DataVisage: A Card-Based Design Workshop to Support Design Ideation on Data Physicalization

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Abstract. As a rapidly booming research field, data physicalization has received significant explorations in recent decades. While previous studies have considered various aspects of creating physical artifacts, there is still a lack of structured method for guiding designers to generate design ideations. In this paper, we propose a card-based design workshop that takes proactive health as a starting point to design physicalizations, aiming at promoting users' self-reflection. Building upon prior researches and our thoughts, we propose design strategies and develop cards and toolkits to bridge designers' thinking processes and workshop process, thereby maximizing the effectiveness. The workshop was implemented and validated within a graduate-level design course. Qualitative and quantitative results demonstrated the effectiveness of the workshop in optimizing group work and structuring the design process. The workshop also contributes to the creation of quick, aesthetic, and practically applicable physical prototypes.

Keywords: Data Physicalization · Physical Visualization · Proactive Health · HCI · Workshop

1 Introduction

With the development of digital fabrication [1], tangible computing [2] and TUI [3], data physicalization has become an emerging research field in the past decades [4]. Compared to data visualization, data physicalization demonstrates greater potential for human-data interaction, such as increasing emotional connections [5], improving data accessibility [4] and enhancing sensory modalities [6]. The physical nature of materials allows physicalizations to be easily explored and interacted with in physical space, and the close contact with human and material promotes reflection on the data [7]. Data physicalization has been increasingly explored in proactive health, where it is used for recording and changing self-behavior [8].

In the theoretical framework of physicalization, some studies tried to summarize and consolidate the design frameworks of data physicalization through case studies and literature review. For instance, Bae et al. [9] suggested describing and analyzing data physicalization from three aspects: context, structure, and interactions, with a focus on

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establishing a dialogue between users and artifacts. Khot and colleagues [8] categorized four categories of representing physical activity: mapping, outcome, material, and process. Additionally, previous researches have emphasized the benefits of creating data physicalization from different perspectives. For example, Hull and Willett [10] based on the architectural scale models and discussed the support for contextualized design and rapid iterative data physicalization exploration through the construction of physical artifacts. Offenhuber and Telhan [11] started from a semiotic perspective, and highlighted the importance of the correspondence between materials and data for users rapidly capturing visual content. From the user's perspective, the aesthetics and attractiveness of artifacts are critical considerations. For instance, Forlizzi and Battarbee [12] indicated that aesthetics must align with user needs.

In the area of data visualization techniques, rhetorical techniques as one of the mapping approaches are considered to be more attractive and capable of fostering user empathy [13]. Some cases of data physicalization tend to employ the metaphor of animals and plants to enhance the understanding of data and promote self-reflection. In proactive health area, for instance, Yu et al. [14] visualized individual heart rate variability data as flowers through mechanical movement, where the size and shape of the printed flowers on paper reflect the user's health status. Stusak and colleagues [15] transformed running data into 3D-printed sculptures in the shape of human bodies, using the sculpture's state to represent the physical activity. Additionally, the simplification techniques could help focus user attention and reduce information overload [16]. For example, Sauvé et al. [17] employed simplified and abstract data sculptures to depict the relationship between food data and carbon emissions. Sauvé et al. [18] suggested that simplifying the representation of spatial and physical data can improve data interpretability and optimize perception of physical space. Moreover, additional means such as storytelling [7], personalization [19] also possess the ability to increase user insights by invoking self-experience and triggering reflection.

However, although there have been many designs and studies using data physicalization to express personal information, there is no unified and clear design guideline for helping designers in creating health data physicalizations [4]. Therefore, we expect to propose a design methodology for supporting designers in constructing data physicalization. Card-based workshops, as a widely accepted method for exploring design approaches, can effectively combine design strategies with design practice. In this paper, based on a comprehensive consideration of physicalization strategies, we propose a card-based design workshop as a support for the design ideations of data physicalization. The contribution of this study includes the following three aspects: (1) We proposed a design method for the design ideation of data physicalization, and collected insights and usage experiences of this method from participants. (2) We explored ways to integrate personal health data physicalization into daily life. (3) Provide insights for future data physicalization in the field of proactive health.

