PhysLens: Enrich Data Physicalization through a Lens of Details

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Abstract

Data physicalization unlocks the opportunity for us to more closely engage with data, to learn about ourselves and our environments. However, data physicalization artifacts are often abstract without details, leading to an assumption-based interpretation. In this work, we propose an interaction approach called "Integrated Data Physicalization" – highlighting the hybrid integration with an additional digital interface as PhysLens next to a data physicalization artifact. PhysLens guides users in exploring data mapping details in data physicalization. Together with an exemplar data physicalization artifact that encodes indoor environmental data, PhysLens was evaluated in a semi-lab setting (N=16). The hybrid approach of interacting with the data physicalization helped and played an essential role for individuals to understand data physicalization through detailed information. The potential of integrating PhysLens longitudinally was demonstrated with its possible expandability in personalizing physicalization, providing data scales, integrating IoT control, and resurfacing different temporal moments of the data.

CCS Concepts

• **Human-centered computing → Interaction design**; **Visualization**.

Keywords

Data Physicalization, Hybrid Interfaces

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1 Introduction

Sensors, data trackers, and the Internet of Things (IoT) have become increasingly common in our everyday lives [17, 37]. A growing amount of data is being collected and analyzed to improve the efficiency and productivity of daily activities [8]. Data is often presented in spreadsheets, graphs, and charts as visualizations [26, 33]. Data visualizations enable people to gather new insights into topics such as personal activity levels [4, 7] and climate change [10]. These data representations are often made available to users with smartphones and tablets [17, 29]. They allow users to identify trends and patterns [33, 34], interact with and receive dynamic updates of the data [21]. However, people often struggle to interpret numerical data and graphs [3, 11, 35]. Data needs to be represented through understandable and accessible means [3, 17, 27], leveraging our perceptual exploration skills and engagements with the data [19].

Data physicalization provides a promising opportunity for non-experts to learn about data comprehensively, accessibly, and intuitively [1, 17, 19, 32]. Data physicalization is defined as "*an emerging research area that uses physical data representations to help people explore and communicate data*" [19]. It bridges abstract data and visualizations into embodied tangible forms, supporting human-data interactions [25, 38] by putting "human-in-the-loop" [38]. Data physicalization tends to be device-centric [19], with a growing number of artifacts developed and studied in context (e.g., [5, 20, 29]). However, recent literature reviews [1, 9, 16, 32] have demonstrated the diversity and richness of the vocabularies or constructs in describing data physicalization. At the same time, empirical studies showed that data representations and provided interaction patterns do not necessarily follow users' assumptions [18, 31]. However, relying solely on the physical artifact in data physicalization often leads to assumption-based interpretation, as users lack sufficient details to fully understand the data mapping [5, 29]. Prior work has suggested the potential of augmenting physicalizations with additional interfaces that enable users to selectively zoom into details, thereby deepening their understanding without overwhelming the core physical representation [5, 32]. This motivated our development of a 'lens of details' approach, offering layered, on-demand exploration of the data."

To balance the level of details and provide transparency in data, a hybrid approach with a combination of data physicalization and a digital interface has shown to be a promising opportunity in enriching interactions and understanding of data physicalization [5, 12, 15]. The digital interface, as an additional interface on top of the physical artifact, plays an essential role in supporting data physicalization to be interactive [32]. They enable user to encode their subjective inputs by submitting the data (e.g., [14, 28]), exploring the dataset with graphs and numbers (e.g., [23, 34]), and configuring the data input-output mappings (e.g., [5, 17]). Nevertheless, current data physicalization research puts the attention on the artifact itself, while the role and the usability of these additional interfaces have been given little attention [32].

In this work, we propose an "integrated data physicalization" approach – integrating digital features as additional interfaces to enrich understanding of and interaction with data physicalization. We present this approach through a digital lens of details. We implement this interaction approach through PhysLens to explain the data mapping details – the encoding process from data to data physicalization. To study the role of data physicalization details and

