

Narrative Physicalization: Supporting Interactive Engagement with Personal Data

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Physical engagement with data necessarily influences the reflective process. However, the role of interactivity and narration are often overlooked when designing and analyzing personal data physicalisations. We introduce Narrative Physicalisations, everyday objects modified to support nuanced self-reflection through embodied engagement with personal data. Narrative physicalisations borrow from narrative visualizations, storytelling with graphs, and engagement with mundane artefacts from data-objects. Our research uses a participatory approach to research-through-design and includes two interdependent studies. In the first, personalized data physicalisations are developed for three individuals. In the second, we conduct a parallel autobiographical exploration of what constitutes personal data when using a Fitbit. Our work expands the landscape of data physicalisation by introducing narrative physicalisations. It suggests an experience-centric view on data physicalisation where people engage physically with their data in playful ways, making their body an active agent during the reflective process.

Keywords—data physicalisation, personal data, embodiment.

I. INTRODUCTION

Through physicalisation, digitalized personal data can acquire physical properties [16], invite people to “feel their data” [9], self-reflect and arrive at nuanced understandings about their data and themselves. To date, most personal data physicalisations are autobiographical (e.g. [1]). In such examples, a developer collects data, and through an iterative process, synthesizes and constructs their personal physicalisation. Baumer et al. [2] argue that to achieve nuanced reflection, data must be synthesized, not simply encountered. The aforementioned process affords such synthesis for the developer, but not the viewer. In current examples of personal data physicalisation [1,16,19], data is encoded mainly in static representations. Being static limits the opportunity for self-reflection for the viewer, as it does not allow for ongoing synthesis of information.

Our research examines the potential of full body engagements, and narrative construction – storytelling – with personal data physicalisations. We hypothesize these two approaches may afford opportunities for people to synthesize their personal data and thus achieve nuanced self-reflection. To explore this idea, we developed Narrative Physicalisations, modified everyday objects that are interactive and designed to support self-reflection. Our concept builds upon the notion of narrative visualizations [14] and data-objects [19]. Narrative visualizations are traditionally used to support text in journalism. They can facilitate narration of “data stories” and are interactive. In complement, data-objects sit at the intersection of industrial design and data physicalisation. They resemble familiar artefacts, and can thus be contextually situated. They benefit from the familiarity that people have

with everyday objects, yet are modified to incorporate personal data.

In this article, we present two interdependent experimental studies. The first, a participatory study, unfolds the development of three customized, narrative physicalisations of participant data. The second, an autobiographical study [10], was designed to challenge preconceptions around what constitutes personal data. Both studies use Fitbit devices to collect the data. Our studies extend the existing corpus of data physicalisation research by introducing the concept of narrative physicalisations. As we demonstrate, through engagement with narrative physicalisations people’s reflective processes are enhanced. This enhancement arises as the entire body is involved in deciding how personal data is synthesized. As a result, the data itself, depending on the way it is experienced, supports the narration of different stories.

Our research examines:

- *How designers and developers might create physicalisations for dynamic bodily engagement with data?*
- *How such physicalisations might facilitate self-reflection, and what the role of narration and storytelling therein might be?*

II. RELATED WORK

Data physicalisation is experienced through the body and may become a ticket-to-talk in daily encounters facilitating reflection through bodily interaction and speech encounters.

In the phenomenological view, as people become skilled with objects, the tools they use to enact each skill becomes an extension of their body. This phenomenon is what Clark and Chalmers call the extended mind [3]. The long cane used by a blind person provides a much discussed, and readily accessible example [11]. Critically, the feeling that a tool becomes an extension of the body is not consistent. Heidegger [5], for example, argues that while nailing with a hammer, the tool may disappear into the experience. However, if the hammer breaks, it suddenly becomes an object in the world. These phenomena demonstrate the complexity of physical engagement with our surroundings. Indeed, Sheets-Johnstone argues for the primacy of movement in cognition [13] and Gallagher and Zahavi that the body literally shapes the mind [4]. These phenomenological understandings of human engagement with the material world are integral to our research.

In data physicalisation, people experience data in different ways. Barrass’s singing bowl [1] allows him to experience his blood pressure data through sound. This experience may

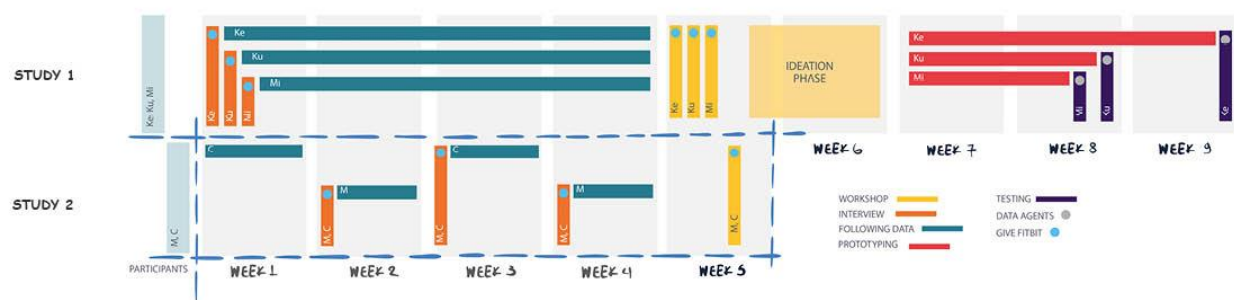


Figure 1. The research timeline showing the overlap in the two studies.

trigger unforeseen reflections. The most common senses activated in data physicalisations are the “felt experience” combined with sight [6]. The DNA ring [12], for example, physically represents a person’s DNA. If the surface of the ring is touched, the wearer can feel distinct data points. The ring thus uses touch to engage with data. The ring is designed to be worn on a daily basis, in real-world settings, where the data may become a trigger for reflective discussion. Similarly, Zhu et al.’s data-objects [19] explore the potential of incorporating personal activity data into everyday objects e.g. a mug with embedded data that can be experienced through touch. In these examples, data physicalisations go beyond their role as reflective object to incorporate dual meaning. The objects suggest reflection through physical properties, and may also be used to facilitate daily tasks. Such objects become an “extension” of the user’s body through familiar use. The data-objects become a ticket-to-talk and can trigger a reflective process. However, the affordances of these objects – that the data is fixed in time – does not allow for deepened experimentation with the data.