2 The Design of the Ideation Cards

As a catalyst for design, the ideation cards play a crucial role in constructing a clear framework for data physicalization and supporting the generation of design ideas. In this workshop, the ideation cards we designed are named as DataVisage, which are used to guide the process of embodying and visualizing health data.

2.1 The Mapping Strategy

By reviewing and integrating relevant researches, we have highlighted certain requirements: The need to focus on the self-reflection, in order to enhance the feasibility of integrating solutions into real life [20]; The cards should not only inspire creativity but also assist designers in selecting and refining solutions, providing logical support throughout the entire process from ideation generation to prototype [21–23]. Our goal is to achieve a structured solution generation process by providing support for different stages of design, enabling designers to propose and create more practical HCI interactive prototypes. Based on these, the design dimensions of physicalization process we propose are as follows:

1. **Task:** *Physical Health (prevention; rehabilitation…), Mental Health (Individual; cooperation; society…).* In the phase of seeking design direction, we segment the domain of health, thereby guiding users in establishing design goals.
2. **Design**: *Visual Coding (metaphor; simplification …), Interaction (user experience…), Context (support reflection; scenarios…).* The mapping logic throughout the three phases ranges from shallow to deep, starting with the data encoding, followed by interaction, and finally practical application and operational scenarios, thus encompassing various aspects of design solutions.
3. **Evaluation**: *Usability, Interactive Feedback, Technical Support, Usage Scenarios.* Reviewing the practicality of the design.

2.2 The Ideation of DataVisage

DataVisage is used to host the design strategies. As shown in Fig. 1, it consists of a deck of 18 cards, categorized into *Task Cards*, *Design Cards*, and *Evaluation Cards*, providing supports for the three stages of a designer's work. The *Task Cards* serve the purpose of grasping the design direction and promoting divergent thinking. The *Design Cards* assist in the selection, refinement, and preliminary evaluation of design solutions. The *Evaluation Cards* aid in the refinement and optimization of the ideas. All 18 cards have undergone careful consideration, and have been discussed and determined by four researchers. The card design employs a concise color scheme and layout to focus attention and maximize information delivery. The color scheme distinguishes different categories. The content of the cards is presented through text, illustrations, and other forms to explain the themes and provide case illustrations. In actual production, the *Evaluation Cards* are designed to be A5 size for content writing, while all other cards are A6 size.

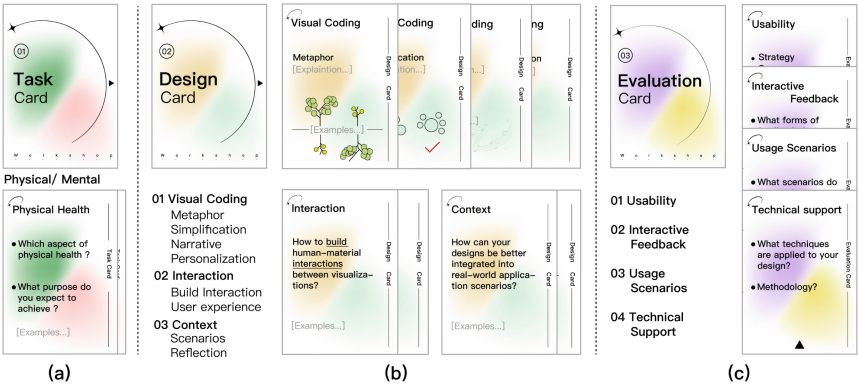

Fig. 1. Overview of DataVisage. (a) Task Cards. (b) Design Cards. (c) Evaluation Cards.

3 The Design of the DataVisage Workshop

3.1 Participants

The workshop was facilitated by researchers and implemented based on a graduate-level course in design studies. The participants consisted of the design students enrolled in the graduate-level course, who are regarded as novice designers, with a total of 19 participants (1 male, 18 females), aged between 23 and 27 (M = 23.42, SD = 1.07). All participants were graduate students majored in design, and possessed at least a basic knowledge of programming. They were divided into five design groups based on their preferences, with each group consisting of 3 to 4 individuals. The five groups were labeled as G1, G2, G3, G4, and G5. The participants were numbered as P1, P2,…, P19.