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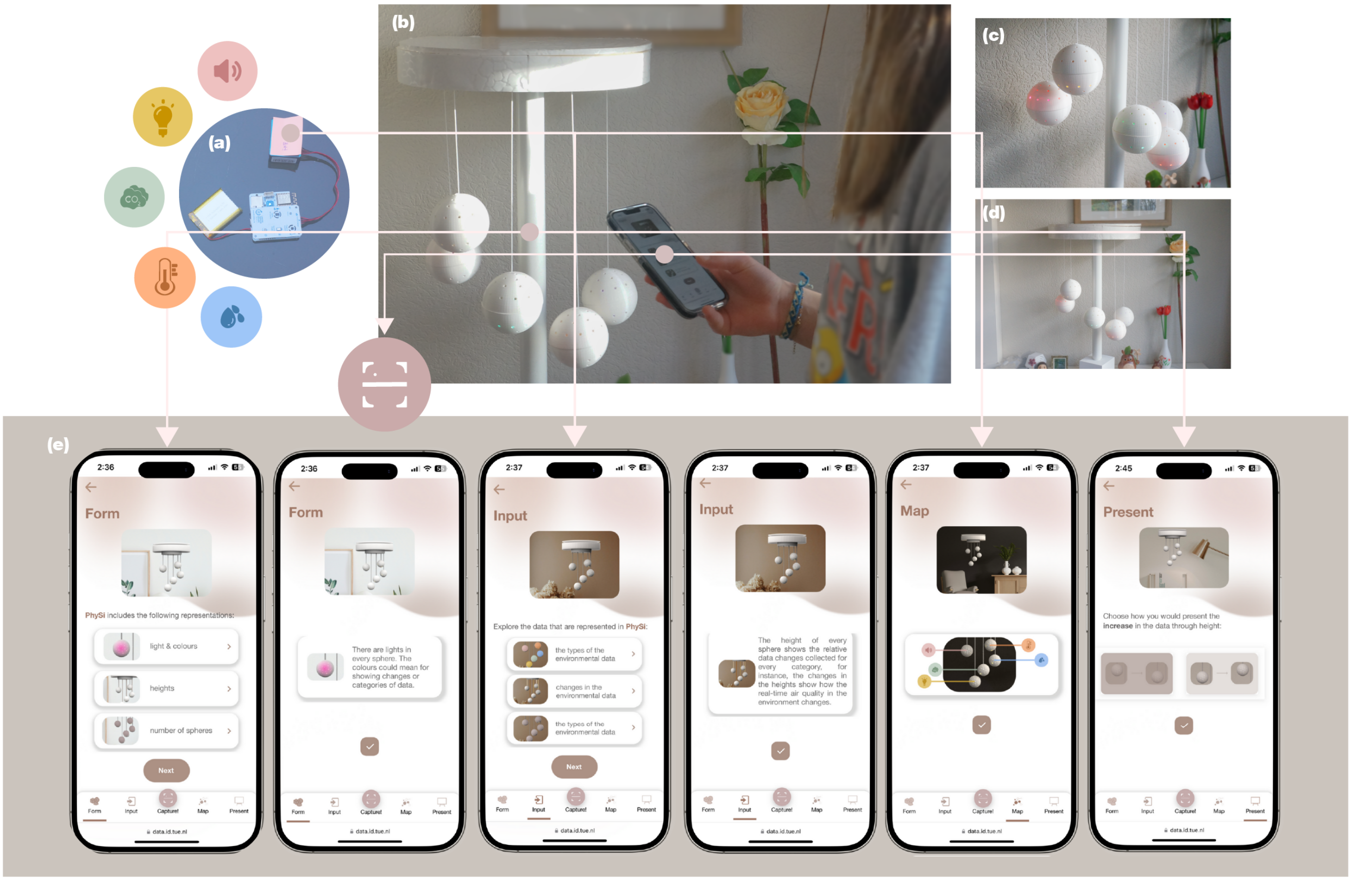

PhySi includes the following representations:

There are lights in every sphere. The colours could mean for showing changes or categories of data.

Explore the data that are represented in PhySi:

the types of the environmental data

changes in the environmental data

the types of the environmental data

The height of every sphere shows the relative data changes collected for every category, for instance, the changes in the heights show how the real-time air quality in the environment changes.

Choose how you would present the **increase** in the data through height:

Figure 1: PhysLens (e; key screens shown) helps users understand the data physicalization exemplar (b) with its environmental data (a) linked to the 'Input' and 'Map' pages, and data encoding channels — light (c) and height (d) — referenced in 'Form' and 'Present' pages. Arrows show connections between physical and digital interfaces.

the necessary components for this integrated data physicalization approach, an exemplar data physicalization – PhySi – was built to physicalize 5 different environmental data (i.e., sound, light intensity, temperature, humidity, and air quality) on a real-time basis. PhysLens (Figure 1), together with PhySi, were evaluated (N=16) under a semi-lab setting. Our results show that interacting with a lens of details was perceived as interesting and helpful in making sense of data physicalization. The potential of applying PhysLens in daily contexts was demonstrated with its possible extendability in providing reading scales (i.e., how to read the data from the physical form), personalizing physicalization (i.e., customizing the look and integrating IoT controls), and providing temporal instances (i.e., resurfacing data and defining instances of presenting data). These insights are relevant for the design foundations of the integrated data physicalization.