In data-driven presentations when objects are taken out of context, they can become facilitators to help people better understand complex data. For instance, Hans Rosling¹ uses everyday objects to explain complex data to various audiences. He enriches this process by including aspects of narration, achieving storytelling *through* the interaction with the objects. In such data-driven presentations the nature of the objects is not altered. Rather, the way the presenter interacts with the objects alters their meaning. Through such data-objects, self-reflection can become part of everyday life, and interactivity and storytelling enhance people’s reflective process. These elements remain underexplored in personal data physicalisations.

III. STUDY DESIGN

Our research examines ways of combining activity data and reminiscence to develop personalized data physicalisations as prompts for self-reflection. We used a participatory approach to research-through-design (pRtD) [18] in two interdependent studies, over 9 weeks (Figure 1).

Study-1 began with semi-structured interviews of three participants with differing interests. A Fitbit device was then given to each of the participants to wear, for five weeks.

Throughout the data-gathering, we followed participants’ data via the Fitbit software interface. We did not make contact with them during this time. Our aim was to identify whether participants’ physiological data would make evident their unique lifestyles. After five weeks, a generative session was held with each participant. These sessions used physicalisations to make sense of participants’ personal data and to speculate on “future data”.

Study-2, conducted in parallel (Week 1–5), was an experimental autobiographical exploration in which the first author (M) and a colleague (C) shared a Fitbit device, exchanging it at weekly intervals. At the moment of exchange M and C collaboratively reflected on the previous week’s data. After three such discussions, they held a generative session to co-construct physicalisations to reflect on their data. This session concluded Study-2 (Timeline: Figure 1).

Drawing on both studies, we developed a single physicalisation for each of the three participants in Study-1. These were modified everyday objects with which the participants were intimately familiar. We hypothesized that the familiarity of the objects and mastery of use would render the proposed interaction intuitive, and allow participants to focus on their data.

Critically, the purpose of Study-2 was to gain first-hand insights into the use of Fitbit, better understand and empathize with participants, experience first-hand physicalisation of personal data, question and challenge the role of ‘the person’ in data generation and data physicalisation, and thus enrich our engagement, as researchers, with our Study-1 participants. As with any autobiographical exploration, this process challenges subjectivity and influence on a project [10]. However, as the research was examining *personalized* interaction with *personal* data, we determined the insights afforded would be invaluable. Indeed, Study-2 enabled us to reflect and iteratively test design ideas—responsive to, yet independent of, Study-1—as the research evolved. This research design aligns with the pRtD approach. It enabled us to deepen our exploration, while gathering physiological data; during generative sessions; and while prototyping physicalisations. It allowed room for reflection during the design process, as we hermeneutically cycled through the emerging findings—

¹ Hans Rosling. 2014. TED: Hans rosling’s ted talks.(2014)

interpreting and reinterpreting our understandings of what personal data is, and how we might design for it.

To make the interdependencies between the two studies clear, we present insights from each research activity at the end of each section. We hope the documentation will allow other researchers to reproduce our process. However, as with all research through design, there is no expectation that others following the same process would produce the same or even a similar final artifact [20].

IV. RECRUITING PARTICIPANTS

Activity trackers serve a variety of industries from commercial to pharmaceutical. That suggests a wide spectrum of users, from patients to fitness enthusiasts and others who are simply curious. We therefore sought participants representing different industries and self-tracking interests.

STUDY-1: We recruited three participants via personal and professional contacts and social media, Ke, Ku and Mi. We searched for people not actively self-tracking but with some experience of wearables; and with different professional backgrounds and interests.

STUDY-2: Involved the first author (M), who had no prior experience with self-tracking; and C, a Fitbit user, recruited through personal connections. C's prior knowledge and experience with wearables enabled us to track how the study engaged previously held opinions about self-tracking.

We use pseudonyms for our participants to enhance the personal tone in our narrative, as our work focuses on the idiosyncratic nature of person-hood. Following, we chronologically unfold our studies, alternating between them where needed. This approach reflects the intertwined and unfolding nature of the research activities.

V. STUDY-1: INTERVIEWS, PERSONAL DATA AND PRIVACY

Week 1, we conducted semi-structured interviews with Ke, Ku and Mi. Our aim was to learn about their habits, interests, important life experiences, motivation to participate in the project, their future goals and views on what constitutes personal data. We also aimed at establishing a context for participant data collection which would then help us make-sense of the gathered information during the project. The three participants were in very different life moments. Ke, a base player, had just graduated from a master's degree and was seeking employment; Ku, a computer programmer, was struggling with demanding university courses; Mi, a retired cancer caregiver, would be in India during the data gathering period, receiving treatment to release tension.

During the interviews, we gained our participants' informed consent for having their Fitbit data collected and observed for a month. Then, each participant was given a Fitbit and shown how it works. From that point, for five weeks, we followed their data without establishing contact. We observed their data graphs online and made our own connections between the data and the information shared during the interviews.

VI. STUDY-2: REFLECTIVE DISCUSSIONS

As noted, (above and in Figure 1), in weeks 1–4, M and C shared a Fitbit. C had experience using the Fitbit as a personal tracker and embraced its transformation into a collective device.

