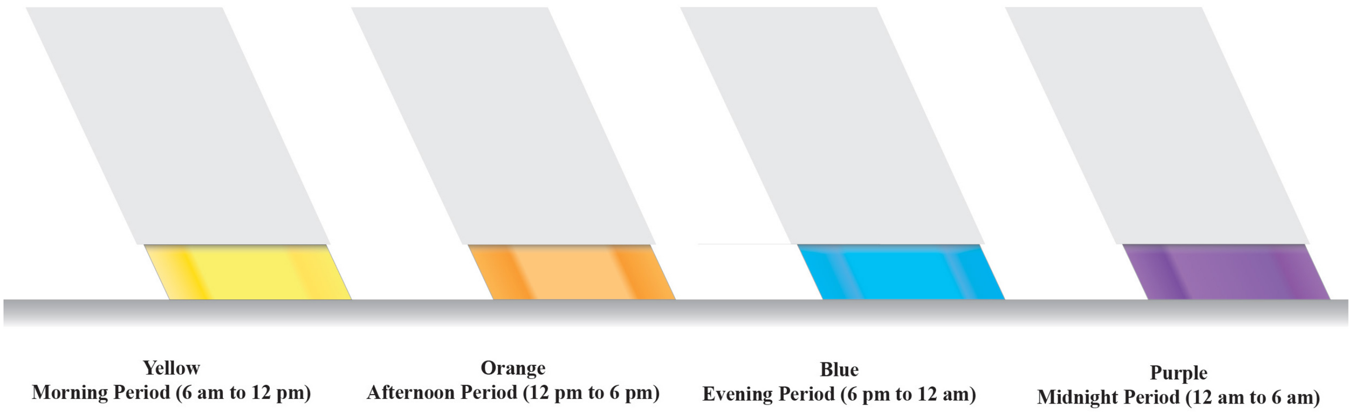

Figure 3: From left to right: The WavData Lamp emits a yellow-colored light to indicate that a user's peak music listening period will happen tomorrow morning from 6 am to 12 pm; the orange-colored light means the user will listen to music most often tomorrow afternoon from 12 pm to 6 pm; the blue-colored light refers to the predicted peak music listening period that will occur this evening from 6 pm to noon; similarly, the purple color means that the user might listen to music most often at midnight tonight from 12 am to 6 am (sketched image).

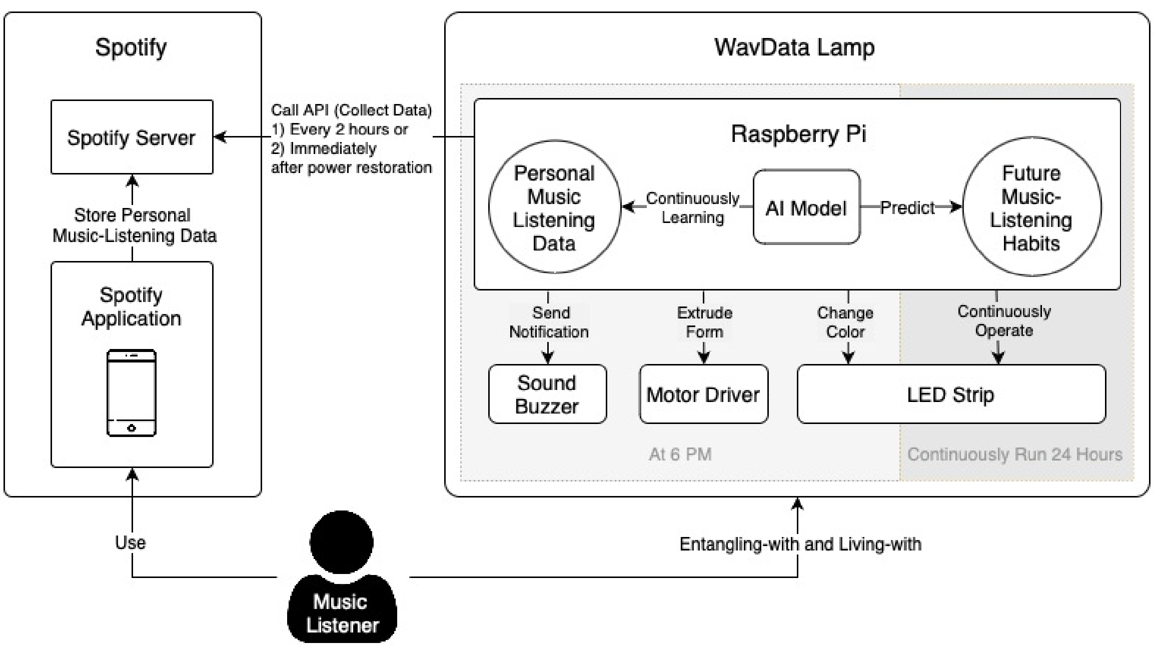

Figure 4: The schematic diagram of the WavData Lamp: it can process a user's music-listening data collected from Spotify API for ongoing AI training. At 6 pm, it can predict the user's music-listening habits for the next 24 hours, which would last for around 20 seconds. It changes height and color immediately once the prediction is completed.

and in relation to the composition that defines the concrete instantiation of the interaction in computational form" [82, p.135]. With such a quality, the WavData Lamp can sustain entangled relations with situated (non)human beings [88].

Ultimately, five WavData Lamps were batch-produced as resources for the field study with the following specifications (Fig.7): the dimension is 12cm (length) by 10cm (width) by 28cm (height); it can be powered by plugging in a 5V output power adapter, and it can be moved to different rooms by unplugging and replugging the cable into a power source. These endeavors contributed to achieving the thing quality of the WavData Lamp because it has

