Image Schema Objects: Evaluating Tangible Image Schema Representations as Data Physicalisation Design Tool

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Abstract

Giving data a tangible form is promising to foster understanding and engagement. Nevertheless, analyses of current data physicalisations revealed that the majority do not use the potential of material and multimodality. We propose image schemas as a tool for facilitating the creation of data physicalisations, as these abstract mental representations of interactions with the world promise to advance design. In an earlier stage, we developed tangible instantiations of image schemas, so called Image Schema Objects to make image schema theory useable as design tool. In this work, we describe the tools' assessment: used by designers to envision concepts for data physicalisations. We gathered qualitative and quantitative data to assess the effect and use of the tools. Even no evidence for impact on the design process was found, participants and expert rater assessed the ideas to be more active and participants also as more innovative.

Keywords

Data Physicalisation, Image Schemas, Design, Design Research, Evaluation

1. Introduction

Data physicalisations are artefacts that convey data through their material characteristics or shape [1]. To engage the audience, produce a more meaningful representation of data, and for artistic expression [2], this form of data representation is promising. Nevertheless, the majority of actual data physicalisations do not adhere the potential of the physical medium. They are generic depictions that make use of arbitrary material selection [3] and abstract metaphors [4]. They focus on vision [5, 4, 3, 6, 7] and are passive [4, 3]. To address this, we propose image schemas to facilitate the design of data physicalisations. Image schemas describe abstract mental representations of dynamic, recurring patterns of body interactions [8]. They showed to support the design process of user interfaces: They provide guidance and structure [9, 10, 11], inspire and facilitate the generation of ideas [12, 13, 9, 14, 15, 16, 11]. Designs influenced by image schemas showed to be more innovative [14, 17, 11, 18] and intuitive [19, 20, 21, 22, 14, 17, 10, 15]. This makes image schemas also promising to foster the design of data physicalisation. Furthermore, as image schemas are multimodal [23, 24, 9, 25, 26] and based on interaction experiences with the world [23], and therefore might also have the potential to facilitate more active, interactive, multimodal, and tangible designs. However, the application of image schemas in the design phase requires additional effort and time [15, 14, 18]. To overcome this, a new way to employ image schemas as easily applicable design tool is required. Previous research evidenced, that the manner in which the image schemas are represented has an effect on the creative process [27, 28, 29]. On this background, we developed and compared visual and tangible image schema representations [30, 31]. As next step, the assessment of the tangible representations within the design process of data physicalisation is presented in this paper. To examine the effect on the design process and the resulting design ideas, we gathered quantitative and qualitative data.

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2. Background

2.1. Data Physicalisation

A "physical artifact whose geometry or material properties encode data" [1] (p. 3228) states the definition of a data physicalisation. This type of data representation has the potential to facilitate exploration, data communication and representation, engagement with data, as well as sense-making and comprehension [32, 33, 1, 34, 35]. Research has been conducted on the physicalisations' accessibility, perception, and readability [36, 37], yet the design activity of data physicalisations remains relatively unexplored [38, 6, 7, 39].

The data physicalisation community has been engaged in analysing current data physicalisations and developing theoretical frameworks [40, 41, 4, 42, 3, 43, 44, 45, 46, 47, 48, 49, 50, 51]. This methodology offers insight into the data physicalisation landscape and shows that the full potential of the medium is not used. The utilisation of abstract metaphors often results in generic representations [4] and only a small number of data physicalisations employ material with a metaphorical relationship to the presented data [3]. Previous research has highlighted the efficacy to use (image-schematic) metaphors as well as using material and its properties metaphorically to facilitate the comprehension of data [43, 52], but this potential is only rarely used. Moreover, many physicalisations pertain to the visual sense [5, 4, 3, 6, 7] and are passive [4, 3]. The theoretical frameworks generated by these analyses were criticised to be complex and challenging to implement in the design process [53]. The necessity of easily applicable design tools has been stated [54].

2.2. Image Schemas

In 1987, Lakoff [55] and Johnson [23] presented image schemas in cognitive linguistics. Image schemas were described as "recurring, dynamic pattern[s] of perceptual interactions and motor programs that give coherence and structure to our experience" [23](p. xiv). They connect embodied sensations and mental representations [23, 55], thereby organising human perception and experiences and advancing our comprehension of the world [26, 8, 56, 57, 11]. For instance, the UP-DOWN image schema is encountered in daily life (e.g., when we use an elevator to get to the upper floor, or when we place objects on the floor or in a high shelf), but also in data representations (e.g., high and low columns in a bar chart or a graph moving up or down).

