Input Physicalization in Practice: An Instructional Walkthrough with Visualization Novices

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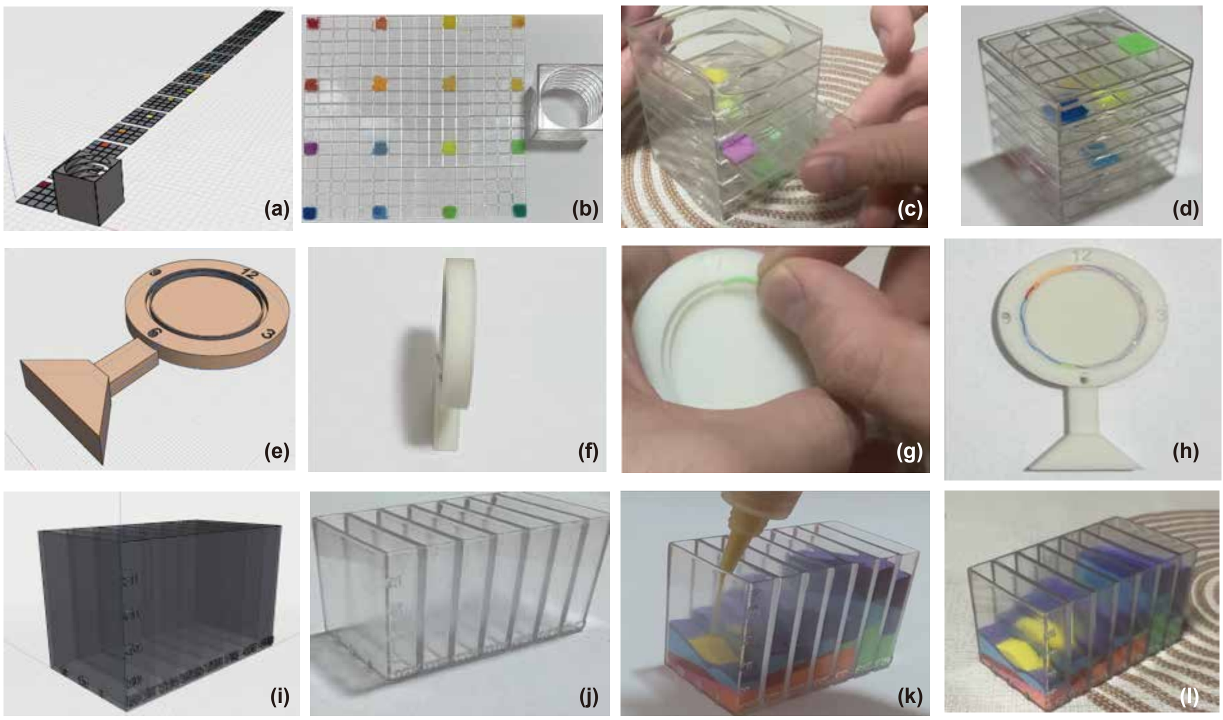

Figure 1: An overview of the physicalizations with data input created in our instructional walkthrough with visualization novices (undergraduate students with limited to no visualization knowledge). First line - *Weekly Mood Shelf*: (a) A 3D modeling of the mood shelf made by the student. (b) The physical form of the shelf: an acrylic seven-layer shelf with a set of prepared color-encoded emotional slices. (c) A student is putting his Friday emotional slice onto the shelf. (d) A completed mood shelf created by the student through a weekly recording of his emotions. Middle line - *Daily Learning Recorder*: (e) A 3D modeling of the learning recorder. (f) A 3D-printed physical entity of the recorder. (g) A student is embedding straightened green paper clips into the groove on the recorder interface to log a single learning activity and its time spent. (h) A completed recorder that shows half a day of learning activities done by the student (sleeping time was additionally included). Last line - *Weekly Hobby Sandbox*: (i) A 3D modeling of the hobby sandbox. (j) An acrylic sandbox comprises seven square sand containers. (k) A student is pouring sand into the Monday container to log their music listening activity and the time spent percentage on that day. (l) A completed hobby sandbox that had been made by the student through a weekly recording of his hobby activities. Demo videos for all three physicalizations are available at osf.io/8quv4/.