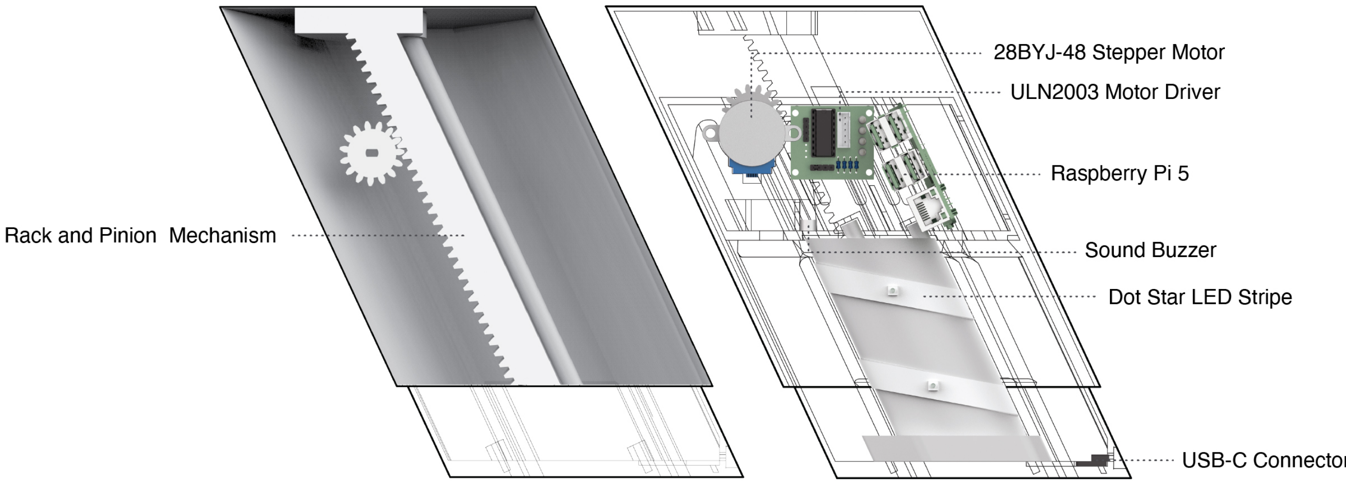

Figure 5: The components of the WavData Lamp: the rack and pinion mechanism (left) and the embedded electronics including a 28BYJ-48 stepper motor, a ULN 2003 motor driver, a Raspberry Pi 5, a sound buzzer, a dot star LED stripe, and a USB-C connector (right).

Figure 6: The embedded electronics are arranged diagonally to fit the form design of the WavData Lamp.

intentionality in predicting and visualizing people's music listening habits by processing their data. That is, it "can 'experience' the world by connecting with other things on a computational network", which aligns with Wakkary's descriptions of the intentionality of the Morse Things [72, p.150].

Figure 7: Five assembled WavData Lamps were tested in a dark context before the deployment study.

4 Methodology

In this section, we intend to elaborate on the research settings of the field study of the WavData Lamp. Specifically, we will clarify the recruitment of the participants and discuss the deployment procedure. Additionally, we will explain the methods that we adopted for collecting and analyzing the empirical data of the WavData Lamp.

4.1 Participants

Five everyday dwellers who lived in the Waterloo region were recruited as field study participants. Our goal was to focus on a small group of music listeners who have used Spotify for more than two years to gain a rich and deep understanding of their daily entanglements with WavData Lamp [28]. Informed by previous research on human-thing relations [15, 77], we set the deployment length to two months to accumulate their interpretations and reflections on their experiences of living with a data-physicalized thing. Similar to our time setting, others have successfully engendered rich entangled relations and experiences through the deployment of unique technological things [77, 78]. Our intention in doing this is not unlike the implementation of including domain experts in qualitative research [85, 86, 90].

We conducted our recruitment by posting a flyer on the information board of our university campus and sharing the flyer with friends and their networks via social media platforms, such as WhatsApp. The latter method is known as snowball sampling: an interconnected method to employ potential music listeners as the participants of the study [55]. Two of five music listeners were recruited via the posted flyer, and three were recruited through friend's contacts. We see the limitations of this sample size and the variables of the involved participants. Informed by prior HCI research on human-technology relations [6, 51, 76], we want to focus on everyday dwellers to gain rich examples of living with and entangling with a highly finished technological thing. We consider the reported intuitive, mundane, and reflective insights by the involved participants can benefit future HCI explorations on novel human-thing relations. Therefore, "we were less concerned with collecting data that would be generalizable or representative of an entire population" [6, p.71]. These participants are diversified in terms of different occupations, genders, and social-cultural backgrounds. During the field study, participants' family members and friends occasionally visited their places. We describe the involved participants with pseudonyms.

Isabella (late 20s) is a computer scientist who lives with her boyfriend in a house. She has been using Spotify for eight years, and her favorite music group is Il Volo, an Italian operatic pop trio.

Olivia (early 30s) is an analytical chemist who is living with her husband and two cats, Croissant and Baguette, in an apartment. She has been using Spotify for around six years and is a fan of K-pop.

Leo (mid 20s) is an AI specialist who lives with his girlfriend in an apartment. He has been listening to music on Spotify for around five years and enjoys listening to popular music in his leisure time.

Sophia (late 20s) has been using Spotify for more than two years and specializes in designing visualizing systems. She lives alone in an apartment with a cat, Coco. She is a big fan of classical music.

Noah (early 30s) is a data scientist who has been using Spotify for around seven years. He lives with his girlfriend and a puppy named Rosie. His favorite music genre is hip-hop.

4.2 Procedure

We delivered the WavData Lamps to participants' homes along with informed consent forms, user manuals, and gift cards selected by themselves. We initially introduced the background of the study while they signed the consent forms. We then helped them connect their Spotify account to the service of the WavData Lamp. Further, we conducted a brief interview to understand their background in music listening and their experiences using Spotify. At the end of the delivery, we added the participants' contacts, so they could share photos and videos about their lived experiences with the WavData Lamp. By the end of the deployment, we collected 51 photos and seven videos from the participants.

We conducted four semi-structured interviews to explore the general, detailed, in-depth, and reflective experiences of entangling with and living with a data-physicalized thing [63] (Appendix A1). Specifically, the first interview was conducted three weeks after the deployment. We wanted to leave time for participants to get familiar with the WavData Lamp, and the AI model required time to learn from the participants' music-listening data. After having a general understanding of their experiences, we conducted the second interview at the end of the 4th week to understand their detailed experiences of entangling with the WavData Lamp. The third interview took place at the end of the 5th week, with an aim to collect in-depth mundane entanglements with the WavData Lamp. The collected data from these interviews informed the question design for the last interview, which happened at the end of the 2-month deployment. The goal of the last interview was to explore music listeners' reflective insights of a particular data-physicalized thing and evaluate their experiences through the lens of the composite relation. All the interviews were conducted online via Zoom, an online conferencing platform. We transcribed the recorded interviews using Otter.ai, a voice-to-text transcription software, which generated a total of around 62,200 words.

4.3 Analysis

We adopted constructivist grounded theory to analyze and frame the transcribed data [9]. We conducted initial coding to allow provisional ideas to emerge by closely sticking to data. Specifically, we moved quickly from word to word and line by line to develop emerging codes. We then focused on incidents to incidents to compare data with data between different participants. These endeavors resulted in some simple, short, and precise codes. We then adopted focused coding to conceptualize early themes by comparing annotated codes back and forth. Additionally, axial coding was utilized to integrate subcategories into coded themes. Our intention in doing this is that the concepts related to the composite relation have diverse connotations, especially the notion of mutual shaping. It includes actions and meanings as two subcategories. It is worth noticing here that we coded data right after each interview to inform the question design for the subsequent interview.

We analyze data and codes early in the research by writing field memos: the "pivotal intermediate step between data collection and writing drafts of papers" [21, p.72]. We did this by annotating interview transcriptions to define relationships between the WavData Lamp and the involved participants. After the first interview, we developed themes of amplified music-listening habits, everyday intersections, and coordinated behaviors to understand their general experiences of entangling with the WavData Lamp. We then refined the themes to adjust music-listening activities, performed actions and meanings, as well as coordinations by coding detailed and in-depth experiences of living with the WavData Lamp. After the last interview, we refined the empirical themes to fit the notion of the composite relation. The empirical data analyzed in this paper are full sentences reported by participants. Next, we aim to unpack these themes by reporting on the selected empirical findings of the study.