2 Related Work

Our study aims to develop a lens of details as a new interaction approach to data physicalization. We examine previous works focusing on the role of additional interfaces for users in understanding and interacting with data physicalization, where we identified 3 key themes: (i) providing details to be conveyed in data physicalization; (ii) exploring details for making sense of data; and (iii) (re-)configuring details of data physicalization.

Hybrid interfaces are applied to engage with users to supply data to be represented through data physicalization. To calculate and communicate individuals' carbon consumption levels, Econundrum [28] collects food intake data through a mobile interface. Similarly, DayClo [24] relies on the calendar data one puts in Google Calendar. The second type of hybrid interface focuses on supporting users in understanding the data details being communicated. An example is CoDa [36]. Using tokens on an interactive surface and a sidebar with various mapping settings, CoDa was designed for education settings to facilitate data interpretations. Another case is Zooids [23]. It takes a composite data physicalization approach, allowing users to explore, filter, and annotate physical line charts and scatter plots with the support of a tablet interface by selecting datasets and dimensions. Finally, additional interfaces in data physicalization were used for reconfiguration activities. For example, SensorBricks [5] takes a Lego-like approach in combination with a digital dashboard, inviting users to construct and modify their own sensor system and data presentations. Another case is Physikit [17].

It introduces an end-user programming interface where users can connect and represent data in physical ambient artifacts.

These examples demonstrate the necessity of additional digital interfaces in supporting users to interact with data physicalization [32]. Although these interfaces enable users to read and interpret the data better, they do not convey details for users to learn and interpret the data physicalization. Additionally, current data physicalization research focuses on the artifacts, with a limited understanding of the role of these additional interfaces. The combined opportunity for a lens of data physicalization details with an additional digital interface grounds the work of PhysLens for an "Integrated Data Physicalization" approach.

3 PhysLens

PhysLens, together with an exemplar data physicalization PhySi (Figure 1), was designed for the concept of "Integrated Data Physicalization". Users scan a QR code next to PhySi to access PhysLens as a web app. PhysLens enriches data physicalization with a lens of details through guided interactions. It allows users to engage with data physicalization through abstracting and elaborating layers of details [1]. To study the usability of PhysLens, it is developed as an interactive web app, coded with HTML, CSS, and JavaScript, and hosted on Data Foundry [13]. PhysLens introduces PhySi with 4 principles:

- **Form**: Introduces the effects that the changes in data could have on the data physicalization, e.g., "*The heights of the balls can inform you about how data changes, for instance, how temperature increases or decreases*".
- **Input**: Entails the encoded data type and data topic, e.g., it explains PhySi encodes the categorical data for various environmental factors through the colors of the light.
- **Map**: Denotes the relations between encoded data input and the form, e.g., an annotated visual was used to explain how light colors (form) are related to environmental data types (input).
- **Present**: Describes and allows for future customization towards how the form reacts to the data mapping through visuals, e.g., the higher the sphere is, the lower the data value is.

PhySi communicates real-time changes in environmental data through height changes, and each sphere represents one data type communicated by light colors. The data was collected from a SmartCitizen sensor kit [6] for sound, light, air quality, temperature, and humidity. Through its API, data was retrieved on a microcontroller WEMOS LOLIN32-ESP32, which was mapped to relative time spans for running TS90D Continuous Mini Servos to control the heights of the sphere. In every sphere, a WEMOS D1 Mini V4 with a battery shield attached and a 3.7V 2000mAh LiPo battery were used to power a light strip with 10 LED lights.