At the beginnings of weeks 2–4 we held shared reflection sessions. During these sessions, we used the online graphs provided by FitBit as reminders of what had happened on any day. The graphs helped M and C narrate their individual experiences as if they were pictures of the place and the time where data was generated. e.g. M (pointing to the graph): *"But do you know what happened [here]? I am going to show you."* Notably, we found that the Fitbit data was sometimes misleading. On a day where M achieved a large number of steps, the device "assumed" based on her performance that she was doing well. Whereas, M reflected that she was in an emotionally difficult space on that day; her steps reflected anxiety and frustration. This information nicely illustrates how context was vital in making sense of the data.

Numerical data offers new perspectives, which can motivate a person to change their behavior [9]. We found that the additional factor of connecting another person with the data helped motivate C to achieve or change their goals. C: *"When I had to do 600 steps I just started playing with my cat and ran just to give [M] 10.000 steps. When [the device] vibrated I went to bed"*. This example demonstrates how motivation can shift from achieving 10,000 steps for personal reasons into achieving them for the other person. What motivated C the most to do the remaining 600 steps was that M would observe the graphs the following day. Having to discuss whether or not she had achieved her personal goals proved to be a more powerful motivator for C, than setting her own goals and accounting only to herself. The human factor thus shaped the device's impact and on occasion enabled C to strengthen their motivation through the device. This is further evidenced in M and C's online chat: C: *"Since you are tracking me, if I have [the device] only for one week it is funny because it is both annoying and interesting. I have been checking it more often because I want to know if I have these 10,000 [steps] or not so you can see that I have made it."* And: *"Sometimes I really considered to take a walk."* The synergy between the human factors and the device helped C reflect on her data, as well as her relationship with the device itself. This reflection was afforded through her engagements with another person (M). C's behavior spoke to an idea of personal data that goes 'beyond the personal'.

Several times, C and M identified which graphs belonged to each other without looking at the dates. C's data graphs had a similar visual flow every day and were identified with ease. In contrast, M's graphs had a variety of patterns that made it difficult to identify what happened, and during which day. As C explains to M: *"[your graphs] look like fifteen different people."* That indicated that there is a distinct 'personality' to the data, even if we need the context to make sense of them and even if they are interpersonally generated.

A. Insights from the reflective discussions

The reflective discussions above, demonstrate that the graph formats can constitute tickets-to-talk about the lived experiences behind the data. Further, the graphs can be used

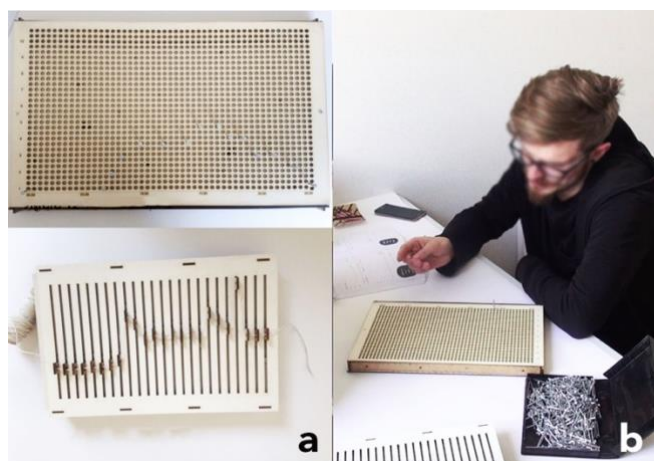


Figure 2. Generative session, task 3: (a) presenting the two probes that assist people to physicalize their data; (b) Ku interacting with one of the two probes.

to support people's memory. Through reflective discussions we learn about C's data, as well her personal life. These findings indicate that graphs can support narration, essential for understanding the data. We explore this possibility in Study-1: Our Study-1 participants' lifestyles were very different from each other. These differences were evident in their graphs. After two weeks of observations it was possible to identify which graphs belonged to which participant by sight alone. At times, we saw nuances in the patterns, but they were still recognizable. We determined that these nuances, in combination with the graphs, constituted tickets-to-talk, and used them to design a customized generative session with each participant. The aim was to learn more about their activities during the data gathering period.

VII. GENERATIVE SESSIONS

In week 5, we conducted individual generative sessions with our Study-1 participants to scaffold qualitative information about their lived experiences during the data gathering period. Following, we held a generative session in Study-2, to understand how to leverage the insights from such sessions when developing data physicalisations. We begin with Study-1.



Figure 3. Three participants during the generative sessions.

A. STUDY-1: Generative Sessions with Ke, Ku and Mi

Each generative session was divided in three parts: i) we conducted interviews seeking to understand the participant's personal experience with the Fitbit, and their opinions about being part of the project; ii) their graphs were collated and used to support the participants to recall experiences, which were discussed in detail; iii) participants were introduced to two interactive props for physicalizing data (Figure 2a). They were invited to choose one and, based on memory, physicalize an average daily graph of the past month, then speculate on a personal future graph and try to physicalize that. We present our findings:

In the first task, we asked participants about their experience of using the Fitbit device. Ke and Mi explained that their behavior was influenced by the device. In contrast, Ku reported that the device did not motivate him to be more active. Ke referred to a moment where he had completed "9000 something steps" and to achieve his daily target of 10000, started walking around his room. Ku said he only looked at his daily data following a stressful experience, as at these moments he was curious about his performance. Ku: "It was after the fact! I was checking the result from the day before" ... "For different instances I would check different things. If it was a stressful day, I would check the pulse."

Noticeably, while Ku said he was not influenced by the device, he also said that his goal was to provide us with "real" data. Ku: "I wanted you to get the actual data of how I live but it was also a conscious decision not to change it." Notably, during the data gathering period Ku reduced his alcohol consumption so that we would get 'the actual data'. Discussing a big night out, he explained: "I feel guilty because of this all night out." From his discussions, we could see that he was influenced and motivated by the data in a similar way to C. The need to share his lifestyle with us, influenced his actions.