5 Findings

During the deployment period, the intentionality of the WavData Lamp was shared with the intentionality of the participants and their family members in their homes. Specifically, as the WavData Lamp is non-neutral in physically visualizing participants' music-listening data, participants subtly changed their music-listening norms during the first two weeks of the deployment. They also developed diverse actions and meanings of entangling with the instantiated materiality and the tilted counterfactual material form of the WavData Lamp. These experiences stimulated them to further collaborate with the WavData Lamp for different personalized intentions beyond music listening.

5.1 Determined music-listening norms

During the first interview, all the participants reported their experiences with the prediction feature of the WavData Lamp after living with and entangling it for around three weeks across different homes. One notable example comes from Noah:

"The interesting thing to me is the prediction feature of the WavData. My first idea is engagement or something like that. Then I felt like there is a sense of a dynamic relationship, which is kind of rare… I also feel a predictive sense, where I'm thinking about how my actions today will affect it [WavData Lamp] tomorrow… There's a thought that goes into it [WavData Lamp], there's thoughtfulness in how it is reacting to today." (**Noah**)

As a music enthusiast who routinely listens to music daily, Isabella described how the design of the WavData Lamp destabilized her norms of music listening:

"I want to see if there's any natural change in my music-listening behavior. … This week, I've been listening to music a lot in the morning. But then next week, …I might listen to music more in the evening because I'm working more in the evening." (**Isabella**)

Other than interactive light, entangling with the actuation of the WavData Lamp also shaped others' music listening habits. Leo described how his experience of living with the WavData Lamp in his living room daily reminded him to listen to more music during the first interview.

"Normally, listening to music doesn't affect my work routines because I do this to help me improve concentration while working. Sometimes, I would not listen to music if I'm reading something. But if I see WavData when I grab water in my living room, it reminds me to listen to more music". (**Leo**)

Similarly, Olivia also reported the non-neutrality of the WavData Lamp as a reminder.

"For me, it's still like a reminder to help me remember to listen to music every day. And even though I play games at my friends' homes, even though I'm busy with studies, I still feel like I have some tasks to do. It's like someone who supervises me to listen to music every day." (**Olivia**)

Interestingly, after describing how the WavData Lamp destabilized her music-listening experiences, Olivia used the "switch button" as the term to describe how she felt she was controlled by the WavData Lamp:

"I'm always curious about how the WavData will react to me based on my behaviors. The motivation for me to listen to music is that it not only requires me to do exploratory activities but also adds a virtual layer to the entire environment, which can enhance my overall experience. It changes colors, and it gives me different feedback. It gave me some virtual elements. . . . I feel I'm the switch of this device [to change the WavData Lamp and the environment]." (**Olivia**)

These examples reflect the non-naturality of the WavData Lamp in reframing participants' music-listening norms in their everyday routines.

5.1.1 Transitioning to move the WavData Lamp. In addition to destabilizing participants' music listening habits, the WavData Lamp also influenced the participants and their family members' choices and actions in their everyday lives. After getting familiar with it over around three weeks, most of the participants intended to move it to different rooms or spots due to its portability and vitality. For example, Noah mentioned how he would like to move it from one room to another based on the light intensity.

"The Lamp was in my living room for about a day. But it just seems that the light was too bright for my dog to sleep because she sleeps right there. And [since] I could unplug the Lamp, I've moved it to my office. I do plan to bring it to the kitchen, so my girlfriend and I could experience it more—like a day-to-day life experience, rather than just a one-time interaction." (**Noah**)

Similarly, Olivia also reported how she intended to move the WavData Lamp to her kitchen by considering the trade-offs of the light intensity.

"WavData was placed in my living room for about one week. . . . It's hard for me to explore another possibility if I keep it at the same location. . . . for example, if it falls, I can put something out there with WavData. I would like to put it on the table just for myself to explore any possibilities. I don't want to put it in my bedroom as the light is too bright for me. So that's why I decided to put it in my kitchen." (**Olivia**)

Interestingly, Sophia would like to move it from her table to the floor of her living room to light up the feeding area of her cat (Fig.9).

"I want to move the Lamp from my desk to the floor to light up my cat's [water] fountain. Because I'm curious about how my cats will react to it or whether it will catch my cat's attention. . . . My cat is so curious about everything. . . . I plan to put it [WavData Lamp] next to the fountain where she [the cat] eats and drinks every day." (**Sophia**)

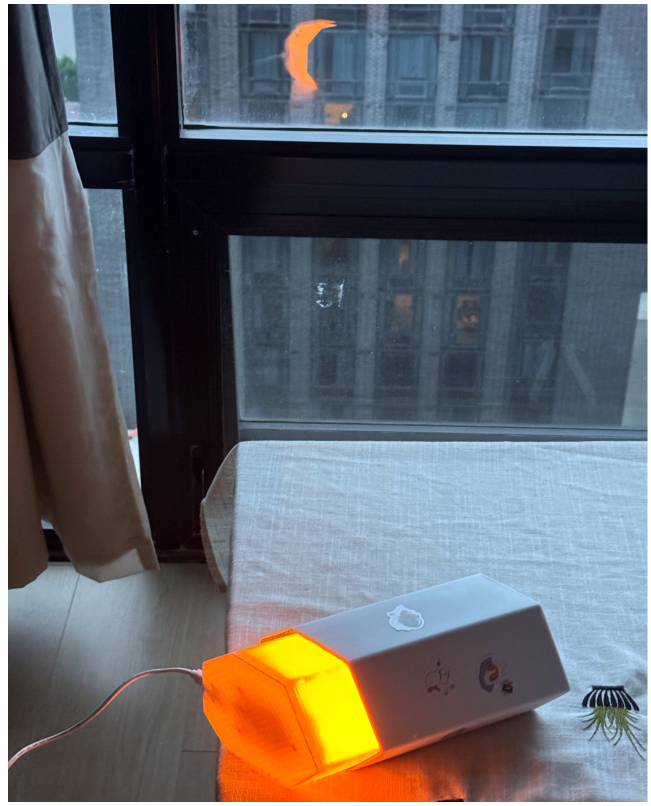

Figure 8: The WavData Lamp fell on the windowsill of Leo's living room while the emitted orange-colored light was projected on the window glass.

These reported experiences indicate that the trade-offs of the WavData Lamp influenced participants' behaviors of moving it for personal experiments. Next, we aim to unfold how the particularities of the WavData Lamp mutually shaped the actions and meanings of participants and their family members who cohabited with it in their homes.

5.2 Explorative actions and interpretive meanings

Living with the WavData Lamp was a mutual-shaping process. During the process, participants and their family members developed diverse actions in entangling the counterfactual nature of the WavData Lamp. The proliferation of their ongoing activities further triggered them to develop diverse meanings.