Abstract

We conduct an instructional walkthrough with undergraduate students who have limited to no visualization knowledge and create three physicalizations with personal data input. While physicalization is widely recognized as a tangible , intuitive, and engaging form of data representation, its design and construction remain challenging, especially for novices who lack basic visualization knowledge. To explore these challenges in practice, we conducted an instructional walkthrough with undergraduate students who have limited to no visualization expertise. A group of students first elicited possible personal data, which was then filtered and categorized under supervision. Next, one lead student discussed with the supervisors to determine the reasonable data items to design with, as well as the possible data input methods. After which, the student individually modeled and fabricated the physicalizations that have corresponding data input mechanisms , and used these physicalizations to complete a period of data input. Our walkthrough revealed insights into input physicalization in connection with visualization novices and education, as well as the research gaps between observed novice challenges with input visualization. Supplemental materials and demo videos are available at osf.io/8quv4/.

Index Terms: Physicalization, personal data, design walkthrough.

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1 Introduction

In recent years, data physicalization has emerged as an alternative approach to representing data—moving beyond digital screens to embrace tangible, material-based forms. Unlike traditional visualizations, physicalizations encode information through shape, texture, material behavior, and spatial arrangement, offering distinct advantages in engagement, accessibility, and personal expression. Although prior work has explored a range of physicalization formats, from self-tracking artifacts [10] to interactive sculptures [6], less attention has been given to how novices approach the design of physicalizations with data input, as well as how to guide them to build their own input physicalizations.

To address this gap, we conducted an instructional walkthrough with undergraduate students who had little to no prior knowledge of visualization. The whole process was under a high-level guidance: Our walkthrough began with a set of introductory sessions. Next, a group of undergraduate students was asked to conduct a brainstorming session to elicit data items. Considering the participating students were all visualization novices, we, as the instructor of the instructional walkthrough, narrowed down the brainstorming scope to the personal data, which is easy to understand and rich in students' life context. After which, the students presented the data items that they came up with to the instructor, followed by the guidance given by the instructor to categorize the data according to various dimensions. Then, the students discussed with the instructor and selected three representative data items (*Emotion*, *Learning*, and *Hobbies*) to use in the following design phase. Next, one student from the group continued to the physicalization stage. Under the guidance of the instructor, he completed a full cycle of physicalization design, fabrication, and data input. His resulting input physicalizations illustrate how he made trade-offs between material choices, metaphors, and data abstraction, from the perspectives of a visualization novice.

In our paper, we first present the instructional walkthrough that we conducted, as well as the tangible outcomes obtained. We next discuss the difficulties and challenges that we observed from our students in creating input physicalizations. We end the paper with reflections on the connections between observed novice difficulties and research challenges in input physicalization. Our work reveals both educational challenges and research opportunities for input physicalization with visualization novices.

2 Related Work

Our topic lies in the domain of physicalization and relates to the personal data input. We thus introduce the related work from broad physicalization and, more concretely, personal data input.

2.1 Physicalization in General

Jansen et al. define physicalization as "a physical artifact whose geometry or material properties encode data" [7]. Broadly, physicalizations can be categorized into static and interactive forms. While static physicalizations are often easy to construct, they lack adaptability. Interactive physicalization, by contrast, allows users to input, rearrange, or manipulate data directly. For example, Engert et al. investigated shape-changing physical data representations, blending with augmented reality overlays, which allow users to interact with them [6]. Daneshzand et al. presented KiriPhys, a Kirigami-based physicalization technique that supports users for interactive exploration with layered data [4]. In contrast, our work focuses on the personal data input, with a flat data structure and a small scale. We select personal data as it is intuitive, easy to understand and collect, and diverse, which is reasonable for novices to start with.

2.2 Personal Data Input

In recent years, there has been an increasing amount of work in the visualization community focusing on personal data input. For example, Panagiotidou et al. [9] provided colorful card papers and a set of handcraft kits at an academic conference, which allowed attendees to make their own badges based on their academic profile. Sauvé et al. [10] conducted a diet recording through wooden tokens within their research institution—the token size represents the carbon emission of vegetables or meat, and they asked people to throw the tokens that correspond to their dietary consumption every day. Bressa et al. [3] created a bunch of situated self-tracking applications to log data and show situated visualization. More recently, Bressa et al. [2] proposed *input visualization* that are designed to collect and represent new data rather than encoding preexisting datasets. Our work is more at the intersection of physicalization and input visualization as we use physical visual representations to log personal data. Besides, our participants are all visualization novices, which is different from the work above that involves participants with basic visualization experience.