3.2 Procedure

As shown in Fig. 2, each group was given a set of toolkits. The activities were supported by DataVisage as well as additional creative ideation and prototyping tools such as paper and pencil, clay, etc. Participants were required to complete six steps within a limited time, following the workshop's arrangements, as shown in Fig. 3. The workshop process complemented DataVisage and introduced two rounds of individual brainwriting and group presentations within each group. Step 1 and Step 2 involve determining the design direction and framing design opportunities, while Steps 3 and 4 consist of 15-min brainstorming sessions using Task Cards and Design Cards separately, followed by 10-min group discussions with rotating speaking. Step 5 is for evaluation, and Step 6 is for prototype development. Throughout this process, participants engaged in thinking through ideations at various steps based on the prompts and case-specific guidance provided on DataVisage. For instance, prompts such as "*Which aspect of mental health?*" on *Task Cards*, "*Utilize metaphors to map data onto familiar concepts*" on *Design Cards*, and "*What techniques are applied to your design?* " on *Evaluation Cards.*

Fig. 2. Toolkits.

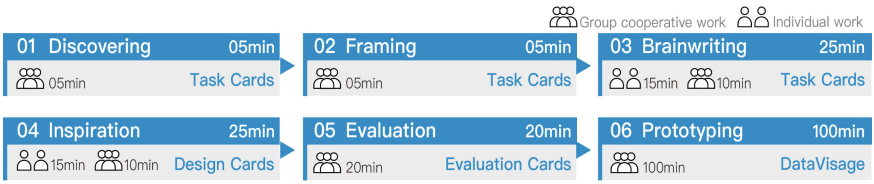

Fig. 3. Workshop procedure.

3.3 Data Collection and Analysis

A combined qualitative and quantitative approach was employed for data collection. Regarding qualitative data collection, firstly, we collected the creative artifacts and demonstration videos from the five groups. Throughout the workshop, researchers observed and documented the proceedings. Secondly, exit interviews were conducted with each participant individually, lasting for approximately 10 to 20 min, to gather their feedback on the workshop. The interview questions were designed based on double-diamond model [24], categorized into four sections: Discovery: decomposition of requirements based on Task Cards and creative divergence, Definition: refining and focusing of ideas through group discussions and individual brainwriting, Idea Generation: generate design concepts based on Design Cards, and Solution: selection of ideas and prototype production based on Evaluation Cards. The semi-structured interviews were audio-recorded and accompanied by note-taking for subsequent thematic analysis.

The questionnaire was employed to collect participants' feedback on DataVisage. The questionnaire design was inspired by [21] and focused on four aspects (see Appendix 1): Perceived Usefulness (PU1 ~ 5), Perceived Ease of Use (EU1 ~ 3), Ideation (ID1 ~ 3), and Evaluation (EV1 ~ 3). Perceived usefulness emphasizes the usefulness of the card information. Perceived ease of use refers to the comprehensibility and ease of mastery of the card information. The Ideation and Evaluation evaluate the divergent and convergent thinking process, respectively. The questionnaire utilized a 5-point Likert scale for rating the responses. Reliability and validity tests as well as data analysis were conducted using SPSS software [25].

4 Results

4.1 Ideas Generated

Under the pressure of limited time, five groups generated five ideations for data physicalization (see Fig. 4). These designs included G1 and G2 focusing on mental health, G3 and G4 focusing on physical health, and G5 encompassing both physical and mental health while ultimately addressing social data. Among these, G1 starts from the *Metaphor* and *Simplification* techniques suggested on *Design Cards*, mapping the stress represented by HRV to simplified synaptic dynamics. G2 emphasizes *Interactivity*, achieving human-material interaction through a dialogue between a person and the bottle. G5 considers the *Context* suggested by *Design Cards*, utilizing data from office coffee corners, such as voice and coffee times, to generate individual social data coffees. Building upon the integration of physical design and online gaming, G3 further harmonized the design style and interaction flow based on the *Evaluation Cards*.