5.2.1 Activities emerged by exploring possible entanglements with the WavData Lamp. As the WavData Lamp can emit colored light, it reshaped participants' music-listening routines, as we described in the former section. Conversely, participants who cohabited with it in their homes also influenced the manifestations and predictions of the WavData Lamp. For example, Noah described the intertwined

Figure 9: The WavData Lamp automatically fell to attach a cat water foundation in Sophia's living room while it emitted a blue light.

processes of how the emitted light of the WavData Lamp transformed his music-listening behaviors and how his actions changed the manifestation of the WavData Lamp.

"Well, I don't know how much it changed, like the amount of music I've listened to. But it did change. In the beginning, I kept getting the same color. I purposely listen to it around mid-day. But for the next three or four days, there's always the same color. That's boring. I'm trying to remember exactly what it was. I think I listened to it in the morning to ensure it was a different color. . . . I ended up getting the blue one." (**Noah**)

Further, Leo's deliberate actions of changing the light colors not only transformed the manifestation of the WavData Lamp, but also assembled a glass, windowsill, and outdoor environment of his apartment (Fig.8):

"There's one night when we went back home, and it was already dark outside. [Since] my curtain was not closed, I saw the light of WavData projected on my living room window. I thought I could use the window as the projector for the light. . . . The next day, I intentionally listened to more music in the afternoon after moving it closer to the window, so the color changed to orange. After I got back home at night, I saw the projected light look like my personalized moon during those rainy days." (**Leo**)

Despite emitting different light colors, another feature of the WavData Lamp is the tilted form that can occasionally fall by itself according to participants' music listening habits. Such a feature inspired participants to explore possible interactions and entanglements with it. Sophia would like to put the WavData Lamp upside down after she moved it next to her cat's water fountain:

"I put it upside down because I wanted to prevent it from falling. . . . To balance the weight, I grabbed [cat] food to put it on the flat surface [the base of the WavData Lamp]. Over the past few weeks, I think it worked—it never outstretches anymore. I'm happy to see something put on top of it. . . . It's just like a toy." (**Sophia**)

Similarly, Noah also experimented with the WavData Lamp by appropriating surrounding objects in his kitchen inspired by its tilted form (Fig.10):

"I experimented more with WavData this week. . . . I remember one time during dinner, I put my spice shakers on it. Just as it was more of a spice thing. I also had it [WavData] upside down for a little bit and moved it [WavData] to make sure that it [WavData] worked with the spice shaker." (**Noah**)

As the prediction happened at 6 pm each day, the actuation of the form enclosure stimulated Sophia to relocate and entangle with the form enclosure of the WavData Lamp.

"I think it's around 6 o'clock. It raised and fell onto the table surface where I worked that day. I needed to put it back onto the top of my printer at that moment, but I could not let it [WavData Lamp] stand. I think maybe it's raised too high and not easy to keep balanced. I

instead pushed it [outstretched form] back and made it more stable to stand on the printer." (**Sophia**)

Unlike Sophia, Isabella did not expect surrounding things to block the WavData Lamp from falling over. Rather, she preferred to lay it on the ground inspired by an accidental event (Fig.11):

"I placed the WavData on the floor of my living room next to a curtain. And then one night when I was closing the curtain, I accidentally tipped over the WavData. ... While that was an accident, it led me to move it a little further away from the wall by laying [it] on the ground. ... And I'd say I have witnessed the instances where the WavData fell over on its own. Because I think that indicates an interesting change in my mutualism behavior. It's always horizontal on the ground, and it kind of loses the fall feature." (**Isabella**)

Mediated by these experiences, the participants began utilizing everyday things in their homes to experiment with the WavData Lamp. For example, Leo reported his actions of arranging surrounding books to intersect with the WavData Lamp while experimenting with the prediction feature.

"Initially, we put it [WavData Lamp] on the bookshelf of my bedroom. There is a wooden bookshelf on our desk in the bedroom, and we put it [WavData Lamp] on top of it [the bookshelf]. For the first and second days, we put it there, I think it just has the same functionality [falling over on its own] as it did before when we put it in a living room. We started to think if there's any possibility to augment the interaction dimensionality to create some additional effect based on the dynamic nature of the WavData. ... We looked around and found that the book, the notebook, and some printed papers on the bookshelf would be a very nice choice because there was no risk of those books falling onto the desk, which kept it safe." (**Leo**)

Similarly, Isabella also reported how she observed the falling moment of the WavData Lamp, which intersected with the wire of her table lamp in her living room.

"There was one day that I spent mostly outside. When I got home, it was late, and I was surprised to see that WavData had fallen over on my table. My first instinct was to set it back upright, as I thought it looked better standing. It was tangled in my table lamp's wire, so I wanted to move it out of the way. I tried to set it upright, but it kept falling to one side. That's when I decided to rotate the device and prop it against the wall so it wouldn't keep falling over." (**Isabella**)

As the intersection between the WavData lamp and other things in participants' homes was a dynamic and sudden process, Olivia interpreted such a phenomenon as a chain reaction:

"I had put the WavData on the kitchen counter and left the knife sharpener and a bottle of kitchen detergent on the table after having dinner. I didn't pay much attention to their positions and just placed them casually next to the WavData. ... One day after dinner, I came back and found them all toppled over. The WavData had fallen, knocked over the detergent, and then the detergent fell and knocked over the knife sharpener. It was like a chain reaction." (**Olivia**)

Surprisingly, participants' family members were also mediated by the WavData Lamp, cohabiting with it daily. For example, Olivia described how the counterfactual feature of the WavData Lamp also shaped her cats' performances, especially at 6 pm (Fig.12).

"When it [WavData Lamp] fell over, my cats came to interact with the WavData. ... They interacted with the WavData by responding to its sounds and movements. Particularly the sound from the WavData at 6 pm is quite like the automatic [cat] feeder at my home. Whenever the device made a sound, the cats thought it was time to eat. They just headed to the WavData, using their face to rub the device and touch it with their hand to tell us that there was no food there or hint to me that they wanted food." (**Olivia**)

These experiences reveal how a purposefully designed data-physicalized thing, such as the counterfactual feature, shaped the actions of the cohabiting music listeners and their family members, like cats. After becoming familiar with the particularities of the WavData Lamp, some participants developed meanings through ongoing entanglements with a data-physicalized thing.

5.2.2 Meanings developed by living with the WavData Lamp. Meanings emerged after entangling with and living with the WavData Lamp for more than a month. For example, Sophia reported how her experience of interacting with the WavData Lamp was close to communicating with a human being, which was beyond the conventional use of an interactive lamp.

"I would like to use 'accompany' to describe my relationship with WavData because it has its behavior beyond that of a Lamp. Most of the time, I can see how it changed to different colors. It attracted my attention during the day when I was working. I felt it's kind of like a accompany that is more than an object. It is more like something you describe an animal or creature because it has behavior. And I am not sure what its behavior pattern is like when you interact with animals, so you don't know it. Or even if you know it [the behavior pattern], you [need to] imagine what the behavior means and when. So, I use 'accompany' to describe it, like an animal or creature rather than an object." (**Sophia**)

Further, Olivia described her entangled relations with the WavData Lamp as a "friend".