3 Instructional Walkthrough: Data Elicitation

Before starting, we gave our students introductory sessions, in which we explained what visualization is, what data can be visualized, and how. We shared a bunch of examples of physicalization [5] to give students a sense of representing data with tangible entities. Next, to elicit reasonable personal data for input physicalization, we asked our students to conduct a 2-hour internal brainstorming.

3.1 Data Brainstorming

Our brainstorming involved 6 final-year undergraduate students, with diverse backgrounds in broad Computer Science. All had little to no prior experience with data visualization. Students first individually listed any personal data items they considered relevant to themselves. Following, each of them explained the meaning behind their entries to resolve ambiguities caused by varying expressions (e. g., one student wrote "movie watching" while another used "film" to refer to the same activity). After the discussion, we consolidated overlapping entries and standardized the terminology across students.

3.2 Data Categorization

The data items that we received from students' brainstorming are diverse. We categorized them based on the update frequency:

On A Daily Basis: The most commonly items mentioned by the students were those that change once or multiple times per day. These include: (a) *Itinerary*: daily movement trajectories; (b) *Diet*: types and quantities of food and beverages consumed; (c) *Transportation*: means of transport (e.g., walking, bicycle, taxi, bus, car) and time spent; (d) *Expenses*: daily spending amounts and their purposes; (e) *Emotion*: daily emotional states and fluctuations; (f) *Sleep*: sleep timing and perceived sleep quality; (g) *Exercise*: types of physical activity and duration; (h) *Learning*: study tasks and time spent.

Based on Personal Routine: These data items are highly individualized and do not follow a fixed temporal pattern. Instead, they are updated according to personal circumstances. Examples include: (a) *Hobbies*: activities pursued for personal enjoyment, such as watching football, listening to music, watching movies or series, and playing video games; (b) *Physical characteristics*: measurable aspects of the body such as height, weight, body mass index, and body fat percentage; (c) *Financial profile*: financial indicators such as income, savings, debts, and assets; (d) *Relationship status*: romantic or legal relationship state, including single, dating, married, in a domestic partnership, separated, divorced, or widowed.

3.3 Data Selection

Considering our following physicalization design and production would be conducted with a visualization novice who had not finished the undergraduate study, the selected data items should be grounded in undergraduate students' daily lives and easy to collect. Thus, we discussed with the student who would continue with the following steps about his data preferences. The student chose to work with *Emotion*, *Learning*, and *Hobbies*. When we asked for his rationale, the student explained that he lived in a university dormitory, walked to campus daily, typically ate at the university canteens, did not exercise regularly, slept well, and seldom left campus. As a result, he felt that data on *Itinerary*, *Diet*, *Transportation*, *Expenses*, *Sleep*, and *Exercise* would lack variability and personal insight. The student also noted that he did not have the necessary devices to measure his *Physical characteristics*. Meanwhile, *Financial profile* and *Relationship status* were considered irrelevant to his current life context. With respect to his choices, we thus selected *Emotion*, *Learning*, and *Hobbies* as reasonable data input in the following physicalization design and production.

4 Instructional Walkthrough: Physicalization Design and Production

We describe here how the student produced his input physicalizations, including his design considerations, data input methods, and the resulting physicalizations. We present the produced input physicalizations organized by data item.

4.1 *Emotion:* Weekly Mood Shelf

Design Consideration: Recognizing that a week is naturally divided into five workdays and two weekend days, with differing environments, contexts, and emotional experiences, the student designed a *Mood Shelf* to capture emotional variation aligned with his weekly rhythm. His *Mood Shelf* consists of a transparent seven-layer rack, paired with a set of acrylic slices. Each slice features a 4×4 grid of cells that can be filled with color to encode emotional states.

Inspired and followed by the previous research on the relationship between color and emotion in psychology [8], the student selected four primary hues: red for anger, yellow for happiness, green for calmness, and blue for sadness. These colors were chosen for their intuitive and emotionally grounded associations. Emotional mixtures are expressed by mixed colors. For instance, a half blue mixed with the other half of red, purple, which results in purple, represents anger accompanied by sadness.