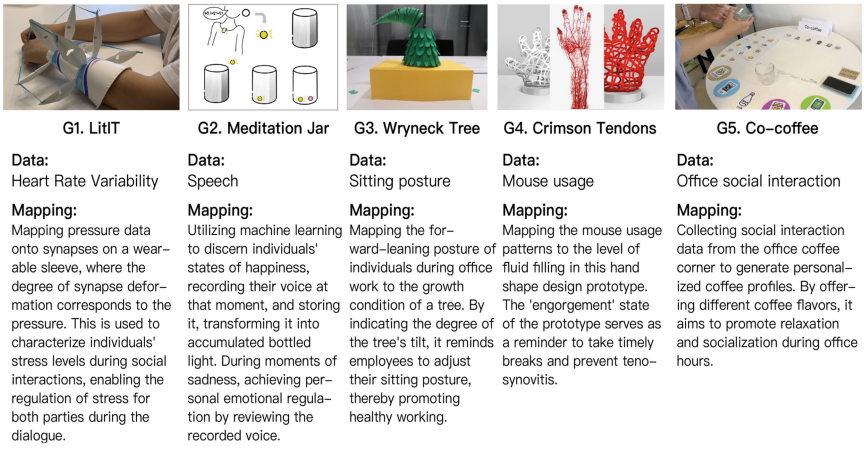

Fig. 4. Outcomes of the workshop.

4.2 Quantitative Result

The reliability and validity of the questionnaire were examined using SPSS. The Cronbach's alpha value was 0.914, indicating excellent questionnaire reliability. The KMO value was 0.6, indicating an acceptable questionnaire validity.

Evaluation of Perceived Usefulness and Perceived Ease of Use. As shown in Fig. 5a, the data from the questionnaire indicates that the cards demonstrate favorable performance in terms of Perceived usefulness ($M = 4.19$, $SD = 0.66$) and Perceived ease of use ($M = 3.95$, $SD = 0.83$). The results indicate that card design is effective in providing clear and useful instructions and guidance, and is good at promoting diverse and rapid ideations, as the card content is easily comprehensible.

The benefits of DataVisage as a Catalyst for Divergent and Convergent Thinking. The participants' ratings for *Ideation* (M = 3.83, SD = 0.78) and *Evaluation* (M = 4.10, SD = 0.61) reflect the role of DataVisage in stimulating creativity and assessing solutions (Fig. 5b). The results indicate that DataVisage contributes to various aspects of the design process, such as design positioning, ideation, and creative integration. Additionally, DataVisage has a positive impact on the selection, evaluation, and refinement of design ideations.

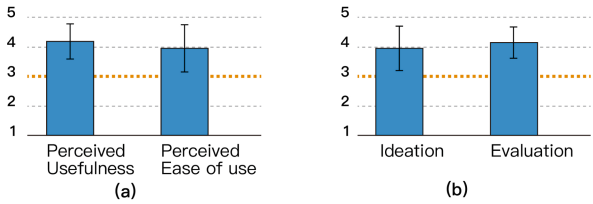

Fig. 5. Quantitative results. (a) Results of PU and PE. (b) Results of ID and EV.

4.3 Qualitative Result

The Balance between Individual Diversity and Group Collaboration. The DataVisage workshop process combines individual brainwriting and group discussions. Firstly, creative ideas are discussed using the cards, and then they are further refined and solidified through brainwriting. This approach facilitates rapid icebreaking and balances each individual's speaking rights (P8). The workshop process enables communication of creative ideas through two methods: direct discussions among group members and communications through writing. In particular, the unloading of individual thinking through brainwriting helps leverage each person's strengths and advantages. For example, P9 stated, "*Settling down to organize the logic helps clarify what the design is about. Moreover, everyone has different areas of focus, so we can each play to our strengths. After exchanging papers, we can complement each other's details.*" P15 believed, "*Writing helps identify points that can be explored in depth.*" P7 found reading others' ideas on paper fascinating: "*Everyone describes their ideas differently, some draw, some write long paragraphs. This transforms my way of thinking and inspires me more.*" Additionally, brainwriting based on DataVisage creates an invisible social connection among group members. For example, P19 stated, "*I tend to add comments to others' ideas, and the next person can see the previous my comments. It's somewhat similar to leaving comments on a social networking site.*"