In terms of motivation, Mi explains: "It did make me walk more but not as much as if I had been at home." What was obvious in our interview with Mi was that the data she produced in India did not correspond to how her data would have been if she was in Denmark. This topic was brought up repeatedly throughout the generative session.

During the second task, our participants selected one or two days and annotated their graphs with what they could recall and discussed their lived experiences. In Mi's case, the main topic was the different lifestyle she was introduced to while being in India compared to when she is in Denmark. Mi: "What I found interesting was the heart rate going down while I was in India." Mi's resting heartbeat graph illustrated that her heart rate average was lower while abroad. This outcome, justified to her the effectiveness of her treatment in India. Mi: "This is not the real me" she said, suggesting that the data we were following was not a realistic data picture of herself, as it corresponded to her wellness retreat in India, where she was advised to reduce her walking for her treatment.

The most significant event for Ke during the data gathering period was receiving two employment offers on one day. He could recall and describe this day in great detail. His narration included receiving the job offers, sharing this information

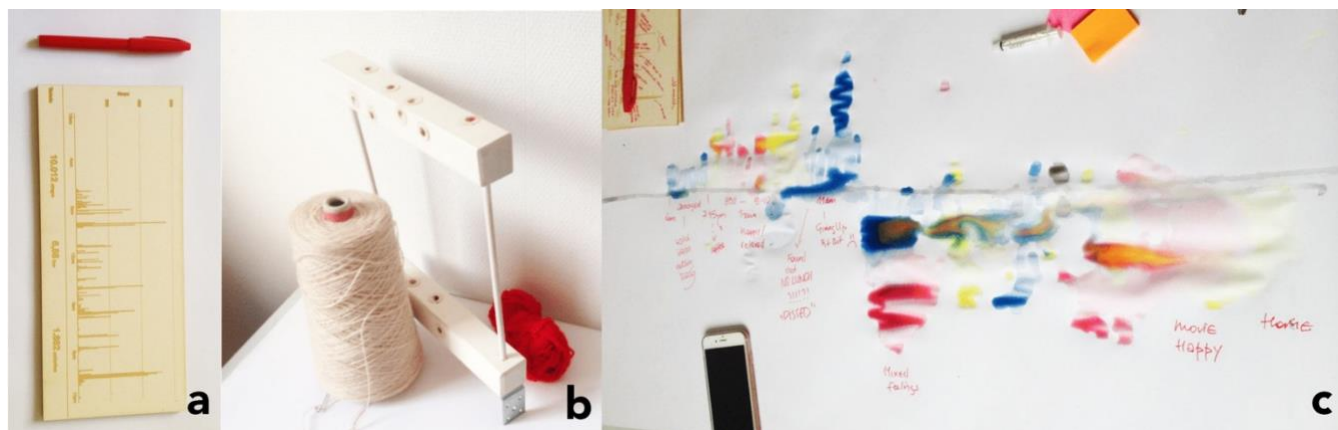


Figure 4. l-r: a) laser cut activity graphs b) two-rod physicalisation c) physicalisation co-constructed by M and C using liquid colors.

with his family and celebrating with friends. During the celebration he consumed a lot of alcohol which resulted in a high heart rate. Fitbit perceived this as exercise and congratulated Ke with a virtual reward. Only when Ke contextualized the data collection – alcohol consumption – were we able to make-sense of his personal data.

The significant moment for Ku was a live performance with his band. Before and after the concert his heart rate was very high. He marked on the graphs when his heart rate was high due to stress and when due to excitement. This again surfaced a contradiction between the data graphs and the lived experiences. Both heartbeat rates before and after the concert were high. However, one peak corresponded to a stressful moment, the other, with excitement or pleasure.

In the third part of the generative session (Figure 3), the graphs that Ke and Mi physicalized were very similar to the visualizations of Fitbit. In contrast, Ku (Figure 2b) focused on narrating a story rather than creating a physicalisation that would resonate with his graphs. The physicalisation he developed helped him to share his story which again brings the focus on aspects of narration and storytelling when interacting with the graphs.

The most important finding of these generative sessions was the ways that the experiences of participants linked to their personal data. The interviews supported our premise that data may partly reveal insights but is not able to demonstrate the complexity and richness of an experience.

B. STUDY 2: Generative session M and C

The generative session with M and C served to explore opportunities that data physicalisation may offer the development of physicalisations for Study-1. The session was divided into three parts. The first investigated the potential of undated data cards (graphs) as reminders of specific events. The second and third examined ways of co-creating physicalisations based on those graphs.

In part 1, C was presented with three different graphs. These graphs corresponded to the days of the month that the shared Fitbit was handed over, and thus combined the data from both C and M. The graphs were not dated; C was asked to guess which days of the month were depicted on the cards. We aimed to discover: i) if C was able to identify her personal data; and ii) if she was able to recall a particular day simply by looking at a graph. Notably, she characterized the data that

did not belong to her as faulty as she could not relate her lifestyle to it.

Part 2 involved M and C working together to physicalize the graphs discussed in part 1. The aim was to better understand the role of materials when physicalizing a graph. The first physicalisation was constructed from two pieces of wood, each with 12 holes, and two roles of white and red thread: one color for each person's data-set (Figure 4b). The artefact was painted white to represent a blank canvas. To begin this exercise, C was asked to associate values to each component of the physicalisation. She associated the top rod to steps, explaining that the holes represented different amounts of steps; and the bottom rod to time, and the shafts to hours of the day. The white thread represented C's data, The red, M's. The sole purpose of the different color threads was to distinguish between the two datasets. The resulting physicalisation shows one side in red and the other in white; one side represents data from the morning, the other from the evening (See Figure 5).

In part 3, C was asked to associate values to four differently colored water glasses. Syringes were provided to use as a pen, to 'draw' in color on a large paper sheet. The paper was intentionally chosen such that the colored water would bleed, and be somewhat uncontrollable. C associated blue with bad feelings, red with good; black with time; and yellow with activity (See Figure 4c).