The entire structure, including shelf and slices, is fabricated from transparent acrylic, enabling users to view both individual daily states and the aggregated emotional landscape of the week from top or side perspectives.

Data Input Method: To support the emotion input process, the student prepared a set of 16 pre-designed slices, each encoding a specific emotional state or combination of states. These slices were generated based on the $2^4 = 16$ possible permutations of four primary emotions (where 1 = perceived, 0 = not perceived). Each permutation corresponds to a unique emotional configuration—for example, “pure happiness” (yellow only), “bittersweet joy” (yellow and blue), or “emotional overload” (all four emotions present).

In addition to the predefined slices, the student also provided blank slices to support personalized expression. These blank slices could be hand-painted to reflect more nuanced or proportional blends of emotions—such as half calmness, a quarter happiness, and a quarter sadness—enabling users to record complex emotional experiences that extend beyond categorical combinations.

Resulting Physicalization: As a result, the *Mood Shelf* takes the form of a transparent vertical shelf structure with seven horizontal layers, and a set of (colored) slices. Each layer is fitted with a circular concave holder to support an emotion slice while maintaining visual clarity and structural stability. Users can use the predefined slices or customize their own slice. By inputting emotional data and stacking slices throughout the week, users can build a weekly layered emotional landscape.

4.2 *Learning:* Daily Learning Recorder

Design Consideration: The *Daily Learning Recorder* draws inspiration from traditional clock interfaces, incorporating a circular form engraved with hourly markers. To represent a full day, the student designed the recorder as a double-sided disc: one side corresponds to AM hours, the other to PM. Both sides share the same surface texture and visual style to ensure consistency and ease of interpretation. Unlike flat clock faces, each side features a shallow circular groove used for physical data input.

The student selected colored paper clips as the data input material due to their accessibility, low cost, and familiarity, especially within students' contexts. The student used color again to distinguish between different learning subjects. In this case, the color-subject mapping is user-defined but consistent across a day. Time spent is encoded using the length of each straightened paper clip.

Data Input Method: To log a learning activity, users first straighten a colored paper clip associated with a specific subject. The clip is then embedded into the circular groove, beginning at the start time and ending at the finish time. Users cut the paper clip to match the appropriate duration. This process can be repeated for each subject studied throughout the day.

Resulting Physicalization: The student's final *Daily Learning Recorder* takes the form of a double-sided circular board with engraved hour markers and embedded colored segments. Each side visualizes either AM or PM learning activities. Together, the two sides provide a tangible, color-coded timeline of the day, revealing when and for how long each subject was studied.

4.3 *Hobbies*: Weekly Hobby Sandbox

Design consideration: Hobbies vary significantly across individuals and occur at irregular frequencies. Some, like listening to music, may happen daily; others, like watching a football match, may occur only occasionally. To accommodate this variability while maintaining a manageable temporal unit, the student designed the *Hobby Sandbox* as a weekly physicalization.

The *Hobby Sandbox* comprises seven square containers, each representing one day of the week. Within each, hobby engagement is encoded using colored sand. The height of sand poured corresponds to the proportion of time spent on a particular hobby relative to that day's total hobby time. External scale markers at 20% intervals support approximate visual comparison. Colored sand was chosen for its fluidity and malleability, reflecting the open-ended and often formless nature of hobbies. Color mappings are user-defined and flexible, enabling individuals to assign colors to activities of personal relevance (e. g., music, gaming, or watching sports).

Data Input Method: To log hobby activity, users pour colored sand into the day's containers. The amount and layering order of sand segments reflect time spent and activity sequence. Due to the sand's softness and shifting properties, the record is not precise. However, the overall hobby patterns and trends remain legible.

Resulting Physicalization: The completed *Hobby Sandbox* forms a layered, color-coded diary of hobby engagement over a week. Each container encodes daily variation in both activity type and relative duration, offering a tactile, visual snapshot of personal interests unfolding across time.

5 Reflections, Discussions, and Limitations

In this section, we reflect and discuss our work from two perspectives: (a) insights into input physicalization in connections with visualization novices and education, and (b) research gaps between observed novice challenges with input visualization. After which, we present the limitations of our work.