Facilitating a Complete Divergent and Convergent Thinking Process. *Task Cards, Design Cards*, and *Evaluation Cards*, as tools throughout the workshop process, established a structured thinking framework for creative generation. Specifically, *Task Cards* serve as the starting point for exploring design directions for constructing group mind maps. As P9 pointed out, "*Task Cards assist in creative thinking, and the proposals diverge, filter, and evaluate based on the cards.*"

Secondly, *Design Cards* facilitate the process of deriving and refining ideas. With a rough design direction and initial design proposals in place, using *Design Cards* helps quickly enhance understanding of data physicalization techniques and solidify solutions from multiple perspectives. For example, P2 suggested, "*The express of visual coding made me pay more attention to the form of visualization."* P16 stated, "*The illustration of data mapping further stimulated my thinking about coffee data extraction, such as color, coffee ground shape and texture, taste, etc."* P1 believed, "*The context illustrations made me consider aspects that I hadn't originally thought of."*

Evaluation Cards played a crucial role in evaluating and improving the final ideas, facilitating reflection on design choices and supplementing design details. For example, P12 stated, "*Evaluation Cards make the logic and structure of the design solution clearer, and unnecessary features and interactive operations were removed based on the evaluation cards."* P10 mentioned, "*Evaluation Cards prompted us to reconsider the connection between physical and web prototypes, and we added a tree image on the web page to maintain visual consistency."* P9 expressed, "*Evaluation Cards pushed me to think and clearly articulate the logical aspects involved on the cards."* P3 stated, "*Using Evaluation Cards, I supplemented some previously unconsidered aspects, such as technical means. It allows me to more comprehensively articulate that the design content is appropriate and reasonable."*

Practical Considerations for Embedding Data Physicalization into Real-World Scenarios. During the process of using DataVisage to assist creative design, participants were advised to consider their own proposals in the context of practical applications. The cards helped participants generate creative ideas sensibly and rationally select and improve design ideas from the perspective of data physicalization's performance, interaction, and practical usability. Ultimately, they generated comprehensive concepts based on daily life. P15 stated, "*The Interaction in Design Cards made me think about specific means, such as how to create a sense of immersion."* P6 mentioned, "*The Interaction in Design Cards helped me consider whether the design should be more entertaining or more rigorous and official."* P14 pointed out, "*When considering the context, I brought in the user's perspective and thought about my needs before and after using this prototype and what reflections I expect. Through this approach, I can create a real scenario to design a complete usage process."*

Benefits to the Details and Layout of the Card Design. Clear and concise design aided participants in quickly grasping information within limited time. For instance, participants indicated that the metaphor with example images serve as a means of "instant understanding" (P9), allowing for an intuitive comprehension of the intended meaning. The categorization and case descriptions on the *Design Cards* effectively stimulated divergent thinking, including association. For instance, P19 stated, "*The plant pattern on the Design Cards made me think about whether animal images like pufferfish or hedgehogs could also be used to represent psychological emotions."* P1 stated, "*The examples on the Context Cards provided excellent suggestions for the potential effects, thereby elevating our design.* "

Challenges. Participants provided constructive suggestions for the design of the cards. For example, there is room for improvement in the elaboration of data mapping. For

instance, P8 pointed out that "*Instead of relying solely on text and graphics, creativity generation can be stimulated by variations in the texture, and even scent of the cards.*"

5 Discussion

This paper proposes a card-based design workshop method as a means to construct the process of data physicalization, assisting designers in logically designing prototypes for data physicalization and enabling subsequent refinement and improvement. In this process, the groups utilize means such as physical sculptures and computer modeling to realize the production of data physicalization solutions. By combining qualitative and quantitative data, we present some indications to guide the process of creating data physicalization.