"I feel it's like a friend. Because whenever I change its location to another place, it seems like WavData has his temper. It's not the first time I tried to move it to my bedroom. I found every time I moved the WavData, the light would turn off by itself. He seemed [like he was] unhappy about me if I moved [him]. ... He doesn't like some of the behaviors I did." (**Olivia**)

Interestingly, as the WavData Lamp can predict participants' music listening habits, some participants developed meanings about such a feature. For example, Noah used the term "lottery" to describe his understanding of the prediction feature:

"Even though it's a predictive thing, there's a feeling like a lottery. I have no idea what it's going to be like. I can maybe guess—it's based on my previous actions, but I don't know what [color and form] it's going to be. Now when I hear it going, the sound is just an indication of a non-visual indication that the prediction model is updating now. At that moment, I was excited to watch it and see what prediction will be, and it's a pretty fluttering thing. Once the predictions are [made] there, I go back, sit down and forget about it. But in that exact moment, when I first hear it activating, there's a moment of euphoria, trying to see what's going to." (**Noah**)

These instances suggest that the WavData Lamp not only triggered diverse actions but also engendered rich meanings. At the end of the interview, our participants described their relationships with the WavData Lamp as a sense of collaboration.

Figure 10: Two spice bottles stood on the surface of the WavData Lamp which was laid flat on a tabletop in Noah's kitchen.

5.3 Senses of collaborations

After participating in the study for around two months, all the music listeners reflected on their entangled relations with the WavData Lamp. Some of them recognized shared intentionalities with the WavData Lamp by describing their relationships with it as a form of collaboration. For instance, Olivia reported how she coordinated with the emitted interactive light:

"It feels like I acted as a collaborator. I collaborated with WavData because I wanted to create the desired atmosphere in my home by adjusting its color to match my preference or mood. . . . I also put it in my bedroom before, but the light was too bright, so I decreased the brightness by listening to less music. After that I realized that I could adjust the brightness by collaborating with WavData." (**Olivia**)

For Isabella, she used the term "communication" to describe her collaborations with the WavData Lamp as a form of communication:

"I think I do have inclinations to coordinate with WavData. . . . I feel like WavData and I are implicitly communicating with each other to better understand each other. I think based on my behaviors, WavData is adjusting its prediction behavior, like how much height to adjust, to better suit my music listening routine. I am also reminding myself to listen to music for certain activities to help WavData get a better understanding of my behavioral pattern. In a way, I think we are communicating or collaborating because I am adjusting my behavior for WavData." (**Isabella**)

In terms of Leo, he described how his girlfriend intended to collaborate with the WavData Lamp to perform predictions:

"Over the past few days, I have adjusted the spot of the WavData, which is closer to my girlfriend's bedroom. Every day at 6 o'clock, she asked me to go outside to see the predictions of the WavData because she had [made] her predictions. She would like to ask me about whether her predictions were correct or not. And she mentioned that her predictions were getting more accurate these days by comparing with her first week of predictions." (**Leo**)

Although Noah was not at home often between the third interview and the last interview, he also described his intention of coordinating with the WavData Lamp:

"I remember yesterday, I was out playing Frisbee with a friend. We weren't anywhere near my house. It was around 5:50 pm when I saw the clock. My thought immediately was like 'oh, the prediction is going to change soon'. And it kind of took me out of it [the Frisbee activity] for a second. Even though I was away from my space, it was still something I was thinking about when it would reset. . . . I think my collaboration with WavData is pretty much like predictive prediction." (**Noah**)

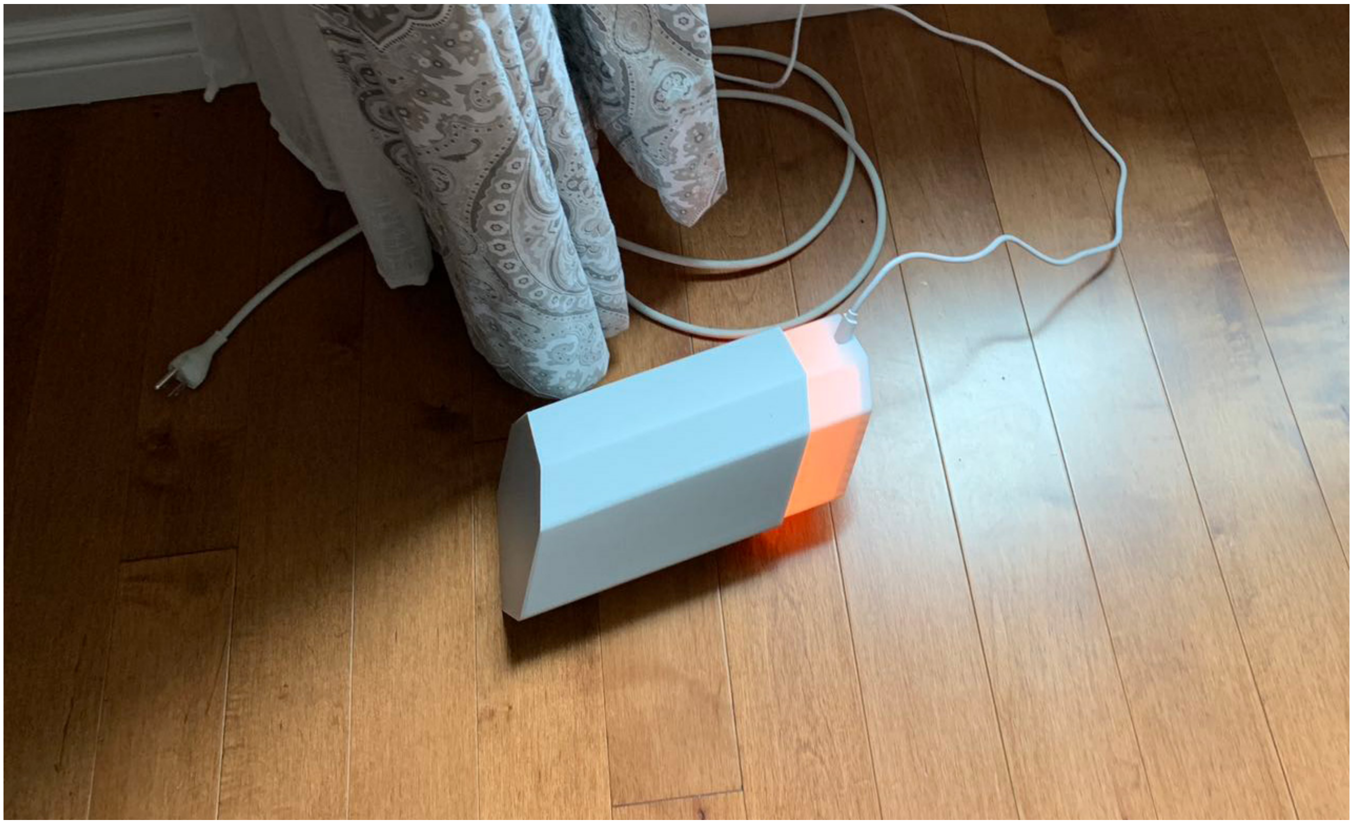

Figure 11: The WavData Lamp accidentally fell to the floor while Isabella moved the curtain in her bedroom.