When a specific image schema is attributed to an abstract notion that lacks a physical equivalent, an image-schematic metaphor develops [9, 28, 24, 11]. Mapping image schemas to abstract domains allows to reason about these domains [23]. The image schema UP-DOWN is linked to a number of abstract domains. For instance, it is connected with our experience of quantity, which forms the image-schematic metaphor MORE IS UP – LESS IS DOWN. A high stack of books (UP) indicates a large number, similar to a high column representing a big data value.

2.3. Image Schemas for Design

Using image schemas in interface design demonstrated to foster the development of more innovative [14, 17, 11, 18] and intuitive [19, 20, 21, 22, 14, 17, 10, 15] designs. Furthermore, image schemas showed to work as inspiration to promote idea generation [12, 13, 9, 14, 15, 16, 11] and structured the design process [11]. However, applying image schemas in design requires additional time and effort [14, 15, 18]. It is recommended to utilise image schema lists to minimise this [25, 58, 18]. The Image Schema CATalouge (ISCAT) [59] provides such a list. It presents a comprehensive collection of image schemas and metaphors, but due to its amount of information and intricate structure it does not provide an easily applicable design tool. Furthermore, research showed that image schemas' understanding and their effect on the design process is contingent upon their way of instantiation [27, 28, 29]. The utilisation of tangible representations was found to enhance the development of more visual, haptic, and interactive design concepts, whereas visual representations were easier to identify and showed to encourage the generation of a greater number of ideas [60].

Figure 1: From left to right, last row: tangible representations of CONTENT-CONTAINER, STRAIGHT-CROOKED, SMOOTH-ROUGH, UP-DOWN; second last row: LEFT-RIGHT, SOFT-HARD, PAINFUL, HEAVY-LIGHT; second front row: WHOLE-PART, PERIPHERY-CENTRE, FAR-NEAR; front row: STRONG-WEAK, LINKAGE, OBJECT

2.4. Image Schemas to support Data Physicalisation Design

Also in the context of data physicalisation, image schemas can enhance creativity [12, 13, 9, 14, 15, 16, 11]. Because of their abstractness, they afford the designer greater flexibility, what facilitates the generation of more innovative solutions [24, 15]. Image schemas facilitate also the generation of more intuitive designs [22, 10, 21, 19, 20, 15, 14, 17]. Design decisions influenced by image schemas, reflect humans' mental models [15] whereas image-schematic metaphors provide links to abstract domains [23]. Image schemas could assist in the selection and metaphorical use of materials related to the represented data, as well as the selection of meaningful metaphors. Derived from interactive experiences with the environment [23], image schemas can be classified as static or dynamic [26, 61]. This may foster the creation of more interactive and active design concepts, while their multimodal nature [23, 24, 9, 25, 26] could encourage the development of more multisensory designs. However, an easily applicable method of expressing and incorporating image schemas as design tools is necessary to overcome the extra time and effort required to use image schemas for design.

In previous work, we created tangible design tools based on image schema theory [31]. For these tangible Image Schema Objects (IS-Objects) we selected 14 image schemas, that were promising to support data physicalisation design. They are made of clay and highlight in blue colour the key characteristics of each image schema (Figure 1). The objects embody image schemas and provide abstract tangible and material inspiration to the design process. They address different sensory modalities and their re-arrangeable parts are intended to foster more active and interactive design ideas.

In this work, we present the first evaluation of the tangible image schema instantiations as tool for designing data physicalisations. We examined the effect of the objects on the design activity as well as the resulting ideas. We expect the tools to create a more positive design process experience, like a higher experience of flow and performance and less concern, lower task demand, mental demand, effort and frustration. Regarding the effect on the design ideas, we expect the IS-Objects to foster more innovative, intuitive, active, interactive, multimodal and tangible ideas.