4 Methodology

PhysLens was evaluated in a semi-controlled lab [22] (Figure 2) with 16 participants (average age of 38, max = 63, min = 22). Participants were contacted via email and were screened for not having a design background or profession. Participants were asked to inspect PhySi (real-time updated according to the study environment) with PhysLens independently with a think-aloud protocol. They also received a booklet with a glossary of icons (to explain icons used in PhysLens). Sessions lasted for 12 min 58 sec on average (max: 30 min 38 sec, min: 4 min 48 sec). Afterwards, semi-structured interviews were hosted with an average duration of 18 min 21 sec (max: 28 min 35 sec, min: 11 min 19 sec). The interviews focused on the usability of PhysLens and the possible future integration of PhysLens. They were audio recorded, transcribed, and thematically analyzed through reflexive thematic analysis [2] in MAXQDA. Additional measures, including think-aloud the meaning of the physicalization before and after using PhysLens, observational videos, and User Experience Questionnaire (UEQ), were used to support interview findings.

5 Results

This section presents the outcomes of our study, focusing on the role of an integrated approach using PhysLens to support understanding and interactions with data physicalization. The following sections address our findings concerning (i) understanding data physicalization details, (ii) data details, (iii) personalization, and (iv) temporality.

5.1 Understanding Data Physicalization Details

Participants indicated that PhysLens was helpful and necessary in understanding a data physicalization – "*I would not want [the physicalization] without the app at all, even if I understand it more fully than I do now, I would still want the app so I can look at*" (P10). This was also noted from our observations of how participants described the data physicalization before and after using PhysLens. However, we noted a few instances where participants were confused. This was caused by: (i) PhysLens does not offer an immediate interaction and feedback mechanism towards PhySi – "*as a user I would like to experience the changes of the environment, and to get a sense of feeling how it changes*" (P8); (ii) icons without text – "*I thought this green thing (the air quality icon) was a brain*" (P6); and (iii) unclear color differences – "*I didn't see the color difference between that one and that one [pointing at the spheres for sound and temperature]. For me it's both red*" (P11).

5.2 Data Details

Current interactions offered by PhysLens were sensed to be a one-time experience – "*If it is only for instructions and explanations, then I only need to look at it once.*" (P5). This was also reflected in a neutral pragmatic quality rating from the User Experience Questionnaire being 0.219. Participants expressed a need to gain concrete data details. One way is through exact values or graphs – "*you can go to the app and then have the analyze, let you know how it was throughout the day*" (P15). The other approach was detailing the scales encoded in data physicalization. We identified two mechanisms: (i) absolute scales based on the data – "*perhaps you can have a threshold line, then I can approximately know that it is above or below the threshold*" (P5); and (ii) relative scales based on the data physicalization – "*I just know it's going up but I have no clue if one centimeter up means 1°C or 20°C*" (P16).

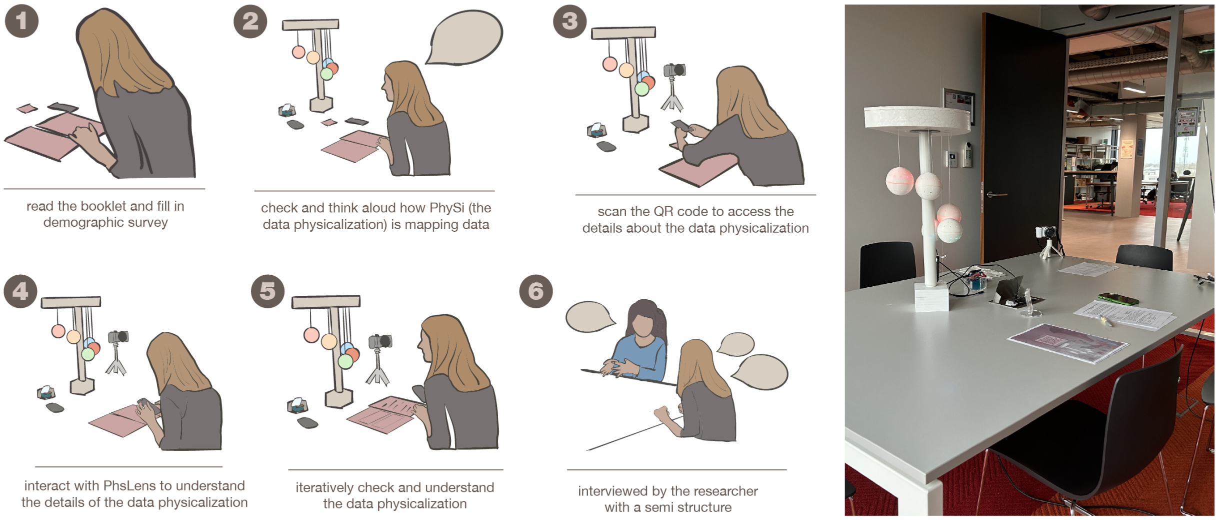

Figure 2: The study setup in steps (left); meeting room setting for hosting the studies (right).