As a data scientist who has expertise in AI algorithms, Noah also reported that his experience of entangling with the WavData Lamp might be changed with an alternative model:

"I think if you were using a more advanced model with more inputs, my interactions with it might be different. Maybe weekends would be different from weekdays. But then the other thing is that you just wouldn't have much control over it. . . . Because I think the cool thing about this right now is that my actions today will vary, which clearly affects tomorrow, the next day, [and] the [the day after the] next day. Whereas there was a two-year data set, my actions today would be probably indistinguishable from any other day." (**Noah**)

In general, these experiences offer some crucial examples in unfolding how the participants developed collaborations with a data-physicalized thing. They also suggest that the collaborative experiences are diverse due to the different listening habits of participants.

5.4 Summary

The collected rich empirical insights about a data-physicalized thing might contribute to the existing understanding of the composite relation. Building on Ihde's human-technology relations, especially the hermeneutic relation, Verbeek developed the notion of composite relation by conducting a meta-analysis to highlight the double intentionalities between humans and technologies [70]. Informed by this initiative, we find a chance to extend the understanding of such a notion by conducting the implementation of situated analysis: reflectively investigating and discussing the values of the generated empirical data of newly designed technological things [89]. Specifically, we want to enrich the intrinsic meaning of the composite relation as the predictability of the WavData Lamp successfully determined participants' music-listening norms that cannot be interpreted by augmented intentionality or constructive intentionality [70]. Similar to prior field studies of technological things [12, 34, 60, 78, 90], discussing the newly collected empirical data can also contribute to future HCI explorations and practices in this direction.

We also find the performed actions by the cohabited participants and their family members can enrich the understanding of the composite relation. To develop the notion of the composite relation, Verbeek has claimed that Ihde's understanding of human–technology relation "does not create enough space to take into account the existence of nonhuman" [70, p.390]. However, the composite relation does not encapsulate nonhuman beings in discussion while it underscores the intentionalities of both humans and technologies. As the cohabited nonhuman cats in participants' homes expressed intentionalities of entangling with the WavData Lamp, our findings in relation to mutual relations might precisely contribute to the discussions on the notion of intentionality. In the following section, we aim to unpack the detailed implications of our findings to inform

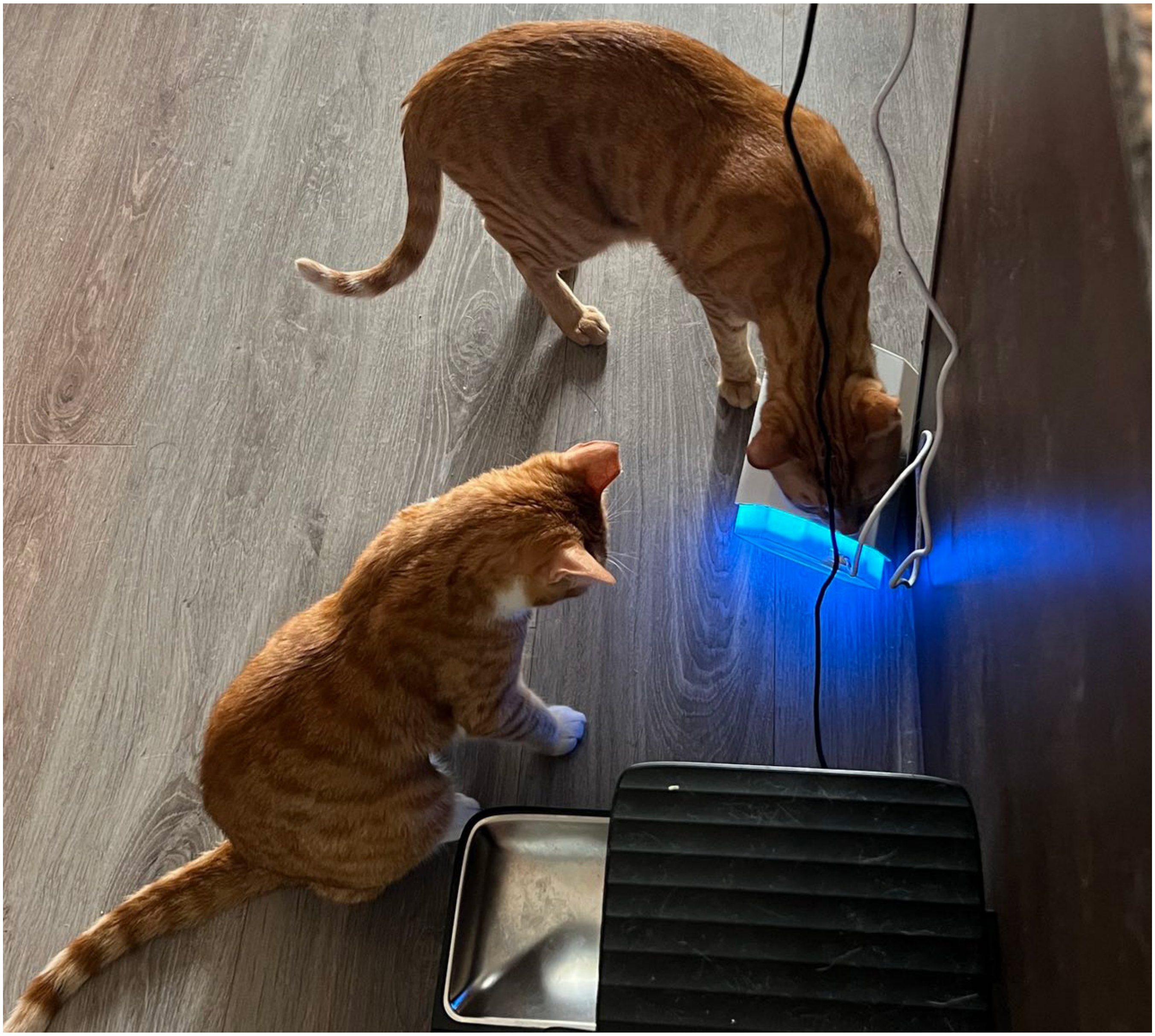

Figure 12: One of Olivia's cats, Baguette, was sniffing and rubbing the WavData Lamp while another cat, Croissant, was watching the WavData Lamp in her apartment.

future HCI investigations on entangled relations with technological things.