5.1 Insights into Education

Difficulties on Notion Understanding: Our participants in the entire instructional walkthrough were all undergraduate students who lacked basic knowledge of visualization and had no experience in making physicalization. Although our students grasped well what data and personal data are and saw a bunch of physicalization examples in the introductory sessions, we still found it is challenging for them to understand the notion of physicalization—the "physicalization" in their mind is closer to a decorative or craft-based object rather than a purposeful method of data inputting or representation. Our students were also confused about why data can be physicalized. They designed and produced the physicalizations under our guidance, but had very little sense of why they were doing so. One possible reason was the lack of self-immersion: we didn't conduct a small comparison test to allow our students to experience the difference between recording data using tangible data representations and recording data using digital text.

Limited and Repetitive Design Choices: We gave introductory sessions where we illustrated the visual channels and concrete examples from curated repositories like Dragicevic and Jansen's Data Physicalization list [5]. Our purpose was to diversify the students' design thinking. However, in practice, we noticed that our students tried to repeat and only use the design choices (such as color) that we made examples with, which highlights that visualization novices lack an understanding of the connection between visual channels, material properties, and the data encoding. Bach et al. proposed a call to action on whole visualization education [1], while physicalization may require not only foundational literacy in data, visual designs, and materials, but also a more experiential approach to teaching. For example, pairing trainings that could help undergraduate students develop a better understanding of how different materials, visual channels, and data are interconnected.

5.2 Research Gaps

Our instructional walkthrough reveals several research gaps between novice challenges and input physicalization.

Loss of Data Precision: We observed that our students tended to narrow design choices, which led to a decrease or loss of data precision (for example, in *Weekly Hobby Sandbox*, the data could only be recorded in a rough way). This observation suggests that visualization novices struggle to reason about the relationship between data types, material properties, and visual encodings. Interesting research questions arise: How are data dimensions and levels of precision constructed, maintained, or lost in the transition from digital to physical input? To what extent of precision do people need to perceive a data trend?

Disconnection of Material and Data Input: We also observed our students tended to simplistic and repetitive design choices, especially apparent when creating physicalizations for abstract data items like *Emotion* or *Learning*. The materials currently used by students are all common materials, such as plastic and metal. While common materials are certainly low-cost and readily available, they may fail to fully utilize one of the advantages of physicalization—tactile sensation, which is especially true when used to express abstract data, as they may not provide a correct corresponding sense. A research gap is the corresponding link between the perceptual feedback of materials and specific data input. For example, what kind of materials can be linked to continuous/numerical data, or categorical/qualitative data? A more concrete example is: when the input data is emotional data, what materials are good to provide suitable reflections, such as happy or sad? In addition, we noticed our student used a material characteristic (fluidity of sands) without linking it to a specific data dimension. How materials characteristics, such as bendability, separability, and re-usability, can be mapped to data expressiveness still requires further exploration.

Lack A Structured Teaching-oriented Framework: Compared to complex coding, input physicalization is more intuitive. It helps people, especially beginners, design, build, and log data with less time and cost. That is why we chose physicalization as a practical exercise for our students. However, the instructional walkthrough was harder than expected. Students with little or no visualization background could not widen their design choices from the introductory sessions alone. Not only component training sessions, such as binding data features with physical properties (for example, categorical data to geometric objects of different shapes), are needed, but also a structured teaching framework to guide visualization novices from scratch.

5.3 Limitations

Our instructional walkthrough lacks user evaluation and design refinement. Regarding design considerations for all three physicalizations, the data encodings used were limited to height, length, and color. While the data input methods used involved putting and pouring, they were essentially similar—returning the physical input to a specific location. Regarding material properties, we explored single properties such as bendability and fluidity, while the combined use of multiple properties was not explored.

6 Conclusion

We present a instructional walkthrough exploring input physicalization with visualization novices. Our students began with an internal brainstorming session to elicit data items, then categorized them by update frequency. From this, we selected *Emotion*, *Learning*, and *Hobbies*, and our student designed physicalization for each with a corresponding data input method. Our instructional walkthrough was conducted with undergraduate students who had little to no prior domain knowledge, offering a grounded view of input physicalization in practice. We end our paper with insights into education and emerging research gaps.

Supplemental Materials

We additionally provide: (a) 3D modeling files of each physicalization we created in our design walkthrough, and (b) demo videos to demonstrate how to use and input data with them. Our repository can be found at osf.io/8quv4/.

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