5.1 Full Utilization of Individual and Teamwork

Group collaboration and individual capabilities need to be balanced and utilized effectively, especially for new designers who tend to favor teamwork while overlooking the importance of individual independent thinking [26]. In this study, in order to balance the power dynamics among designers and avoid a leader prevailing, brainwriting exercises and rotating speaking method were introduced to enhance individual expression, ensuring that everyone's thoughts are equally represented. Additionally, the use of DataVisage further subdivided task details, providing each team member with a starting point for divergent thinking, enabling everyone to participate in the refinement and decision-making process of the final solution [21].

5.2 Establishing Suitable Mapping Strategies of Data Physicalization

In this study, a data physicalization strategy was constructed through DataVisage, by categorizing *Visual Coding, Interaction*, and *Context*, which supported participants in considering the content of prototype construction. Throughout this process, participants were guided to create design solutions that align with logical thinking by providing concepts, questions, and case studies. Enabling designers to think about the bottom and top layers of prototypes from shallow to deep. Additionally, prior research suggests the creation of more rigorous design frameworks through iterative approaches [8]. Building upon the integration and iteration of previous research, our work proposes the design strategy for designers, serving as a and further exploration of previous experiences. The evaluation of participants' feedback on the DataVisage highlighted the importance of card-guided thinking logic, such as framing design directions and encouraging creative divergence. Additionally, other methods such as involving participants in the formulation of design frameworks [8] and integrating interdisciplinary knowledge [9] may also effective ways to enhance and refine design approaches.

5.3 Guarantee a Fluid Design Thinking Process

Previous researches have emphasized the importance of creating a fluent thinking process [22]. DataVisage establishes the entry, process, and output of design thinking to ensure logical and smooth thinking within a limited time. Participants can focus on the scope and specific directions defined by the *Task Cards*, combine them with their own practical insights to propose meaningful design opportunities and solutions, and purposefully refine and select solutions based on *Design Cards* and *Evaluation Cards*. This approach prevents participants from feeling lost or stuck in one direction. By combining exploratory thinking with hands-on construction and integrating workshop procedures, cards, and physical materials, DataVisage facilitates a multidimensional and practical design exploration process. Further exploration can be conducted from a technological standpoint, utilizing 3D printing techniques [27], VR [28]. AR [29], to enable rapid prototyping and more extensive multi-sensory interactions with data. Alternatively, the integration of different tools, such as creating multi-modal design cards, may stimulate design creativity.

6 Limitations and Future Work

In this workshop, the participants did not achieve a well-balanced gender ratio, which may raise concerns about the generalizability of the results. We will address this issue in subsequent iterations and validation of the workshops. Besides, the design and prototyping process of the workshop took place within a laboratory environment, where participants' creativity and ideas were based on their own experiences rather than real-life exploration. Therefore, when considering the application of data physicalization in real-world scenarios, although participants engaged in thoughtful reflection and review using the ideation cards, there may still be a tendency for design ideas to remain detached from practical contexts. To optimize this situation, we can further integrate and improve design concepts in everyday life. Our future designs aim to integrate the workshop with daily life, helping designers identify problems and design opportunities from real-life experiences.

7 Conclusion

This paper proposes a card-based design workshop to support the creation of design ideations for data physicalization. By designing a data mapping strategy and integrating it with the workshop process, a fluent and efficient structured artifact creation process is achieved. 19 designers engaged in this workshop, aiming at promoting users' self-reflection and health promotion in the domain of proactive health, resulting in the creation of 5 design concepts. The quantitative results demonstrated the role of the ideation cards in standardizing the design process and promoting creative generation. The qualitative results highlighted the effectiveness of organizing design thinking and balancing individual and group collaboration. Our contribution lies in providing a design method for data physicalization, and gains insights for future related researches.