6 Discussion and Implications

To investigate the composite relation with a data-physicalized thing, we conducted the field deployment of the WavData Lamp. Our study explicitly responds to recent HCI calls to adopt RtD approaches to explore data-physicalized things in the real-world context of everyday [4]. It also reveals how the purposefully instantiated materiality and designed counterfactuality of a technological thing can engender rich entanglement insights of cohabiting (non)human beings. With the collected empirical findings, there might be a chance to explore the implications of the empirical findings by connecting them to existing concepts related to the composite relation, such as reality and intentionality. As a design-oriented study, we also aim to frame our discussions within existing technological things in the HCI community [14, 17, 91].

6.1 Non-neutrality of a data-physicalized thing

As a particular thing, the instantiated materiality of the WavData Lamp successfully determined participants' music-listening norms. These experiences reveal that the WavData Lamp, as a particular thing, has non-neutral and trade-off qualities. In terms of non-neutrality, all the participants reported how their Spotify music listening habits have subtly changed in responding to the emitted interactive light and outstretched physical form. For instance, **Olivia** mentioned that the WavData Lamp played a reminder role in shaping her music listening norms as well as she played a switch role in entangling with it daily. For the trade-offs, one example is how **Olivia** moved the WavData Lamp to different rooms as she described the "light is too bright for me". The collection of these examples suggests that participants' music-listening behaviors were shaped by the predictive possibilities of a technological thing rather than the represented or constructed realities of technologies [70].

Verbeek has claimed: "Not all technological intentionalities are directed at actually representing [or constructing] a phenomenon in the world" [70, p.393]. Indeed, our findings suggest that the predicted possibilities of a particular thing can also determine participants' conventional norms, like daily music listening habits. Here, *predicted possibilities* describe the intentionality of a data-physicalized thing in processing the proliferated music listening data on Spotify API and encoding the data with the instantiated materiality of the designed computational material form. This extended notion from the reality of the composite relation creates a space where HCI researchers can generate rich empirical insights. They can do this through the design of more diverse technological things by working with alternative materials and resources. Our work suggests that attending to a particular data-physicalized thing successfully engendered rich experiences in relation to prediction. Following this example, future research can investigate how alternative things can engender different norms and influence more diverse choices and actions in their everyday lives [2, 43, 44].

In addition, HCI researchers can explore what methodological approaches can amplify the predictabilities of the designed technological things. Our findings suggested that the purposefully instantiated materiality of a data-physicalized thing successfully destabilized participants' conventional music listening habits. For instance, both **Sophia** and **Olivia** reported the importance of the emitted digital light in shaping their music-listening activities. Similarly, the deployment of the Prayer Companion also highlights the importance of materiality in affecting cloistered nuns' understanding and use of a technological thing [15]. Given this, future work can inquire into how alternative materials, in addition to light sensors, can contribute to instantiating the materiality of technological things, like digital materials [3, 35, 66]. Additionally, as things have *trade-offs* [72, p.104], another opportunity is to purposefully highlight this quality to augment predicted possibilities. From our findings, both **Noah** and **Olivia** reported how the emitted light intensity determined their actions of rearranging the WavData Lamp to different places. With our example, Future HCI research can explore what alternative materials can amplify the trade-offs of designed things. For instance, researchers can investigate the trade-off value of alternative sound sensors by conducting practice-based design research [18].

6.2 Mutual shaping of a data-physicalized thing

We also found that the purposefully designed WavData Lamp has mutually shaped the actions and meanings of the cohabiting participants and their family members. More specifically, most of these actions and meanings were developed by entangling with the tilted counterfactual form of the WavData Lamp. For example, **Sophia** described how she would like to "push it [outstretched form] back and made it more stable to stand" on her printer each day at 6 pm if she was at home. Another instance is **Olivia**'s description of her cats rubbing their faces against the tilted counterfactual form of the WavData Lamp, which was shaped by the predesign materiality. These experiences reveal a phenomenon of assemblage of the cohabiting music listeners, cats, and other things in their homes. Nevertheless, we find the existing notions of human intentionality cannot fully encapsulate these findings, particularly when considering the intentionality of nonhuman beings, such as a cat.

In response to HCI's calls to generate reflective insights with nonhuman beings [23], we would like to introduce the notion of *cat intentionality* to describe the mental states of nonhuman cats directed toward something or affairs, such as perceptions. As nonhuman actors can advance explorations of entangled relations with things, there is an opportunity to enhance the participation of nonhuman family members by closely attending to the particularities of technological things. Our empirical findings suggest that purposefully mimicking the intentionality between relational things can contribute to future explorations in this direction. For instance, the sound produced by WavData Lamp successfully shaped **Olivia**'s cats' behaviors as it was close to the working sound made by an automatic cat feeder. Additionally, we find the proposed strategy in designing technological things explicitly expands upon prior HCI suggestions that emphasize the usefulness of things in raising the participation of nonhuman rats [23]. With our initiative, we expect future research to contribute more diverse and purposeful claims to facilitate HCI explorations and practices on technological things, because developing knowledge in this subtle domain can precisely respond to Wakkary's calls on: "purposeful design by designers of things is a necessity for things to exist" [72, p.119].

Additionally, our findings also unfold how the tilted counterfactual form of the WavData Lamp contributed to mutually shaping the actions and meanings of cohabiting (non)human beings. If the inhibitive interface is a tactic of designing the counterfactually of things [58], we would like to introduce the notion of the *unstable interface* as a complementary to inform the implementation of counterfactual things. This concept is derived by reflecting on how **Sophia** developed the meaning of animal or creature from the fall feature of the WavData Lamp. Specifically, this notion highlights the tilted counterfactual form of the WavData Lamp in mutually shaping the explorative and interpretive behaviors of the involved participants. We see this minor but important concept might contribute to future HCI discussions on the assemblage of things. For our study, we find there is a need to enrich the connotation of this concept because **Olivia**'s cats also belonged to the assemblages of the WavData Lamp in addition to music listeners and other things in her home. That is, the assemblage is the ensemble nature of action and the interconnections among human beings and nonhuman things. Building on our example, we expect future research can contribute more diverse entanglement insights to the HCI community to enrich the understanding of the assemblage of things.

6.3 Shared intentionalities of a data-physicalized thing

In addition to engendering experiences on non-neutrality and mutual shaping, our empirical findings of the WavData Lamp also embody the notion of shared intentionalities. Specifically, we found that involved participants developed diverse senses of collaborating with the intentionality of the WavData Lamp. These collaborative senses were diversified in relation to their personal hobbies, personalities, living conditions, and the purposefully instantiated form of materiality. For example, **Olivia**'s collaborative sense was to create the desired atmosphere with the interactive light of the WavData Lamp. For **Leo**'s girlfriend and **Noah**, their experiences of shared intentionality were aimed at predicting their music listening habits by themselves.