At the end of the session, M and C analyzed the two physicalisations. C proclaimed the first too abstract, as she was not able to understand or read the graphs. To engage reflectively with such an abstract physicalisation, a person must learn to read it. The lack of specificity in the data and the absence of what C felt were relatable material choices seemed to eliminate any sense of the personal. C described the resulting physicalisation as 'distant'. For the second physicalisation, C explained that the way the color spread provoked reflections about the nature of emotions and their indeterminate form (Figure 4c). C: "The fact that it flows on its own direction gives you the feeling that ok I can drop some in many places so it makes it more real." In this case, that the physicalisation was abstract, less 'precise,' open for interpretation, is what made it more 'real' for C. It allowed for complexity and multiple interpretations of data. It was

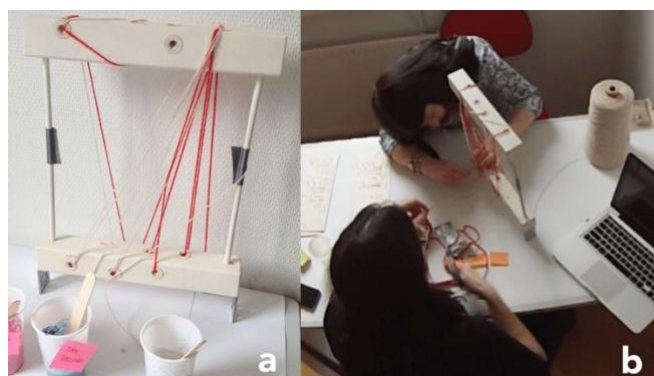


Figure 5. The completed two-rod probe (study 2).

deemed to come closer to ‘reality’ than a ‘fixed’, precise and final-seeming form.

Because of these attributes, the second physicalisation became a tool for reflection. It presented alternative image of the participant’s self and prompted her to explore. New relations between emotions and data, reality and extraction of reality, were demonstrated here. This activity showed us that it was possible to physicalize personal data in ways that would add some of the richness of lived experiences. Critically, the level of abstraction in the first physicalisation seemed to depart too far from C’s experience. Whereas the abstraction in the second—created by C, herself—supported the reflective process.

Overall, the autobiographical exploration showed how a) visualizations of personal data can support remembering, and b) for reflective physicalisations the format should support subjective expression.

The choice of the forms and materials used in the generative session were not as rich as previous studies where a variety of materials are provided for people to engage in open ended ways in prototyping [7,16]. However, similar to [7], our design constraints afforded more “*focused engagement with physicalization construction.*” We anticipated that a wider range of materials would make the construction process more laborious. The two physicalisations included abstract materials with diverse properties. The aim was to cover different form and material behaviors, and afford nuanced ideas and reflections. For example, the physicalisation with two rods is a closed shape which allows for limited extrapolation, while in the second physicalisation, the colored water bleeds in ways that are unpredictable affording nuanced reflections and insights.

VIII. STUDY 2: NARRATIVE PHYSICALISATIONS

To develop personalized physicalisations for Study-1, we scheduled a two-week ideation phase. We reflected on the themes that arose in the two studies and considered how to highlight those themes. The strongest theme was that **data is always situated within a particular type of experience**. Two other criteria came out of the ideation phase: the physicalisations i) **should support data expression through ambiguous formats**, ii) **should lay the ground from which to recall lived experiences**.

Based on these criteria, a personalized physicalisation was developed for each participant. The participants’ character

traits also served as inspiration. We developed a foosball table for Ke, a one string instrument for Ku and a treadmill for Mi. Each of these included the data graphs in a unique way (Figure 5). We invited our participants to interact with these modified, interactive data objects. During the interaction we asked open questions such as: “*How did you feel interacting with the object? Can you demonstrate how did you feel that day?*” (the day that the data was captured). This approach aligns with Sanders and Stappers [15] work on generative sessions. Following present the physicalisation and testing.

A. The Foosball Table

Ke is a problem solver and a competitive person, who loves foosball. We converged these traits to make him a personal data Fussball Table (Figure 6). Our aim was to provoke him to ‘compete’ against his own data. The physicalisation had the format of an ordinary foosball table with small modifications. The handles of one opposite side were removed, so it could only be played by one player. The remaining four handles were made of wood and had a different number of foosmen on each, so their weight varied. Handling the rods thus required a specific learning of force and speed. A ping pong ball was used to increase the level of difficulty and two fans were placed closed to the net with the aim of blocking the participant from scoring a goal – the fans blow the ball away from the target and so make scoring more challenging.

The end of the table was left open to allow a data-sheet to rotate freely on the table’s surface, like a conveyor belt (Figure 6). The data-sheet showed the heartbeat of three graphs: one from the day that Ke received two employment offers, one from the day before, and one from the day after. These graphs were chosen to evidence his behavior change on the day he received the employment offers. The rules of the game were: a) keep the ball within the borders of the paper, b) do not let the ball fall out of the foosball table, c)