5.3 Personalization

Participants found that the integrated approach could be used for personalization. They suggested encoding other data topics such as "*representing emotions I am having, because it is very concrete, but also not concrete at all*" (P1). PhysLens can also be used for "*people [to] specify which environmental factors they want to know about and they could program the balls*" (P14). Participants thought the integration of PhysLens can be used for IoT controls – "*if I can change [the temperature] with the app, then I can check [with the data physicalization] if it really does it*" (P15). Moreover, participants indicated potentials of changing the light colors – "*It would be nice if you could change the color and choose yourselves*" (P2) and turning the data physicalization on/off – "*if I'm not in the space, it should go off for saving energy*" (P9).

5.4 Temporality

The real-time updates of data physicalization were favored – "*I think it's about making you more in the present, making you more aware of your environment*" (P10). Next to a regular updating frequency, some participants suggested being notified when data is "*changing drastically, you would want to know right away, what is causing that*" (P16). Moreover, participants were interested in resurfacing past data with various temporal instances, ranging from past hours to days, weeks, and years. We identified 2 needs of resurfacing: (i) identifying potential problems – "*if I'm suddenly having mold allergies and I look at how last year was, maybe I would note there's a leak somewhere*" (P14) and (ii) finding ideal settings – "*maybe you can see that day I was really working well, and the temperature and the humidity were high*" (P11).

6 Discussion and Future Work

Our work studies the role of a detailed lens in enriching users' understanding and interaction with the data physicalization. In this discussion, we reflect on (i) Integrated Data Physicalization, (ii) scales as a frame of reference, and (iii) temporality.

6.1 Integrated Data Physicalization

The combination of the data physicalization and the additional digital medium, as we call "Integrated Data Physicalization", is acknowledged and shown as a necessity for initializing the understanding of the data physicalization. It captures the individual strengths of each medium [12, 15]. Our study showed that this approach has the potential to support longitudinal user interactions with data physicalization. This could be achieved through 4 ways: (i) communicating data through additional labeling [34, 36], data dashboards [5], or remote access [14]; (ii) personalizing physicalization through subjective inputs [28] or configuration interfaces [17]; (iii) resurfacing past data [5, 32]; and (iv) including IoT controls to enable users to take actions based on the data and the context [3, 5].

6.2 Scales as Frame of References for Detailing Data Physicalization

Our results showed that interacting with data scales plays an important role in interpreting data physicalization. We identified two types of scales: (i) absolute – based on the data; and (ii) relative – based on the physicalization. The most straightforward approach to apply absolute scales is to provide numerical values [5, 29, 34]. Another approach could be indicating a threshold line, which has been seen in data physicalizations related to goal settings [20, 29]. Relative scales stand for the data being fit into the data physicalization without a maximum or minimum boundary. Examples reflected in prior works are Econundrum [28] – presenting the relative comparisons among users with a social frame of reference, and Mood Squeezer [14] – demonstrating variations of individuals' moods based on their ratios of occurrences.

6.3 A Lens of Temporal Instances in Data Physicalization

The relevance of the presence and the actionability of real-time information was favorable to our participants. There are two approaches of giving the real-time information – (i) data physicalization updates with a regular frequency (e.g., every 10 minutes) [28, 29]); and (ii) a threshold setting – data physicalization only updates when data falls out-of-sync, as often integrated in physicalization toolkits [5, 17]. We also noted a need to resurface past data to create a historical frame of reference. One could be interested in data of past days [29], whereas others might wish to learn the data of past weeks, months, or years [32]. Overall, temporality remains to be underexplored [30]. Future work could use the integrated data physicalization approach to further explore the role of temporality in data physicalization [32].

6.4 Limitations and Future Work

PhysLens was studied with an exemplar data physicalization, where future works could investigate its generalizability for other data physicalizations and fine-tune the vocabularies when necessary [9, 16]. Additionally, PhysLens could be examined in the field to learn about natural and longitudinal intersections and interactions users may have with PhysLens. Moreover, future work shall investigate the longitudinal role of this Integrated Data Physicalization approach by studying the integrations and user preferences of temporality, IoT controls, and scales in data physicalization.

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