Given the diversity of shared intentionalities, we found that there is a need to explore what qualities of the designed technological things can engender rich empirical insights about the sense of collaboration. Our study suggests that highlighting the *uncertainty* of a technological thing can contribute to future explorations in this direction. This notion refers to the randomness and autonomy of a technological thing that can be directed at specific aspects of reality or prediction by humans. Similarly, the deployment of the Tilting Bowl also reveals participants' sense of collaborating computational bowls and cups in predicting the next tilt [78]. With these examples, HCI researchers can contribute more diverse empirical insights on shared intentionalities to the HCI community. They can do this by building on the framework of designing-with to develop novel repertories in attending to the uncertainty of designed things [72].

Despite exploring alternative ways of sustaining collaborative senses with technological things, future research can contribute more diverse empirical insights about such experiences to the HCI community with existing things. Like our findings, the Morse Things revealed the importance of ambivalence in maintaining not-knowing relations with computational bowls [77]. To this end, there is an opportunity to generate new empirical data about shared intentionality by redeploying the Morse Things. With novel thing-centered methods [20], HCI researchers can generate collaborative senses with everyday computational things. For instance, prior research has successfully unpacked the intentionality of 3D printers in mutually shaping the intentionality of the entangled makers [64]. Additionally, as co-speculators can be trained with expertise in entanglement theories [11, 76, 89], we expect future research can contribute more empirical insights about shared intentionality to the HCI community by employing co-speculators as participants, such as philosophers [76].

7 limitations

It is known that a purposefully designed data-physicalized thing has scaffolded the composite relation with the cohabiting (non)human beings in the context of everyday. The collected empirical data was reported by music listeners who had more than two years of Spotify experience. Although they are hobbyists who listen to music often in their everyday routines, they might not have enough robust data to effectively train the AI model. As a result, the physicalized form in terms of light colors and outstretched form might lack accuracy. Therefore, people might have difficulty in connecting their music-listening behaviors with a data-physicalized material form, especially at the beginning of the field study. In addition, our study might be limited by the diversity of participants' occupational backgrounds. Because they were recruited via posted flyers in our university department context. As musicians have a sense of timing and rhythm [56], employing them as participants might contribute more to the investigation of the composite relation, especially the sense of collaboration. Further, this research is shorted at the variables of the sampling group, such as not fully considering the psychological well-being and effect of affluence. To tackle this problem, future work can include more variables in the sampling group to generate more diverse empirical insights in relation to the composite relation. As snowball sampling can include biased samples [55], HCI researchers can adopt alternative probabilistic methods to enhance the validity of the collective empirical insights. For instance, setting up a control group can contribute to the assessment of participants' explorative actions in entangling with the WavData Lamp [37].

More broadly, we see this study is limited to the deployment duration of the WavData Lamp. As technological things have intentionality in assembling the entangled (non)human beings and everyday things, extending the deployment duration of the WavData Lamp might generate more diverse nuance and detailed empirical data on the composite relation. To tackle this issue, future work can contribute more intimate insights to the HCI community by extending the deployment duration of designed technological things. For instance, deploying the deformTable over 11 months assembled more diverse everyday things with the involved participants [89]. Therefore, we expect future work can generate more longitudinal empirical data leading a deeper understanding of human-thing relations with the shift of entanglement HCI [13].

8 Conclusion

This paper reports on a field study of the WavData Lamp, exploring new empirical insights of entangling with a data-physicalized thing. We recruited five music listeners to live with the WavData Lamp for around two months. The instantiated materiality of the WavData Lamp reshaped their routines of listening to Spotify music during the early days of the field deployment. As they were unfamiliar with the counterfactual feature, they developed diverse actions and meanings of entangling with the WavData Lamp over two months. By the end of the study, they shared diverse reflective insights about their sense of collaboration. These findings contribute to ongoing empirical studies on data physicalization in HCI, enhancing the existing discussion on the composite relation, and offering insightful implications to promote future explorations on technological things. Due to the limitation of this study, we expect future research can contribute more diverse entanglement insights to the HCI community by including more variables in research settings. We hope our endeavor will inspire HCI researchers to develop more vital, transformative, interconnected, and relational things [72].

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A Appendix

A.1 The list of semi-structured interview questions

First interview questions:

- Could you please talk about how many family members you have in your home, including pets?
- Can you describe what types of music you would like to listen to most?
- Do you have favorite singers? If so, can you describe it in detail?
- Did you have any experience interacting with AI-powered products or services?
- Could you please tell us what's your understanding of music listening history data?
- Has the WavData Lamp affected your music-listening experiences over the past weeks? If so, can you describe it in detail?
- Has the WavData Lamp shaped you or your family members' perceptions over the past week? If so, could you please provide some examples?
- Has the WavData Lamp triggered you or your familiar members' actions in your home during the last week? If so, could you please describe it in detail?
- What makes the WavData Lamp different than other things in your home?
- Is there anything you want to add? Do you have any questions for us?

Seconded Interview Questions:

- Where is the WavData Lamp during the past weeks?
- What are you thinking of the interactive light of the WavData Lamp? Were there any interactions happening related to this feature during the last weeks?
- What are you thinking about the sound made by the WavData Lamp? Were there any interactions or experiences related to this feature over the past weeks?
- What are you thinking of the tilted enclosure of the WavData Lamp? Were there any interactions or experiences related to this feature during the past weeks?
- What are you thinking about the irregular heptagon form of the WavData Lamp? Were there any interactions or experiences related to this feature over the past weeks?
- What are you thinking of the prediction character of the WavData Lamp? Were there any interactions or experiences related to this feature during the last weeks?
- How would you describe your relationship with the WavData Lamp over the last week?
- What are your expected interactions or uses of the WavData Lamp in the upcoming weeks?
- Is there anything you want to add? Do you have any questions for us?

Third interview questions:

- Where is the WavData Lamp during the past weeks?
- Moving the WavData Lamp and putting things on it and around could be considered an experiment or inquiry. If so, can you describe these actions?
- Are there any nuanced, intimate, and unexpected moments that happened between you (or your familiar members) and the WavData Lamp over the past weeks? If so, could you please describe it in detail?
- How would you describe or interpret your relationship with the WavData Lamp over the past weeks?
- What do you think of your family member's relationship with WavData Lamp over the past weeks?
- Are there any actions you performed that are related to the WavData Lamp?
- What are your expected interactions or experiences with the WavData Lamp in the upcoming weeks?
- Is there anything you want to add? Do you have any questions for us?

Fourth interview questions:

- Where is the WavData Lamp during the past weeks?
- How do you now explain the WavData Lamp to others or yourself?
- Does the WavData Lamp represent anything to you? If so, what?
- Does the WavData Lamp indicate anything to you about what has happened or is happening in your space?
- Do you see a simple action makes the WavData Lamp hard to understand even though it is only an interactive lamp?
- Do you feel a sense of collaboration with the WavData Lamp over the past weeks? If so, could you please describe it in detail?
- How would you describe your role in collaborating with the WavData Lamp?
- How would you like to describe the role of the WavData Lamp in your collaboration?
- Is there anything you want to add? Do you have any questions for us?