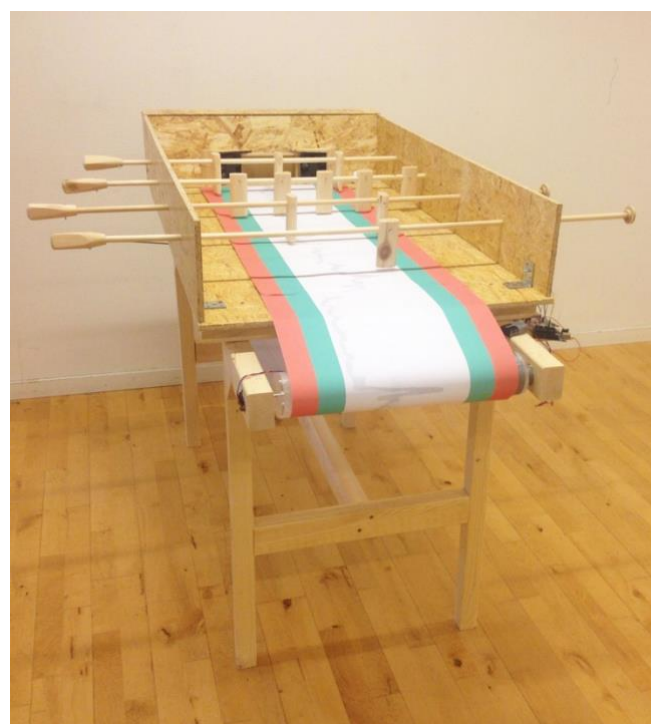


Figure 6. The Foosball table.

score by the end of each day (meaning the period of time that a graph would need to start appearing from the net side until the moment that it would disappear completely from the surface of the table).

At first, Ke identified the differences and similarities of the physicalisation with a traditional foosball table, saying that the game was different but the elements were the same. The process of learning how to use it and then score took a while, as the physicalisation had different affordances than a regular foosball table. Ke first interacted with the artefact without activating the rotation of the paper. Once the rotation was activated, Ke was asked to follow the rules.

We observed that the graph did not seem to interfere with the experience. Ke later demonstrated how he would play one of the visualized days. The graphs did not assist him to remember or tell his story; rather, his narration depended completely on his memories. Though Ke did not use the graphs in the physicalisation, the rotating paper added a level of difficulty to the experience. “It is annoying that the paper is moving because I can’t rest.” His experience demonstrates the asymmetrical relationship between the embodied familiarity Ke has with a regular foosball table compared to his interaction with the physicalisation. The only moment the graph played a prominent role was when Ke attempted to follow the line of the visualization. This action took the experience far from the initial concept. At this moment, Ke’s vocabulary was influenced by his actions. Even his speech was shaped by and adjusted to what he was doing. “*It was kind of all over the table*” he said, referring to his mood, instead of saying all over the place.

While interacting with the foosball, Ke’s sense of the data passed into the background. The physicalisation failed to trigger competition. Nonetheless, it led to a rich discussion with Ke. We suggested making the visualizations more prominent in the interaction and asked him to speculate how he might interact with that physicalisation. Ke responded: “*The same agent is doing all these but has different wishes*” meaning that the person who generates the data also wants the data to be easy to play to then win the game. The same person could also change his lifestyle to win but with the cost of making life compromises with a risk of a positive or negative outcome. Reflecting on the use of the physicalisation Ke said: “*I am creating the difficulty while living my life*”.

The physicalisation is not trying to digest the ‘data’ for Ke. Rather it seeks to provoke reflection and critique by showing how our engagement with data is not ‘neutral’. Data may reflect an experience (or aspects of it) and may spark stories and reflections upon that experience. Ke’s last remark indicates that physical interaction with data has the potential to change not only the experience of the data, but the person engaging with it.

B. The One String Instrument

Our second participant, Ku, has contradictory traits in his personality – he is at once an introvert and a very social individual. Ku was initially against the use of the tracking device. We therefore aimed to develop a physicalisation that would be pleasing for him to interact with. Fortunately,

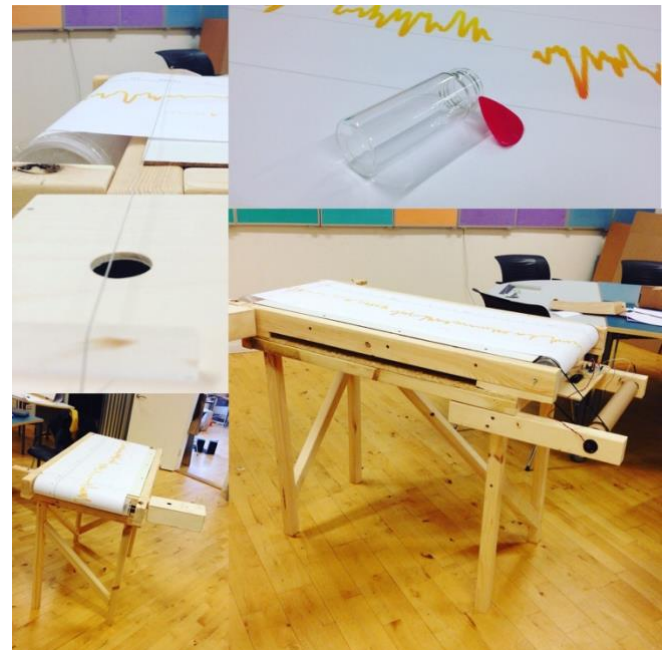


Figure 7. The one-string instrument.

finding what he was passionate about was easy as he is a musician, a base player.

After working through several design ideas, we created a one-string instrument (Figure 7). This design decision made our design less complex than a multi-stringed instrument, yet still engaging. The physicalisation consisted of one guitar string, slightly elevated from the rest of its components. A data-sheet of heartbeat visualizations slid under the string. The heartbeat visualization was of four days during which Ku was rehearsing and then performing in a concert. We positioned the string against his heartbeat visualizations to create a sonic asymmetry that made it difficult to generate a pleasing sound. A plectrum and a glass container with a cylindrical form were included to compliment the physicalisation. Ku was asked to pluck the string with his right hand and follow the line of the heartbeat data with the glass container while the data-sheet slid under the string. He thus could generate the soundtrack from each of his days.

Ke’s physicalisation is not dissimilar to a slide guitar and was perceived as such. Ku has experience playing slide guitar. This experience reinforced his excitement about interacting with the physicalisation. His previous (embodied) knowledge of playing string instruments helped him interpret the graphs quickly. The way that the string was plucked in parallel to the narration of his experiences seemed effortless.