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Appendix 1. Questionnaire

Dimensions	Items	
Perceived Usefulness (PU)	PU1	The cards provide clear-cut usage instructions
	PU2	The cards have well-defined design keywords and descriptions
	PU3	The cards provide clear examples
	PU4	The cards have clear and easy-to-understand visual design
	PU5	The cards improved the quality of design ideas
Perceived Ease of Use (EU)	EU1	The content is easy to understand
	EU2	The presented knowledge can easily inspire design ideations
	EU3	The examples and guidance can help quickly generate ideas
Ideation (ID)	ID1	The cards can help identify and dig out design problems
	ID2	The cards can help generate more ideas
	ID3	The cards can help in the selection and integration of creative design proposals
Evaluation (EV)	EV1	The cards can help evaluate and inspect ideas
	EV2	The cards can help evaluate creative ideas from different perspectives
	EV3	The cards can help refine and improve ideas

References

1. Djavaherpour, H., et al.: Data to physicalization: a survey of the physical rendering process. Comput. Graph. Forum. **40**, 569–598 (2021). https://doi.org/10.1111/cgf.14330
2. Peschke, J., Göbel, F., Gründer, T., Keck, M., Kammer, D., Groh, R.: DepthTouch: an elastic surface for tangible computing. In: Proceedings of the International Working Conference on Advanced Visual Interfaces, pp. 770–771. ACM, Capri Island Italy (2012). https://doi.org/10.1145/2254556.2254706
3. Zuckerman, O., Gal-Oz, A.: To TUI or not to TUI: evaluating performance and preference in tangible vs. graphical user interfaces. Int. J. Hum.-Comput. Stud. **71**, 803–820 (2013). https://doi.org/10.1016/j.ijhcs.2013.04.003

4. Jansen, Y., et al.: Opportunities and challenges for data physicalization. In: Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems. pp. 3227–3236. Association for Computing Machinery, New York, NY, USA (2015). https://doi.org/10.1145/2702123.2702180
5. Wang, Y., et al.: An emotional response to the value of visualization. IEEE Comput. Graph. Appl. **39**, 8–17 (2019). https://doi.org/10.1109/MCG.2019.2923483
6. Lallemand, C., Oomen, M.: The candy workshop: supporting rich sensory modalities in constructive data physicalization. In: CHI Conference on Human Factors in Computing Systems Extended Abstracts, pp. 1–7. ACM, New Orleans LA USA (2022). https://doi.org/10.1145/3491101.3519648
7. Karyda, M., Wilde, D., Kjarsgaard, M.G.: Narrative physicalization: supporting interactive engagement with personal data. IEEE Comput. Graph. Appl. **41**, 74–86 (2021). https://doi.org/10.1109/MCG.2020.3025078
8. Khot, R.A., Hjorth, L., Mueller, F.: Shelfie: a framework for designing material representations of physical activity data. ACM Trans. Comput.-Hum. Interact. **27**, 1–52 (2020). https://doi.org/10.1145/3379539
9. Bae, S.S., Zheng, C., West, M.E., Do, E.Y.-L., Huron, S., Szafir, D.A.: Making data tangible: a cross-disciplinary design space for data physicalization. In: CHI Conference on Human Factors in Computing Systems, pp. 1–18. ACM, New Orleans LA USA (2022). https://doi.org/10.1145/3491102.3501939
10. Hull, C., Willett, W.: Building with data: architectural models as inspiration for data physicalization. In: Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, pp. 1217–1264. ACM, Denver Colorado USA (2017). https://doi.org/10.1145/3025453.3025850
11. Offenhuber, D., Telhan, O.: Indexical visualization—the data-less information display. In: Ekman, U., Bolter, J.D., Diaz, L., Sondergaard, M., Engberg, M. (eds.) Ubiquitous Computing, Complexity, and Culture, pp. 288–302. Routledge (2015). https://doi.org/10.4324/9781315781129-31
12. Forlizzi, J., Battarbee, K.: Understanding experience in interactive systems. In: Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques, pp. 261–268. ACM, Cambridge MA USA (2004). https://doi.org/10.1145/1013115.1013152
13. Lin, J.J., Mamykina, L., Lindtner, S., Delajoux, G., Strub, H.B.: Fish'n'Steps: encouraging physical activity with an interactive computer game. In: Dourish, P., Friday, A. (eds.) UbiComp 2006. LNCS, vol. 4206, pp. 261–278. Springer, Heidelberg (2006). https://doi.org/10.1007/11853565_16
14. Yu, B., Arents, R., Hu, J., Funk, M., Feijs, L.: Heart calligraphy: an abstract portrait inside the body. In: Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction, pp. 675–680. ACM, Eindhoven Netherlands (2016). https://doi.org/10.1145/2839462.2856341
15. Stusak, S., Tabard, A., Sauka, F., Khot, R.A., Butz, A.: Activity sculptures: exploring the impact of physical visualizations on running activity. IEEE Trans. Vis. Comput. Graph. **20**, 2201–2210 (2014). https://doi.org/10.1109/TVCG.2014.2352953
16. Evergreen, S., Metzner, C.: Design principles for data visualization in evaluation: design principles for data visualization. New Dir. Eval. **2013**, 5–20 (2013). https://doi.org/10.1002/ev.20071
17. Sauvé, K., Sturdee, M., Houben, S.: Physecology: a conceptual framework to describe data physicalizations in their real-world context. ACM Trans. Comput.-Hum. Interact. **29**, 1–33 (2022). https://doi.org/10.1145/3505590