Without being asked, Ku started following the line of the graphs with the glass container, while plucking the string. Unlike the foosball physicalisation, the data-sheet in this case rotated from the beginning of the experiment. Ku: “*The first thing I want to do is to follow the line.*” He described the sound experience as almost disturbing or “messy.” After a while, he developed an understanding of the sounds related to high or low peaks. He explained, because he is a bass player, he enjoys lower sounds. He was enthusiastic about the lower peaks relating to him being calm.

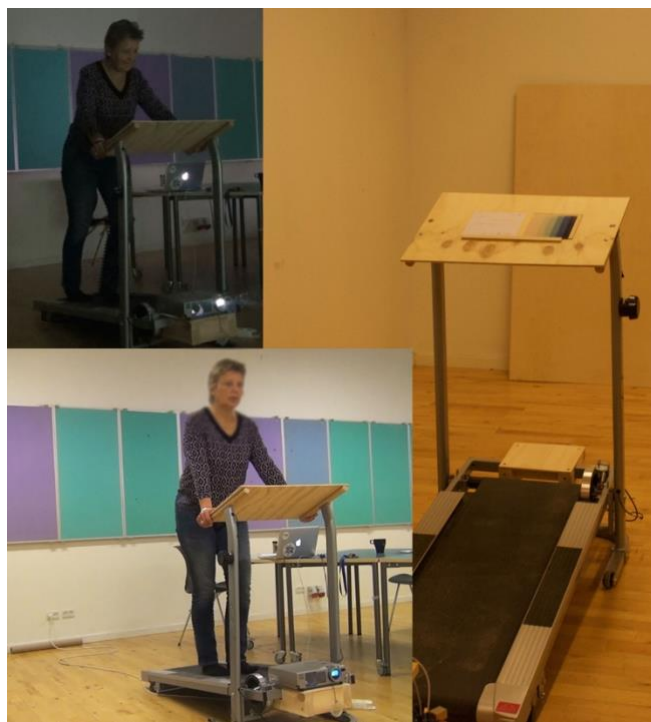


Figure 8. The treadmill.

As with Ke and the foosball physicalisation, Ku was asked to imagine and freely play the sounds of the days that were on the data-sheet, based on his lived experiences. In particular, we asked: *“Can you play how those days felt?”* Here, a shift occurred in his interaction with the artefact. Plucking the string and giving a high or low tempo according to each day became more important to him than controlling the sounds with the glass container. At a certain point, he perceived the four graphs as a singular sonic experience. He connected the high tempo to the excitement or the stress of the days in question.

Similar to Ke’s experience with the foosball table, Ku’s vocabulary was influenced by his interaction with the physicalisation. He used the high tempo to describe the intense days or, as he described them: days with pleasant or unpleasant stress. Similar to C, his interaction with his personalized physicalisation prompted him to share more about the days of the graphs. This contrasted with his reluctance to share during the generative session.

Ke’s physicalisation was deemed to have a ‘personality’ that provided context for making sense of the personal data. Similar to Ku’s experience with his personalized data Foosball Table, Ku’s sense-making was described in relation to the interaction with the data, rather than with the data itself.

C. The Treadmill

While in India on her stress-relief retreat, Mi, our third participant was instructed to reduce walking—one of her favorite activities. This compromise transformed her data image. It presented a strong contradiction between her impression of her data in Denmark versus in India, and inspired her personalized physicalisation. During ideation, we focused on Mi’s step visualizations. When walking one proceeds by advancing the feet alternatively so there is always one foot on the ground. Steps unfold in a corrugated

way. When juxtaposed to graphs of steps, the way the action unfolds in the body does not seem to match the graphs. The differences between the visual output of a graph and the way the action of walking looks, were significant elements of our ideation process. This difference led us to wonder how one might walk if one needed to follow the image of a graph.

To make the physicalisation, we modified a treadmill (Figure 8) to fit the design idea. The top part was transformed into a speech roster, including a stand on which the graphs could lie. Six non-consecutive graphs were chosen for this activity. Two, from the days with the lowest and highest values of steps. The others were discussed during the generative session. All six were placed on the platform in a specific order, building from the day that Mi walked the least steps to the day with the most steps. A square acrylic sheet with the same dimensions as the graphs was placed next to them. The sheet showed a color scale of eight colors from dark blue to light pink. It was to be placed on the graphs and divide them into the eight differed colors. At the bottom of the treadmill was a wooden square, hiding a projector. The projector was connected to the treadmill. As Mi walks on the treadmill she generates a projection of the color scale on a large wooden canvas on the opposite was. The colors change from dark blue to light pink, according to Mi’s walking speed. As she walks, Mi recalls and narrates her experiences.

The physicalisation was controlled by Mi, without support of an external power supply. The treadmill thus required extra effort. Similar, to the other physicalisations, to interact required learning how to use the device. While walking on the treadmill, Mi said: *“I had to use more force than what I was expecting.”* Her speed correlated with her ability to identify the colors. On her second attempt, Mi tried to go through the entire color scale; every time a color appeared, she walked more slowly. Ultimately, she was able to identify the changes between the colors, leading her to reflect: *“I was thinking that I often walk quite fast, and I like it, but I also really like the slow. It is like you see more the changes.”* This reflection was facilitated by the affordances of the prototype.

After Mi learned how to use the treadmill, she focused on looking at the graphs. She interpreted a large number of steps as high speed and a small number of steps as low speed. She explained: *“When I look at this, is life in slow”* meaning that her experience in India shifted her actions from very active to a slower pace. From then on, when describing experiences during the testing she refers to them as slow or fast, influenced by the interaction with the physicalisation. Then her discussion transitioned to other life experiences. Her reflections triggered questions such as, *“How would you walk your first wedding”* or *“How would you walk the birth of your first child.”* Walking was related to feelings. Her speed reflected the overall feeling she had of an experience. Occasionally when the feeling of the experience in the past did not match the feeling of the experience in the present, it was difficult for her to adjust her speed to the experience. The conflict in her mind was evident in her bodily movements.

IX. DISCUSSION

All three physicalisations in Study-1 provided the participants with a double opportunity. First to interact with their personal data and relate to it through embodied learning

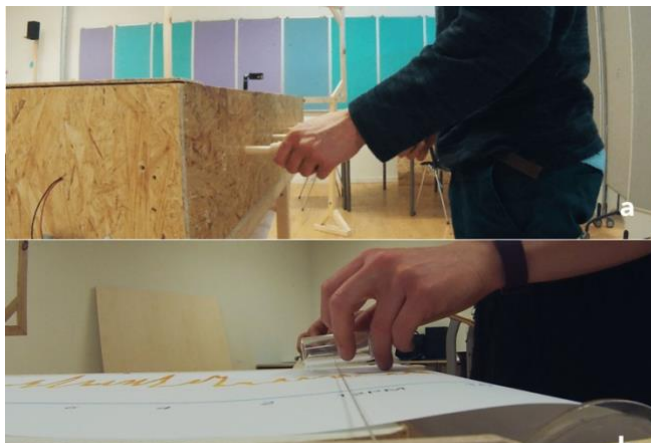


Figure 9. Ke and Ku interacting with the physicalisations.

(Figure 9). Second, through this learning, and by associating new identities to their data, they were able to explore, understand, share and reflect on their experiences, and personal data more broadly. The overall interaction may be divided in two parts:

A. Read and Act

The first type of interaction we observed was being guided by the graphs but ignoring which day they represented. This interaction positions the visualizations as the main actors of the activity. The person interacts with their data yet does not connect the data to an experience. Despite the gap between data and experience, the interactions trigger reflections about personal data on a different level. For instance, for Ku, the lower sounds resonated with him being calm, this evoked good feelings about the data. This experience was not connected to any real-life experience captured by the data. The associated interaction triggered a kind of private knowledge. For both Ku and Mi, we observed the data determine and lead the interaction as it became the element of attention.

B. Interpret and Act

In this second phase of the interaction, each person had completed reading their graphs and was trying to recall their experiences based on the days depicted. Critically, the physicalisations are customized artefacts that our participants were intimately familiar with. The interactions, thus, benefit from participants' embodied knowledge. While interacting with their physicalisations, the participants associate feelings with their personal data. The graph seemed to provide an "impression of data," to play the role of a reminder. At times, the personal data became transparent. For example, when the participant focused on the interpretation of the experience rather than on the data itself. The physicalisation thus became a mediator through which the participants expressed their feelings both bodily and through speech.

When the interpret and act interaction takes place, the physicalisations become artefacts again in the world. They become ready-to-hand tools that the participants know how to use. The use of physicalisations in this way, leads to reflections about people's lived experiences. If we consider that the participant's body at once knows how to use an artefact and is learning its use. The physicalisations thus have a dual nature. They become the medium for interaction as

both master and student. The first nature is associated with kinesthetic learning, the second focuses on emotions related to lived experiences. Verbeek [17] argues that the mediating role of technologies suggests two ways that artefacts can influence humans being: as mediators of perception or mediators of action. Artefacts become mediators of perception when they mediate human experience and interpretation of reality. e.g. technologies such as the ultrasound shape the way we perceive and interpret a fetus before it comes to the world. Mediation of action is related to how artefacts incorporate meanings that provoke human actions, e.g. a traffic sign signifies that drivers should slow down, mediating this action through its material existence.

Similarly, data visualizations are mediators that do not require an embodied relationship to provoke action. Instead, they suggest action. Whereas, in personalized data physicalisations, the graphs become ready-to-hand. They transform into mediators of perception as participants, while interacting with them, mentally build an interpretation of an experience.

X. ON THE DEFINITION OF DATA PHYSICALISATION

Jansen et. al. propose that, "*A data physicalization ... is a physical artifact whose geometry or material properties encode data.*"

Our physicalisations do not explicitly follow this definition, as they incorporate people's visualizations. The graphs were included as necessary elements for people to recall the experiences and reflect, highlighting the important of context and experience to spark reflection. Our work extends understandings of personal data physicalisation by introducing interactivity; by illustrating the person-data relation as dynamic, complex, ambiguous and unsettled - reflected even when data remains 'graphical'; and by affording interaction with data, rather than simply physicalisation of data.

Critically, in our personalized data physicalisations, the graphs acted as triggers for interaction with the artefacts; by extension with the data; and thereby narrative offerings from the participants. Hogan et al. [6] argue that in dynamic physicalisations the data is "*encoded in the shape as well as the behavior of the representation.*" We extend that by arguing that through bodily interactions with narrative (*interactive*) physicalisations, the understanding of *personal data* is extended. This extension allows the person to view their personal human-data relationship as a whole rather than as two separate elements. The data is encoded in the interaction with the body and is extended by it.

XI. CONCLUSION

We presented a two-part study that resulted in three personalized data physicalisations, what we call Narrative Physicalisations. Our research demonstrates the potential in narrative physicalisations to enable people to develop meaningful narratives around data and personal experience. Building on research into data objects, our findings demonstrate that narrative physicalisations effectively leverage the affordances of objects and the fact that people know how to use objects. Following this work, designers and developers of data physicalisations can use familiar objects

to leverage participants' embodied knowledge, and prompt them to reveal insights that may not otherwise come to mind.

Our focus has been on people's ability to engage with their personalized objects and, through that engagement, recall personal stories and reflect upon person-data relationships. For future research, we anticipate exploring other sense modalities for personalized, kinesthetic, tasty, smelly, stimulating narrative physicalisations based on personally meaningful data.

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