18. Sauvé, K., Verweij, D., Alexander, J., Houben, S.: Reconfiguration strategies with composite data physicalizations. In: Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, pp. 1–18. ACM, Yokohama Japan (2021). https://doi.org/10.1145/3411764.3445746
19. Panagiotidou, G., Görücü, S., Moere, A.V.: Data Badges: Making an Academic Profile through a DIY Wearable Physicalisation. https://doi.org/10.1109/MCG.2020.3025504
20. Thudt, A., Hinrichs, U., Huron, S., Carpendale, S.: Self-reflection and personal physicalization construction. In: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, pp. 1–13. Association for Computing Machinery, New York, NY, USA (2018). https://doi.org/10.1145/3173574.3173728
21. Mora, S., Gianni, F., Divitini, M.: Tiles: a card-based ideation toolkit for the Internet of Things. In: Proceedings of the 2017 Conference on Designing Interactive Systems, pp. 587–598. ACM, Edinburgh United Kingdom (2017). https://doi.org/10.1145/3064663.3064699
22. Huron, S., Gourlet, P., Hinrichs, U., Hogan, T., Jansen, Y.: Let's get physical: promoting data physicalization in workshop formats. In: Proceedings of the 2017 Conference on Designing Interactive Systems, pp. 1409–1422. ACM, Edinburgh United Kingdom (2017). https://doi.org/10.1145/3064663.3064798
23. Deng, Y., Antle, A.N., Neustaedter, C.: Tango cards: a card-based design tool for informing the design of tangible learning games. In: Proceedings of the 2014 conference on Designing interactive systems. pp. 695–704. ACM, Vancouver BC Canada (2014). https://doi.org/10.1145/2598510.2598601
24. Ferreira, F.K., Song, E.H., Gomes, H., Garcia, E.B., Ferreira, L.M.: New mindset in scientific method in the health field: design Thinking. Clinics **70**, 770–772 (2015). https://doi.org/10.6061/clinics/2015(12)01
25. IBM SPSS Statistics | IBM, https://www.ibm.com/products/spss-statistics. Accessed 20 Jul 2023
26. Truong, K.N., Hayes, G.R., Abowd, G.D.: Storyboarding: an empirical determination of best practices and effective guidelines. In: Proceedings of the 6th conference on Designing Interactive systems, pp. 12–21. ACM, University Park PA USA (2006). https://doi.org/10.1145/1142405.1142410
27. Mueller, S., et al.: WirePrint: 3D printed previews for fast prototyping. In: Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology, pp. 273–280. ACM, Honolulu Hawaii USA (2014). https://doi.org/10.1145/2642918.2647359
28. Seth, A., Vance, J.M., Oliver, J.H.: Virtual reality for assembly methods prototyping: a review. Virtual Real. **15**, 5–20 (2011). https://doi.org/10.1007/s10055-009-0153-y
29. Freitas, G., Pinho, M.S., Silveira, M.S., Maurer, F.: A systematic review of rapid prototyping tools for augmented reality. In: 2020 22nd Symposium on Virtual and Augmented Reality (SVR), pp. 199–209. IEEE, Porto de Galinhas, Brazil (2020). https://doi.org/10.1109/SVR51698.2020.00041