3. Method

3.1. Participants and Procedure

The study involved twenty-two design experts and students. Participants' mean age was 25.73 years (SD = 3.87 years), while the mean experience in design was 6.75 years (SD = 6.29 years). The session commenced with giving informed consent, the presentation of a brief video to introduce the concept of

Dependent Variable	Questionnaire	Scale
Design Process	Flow Short Scale: Flow [62]	7-point Lickert scale, 1 = not at all to 4 = partly to 7 = very much
Design Process	Flow Short Scale: Concern [62]	7-point Lickert scale,1 = not at all to 4 = partly to 7 = very much
Design Process	Flow Short Scale: Task Demand [62]	9-point Lickert scale, 1 = too low to 5 = just right to 7 = too high
Design Process	NASA-TLX: Mental Demand [63]	20-point Lickert scale, 1 = Very Low to 20 = Very High
Design Process	NASA-TLX: Effort [63]	20-point Lickert scale, 1 = Very Low to 20 = Very High
Design Process	NASA-TLX: Frustration [63]	20-point Lickert scale, 1 = Very Low to 20 = Very High
Design Process	NASA-TLX: Performance [63]	20-point Lickert scale, 1 = Failure to 20 = Perfect
Design Process	Interview Questions	"Did you feel more positive about the idea generation process from the first or second task? Why?"
Design Process	Observation	
Innovativeness	UEQ+: Novelty [64]	7-point Lickert scales, 1-7, dull-creative, conventional-inventive, usual-leading edge, conservative-innovative
Intuitiveness	UEQ+: Intuitive Use [64]	7-point Lickert scales, 1-7, difficult-easy, illogical-logical, not plausible-plausible, inconclusive-conclusive
Activity	Self-developed scale	7-point Lickert Scale, 1 = passive to 7 = active
Interactivity	Self-developed scale	7-point Lickert Scale, 1 = not interactive to 7 = interactive
Multimodality	Interview question	"Which senses were addressed?"
Tangibility	Self-developed scale	7-point Lickert Scale, 1 = visual to 7 = physical

Table 1
Assessed variables and methods used for data collection.

data physicalisation, and a questionnaire requesting demographic information and design experience. The initial task, which lasted twenty minutes, started with providing written instructions and the dataset (included as Supplementary Material A and B). The participants were required to devise and illustrate design concepts to physicalise the provided dataset. During the design action, observations were made, and videos were recorded. Subsequently, participants provided a brief interview in which they shared their thoughts on the generated ideas and completed a series of questionnaires. A short break followed. In the second part, participants were required to conduct the assignment once more, now using the IS-Objects. The participants again completed the design assignment, interview, and questionnaires. Additionally, we now asked participants in the interview to compare ideas and design processes. The design task without IS-Objects which was conducted initial, and the subsequent design task applying IS-Objects were conducted in a univariate within-subject design. This order was chosen to avoid the IS-Objects influencing the without-tool-condition. The study was approved by the university's ethics board.

3.2. Data Collection and Analysis

For collecting data regarding the dependent variables 1) design process experience and 2) rating of design ideas, the questionnaires and scales listed in Table 1 were employed. The full questionnaires and interview questions are provided as Supplementary Material C and D.

The interview data was organised and analysed using Contextual Design as approach for data analysis [65]. For analysing the quantitative data we used the statistics software JASP [66]. Additionally, using the same questionnaires, an expert in data physicalisation design, who has been active in the field as a researcher and designer since 2019, evaluated the design ideas. For this, the participant-produced drawings were accompanied by bullet-point explanations excerpted from the interviews and provided in randomised order to the expert.

4. Results

Dependent t-Tests were employed to evaluate significant differences across conditions. When data was not normally distributed or when outliers appeared, we employed the Wilcoxon-Signed-Ranked test. No data values were missing, and no outliers were excluded. We set the significance level at alpha = .05. The Bonferoni-Holm p-values were employed to adjust the multivariate findings of the participant self-assessment and the expert rater's evaluation. To assess multimodality, the number of sensory modalities which were addressed by the generated ideas were set in relation to the total number of generated ideas. We differentiated full ideas (count 1) and ideas that were added to or varied from previous ideas (count 0.5). Table 2 presents the results of the questionnaires used to gauge the participants' experience of the design activity.

4.1. Design Process

Reviewing the observational data revealed that design processes were highly individualistic. We identified four methods for interacting with the IS-Objects: a) No Physical Interaction, b) Occasional Physical Interaction, c) Exploration Phase, and d) Exploration Phase & Occasional Interaction.

In the interviews participants indicated there was an excessive number of opportunities and distractions provided by the IS-Objects, which they perceived as overwhelming. Therefore, participants recommended to present less objects (P4, P2, P12, P21, P22, P5). Furthermore, it was perceived as challenging to simultaneously study the objects and develop ideas (P21, P22, P2). Some participants expressed that they were inspired by the artefacts (P5, P6, P7, P8, P9, P10, P11). Others indicated that the

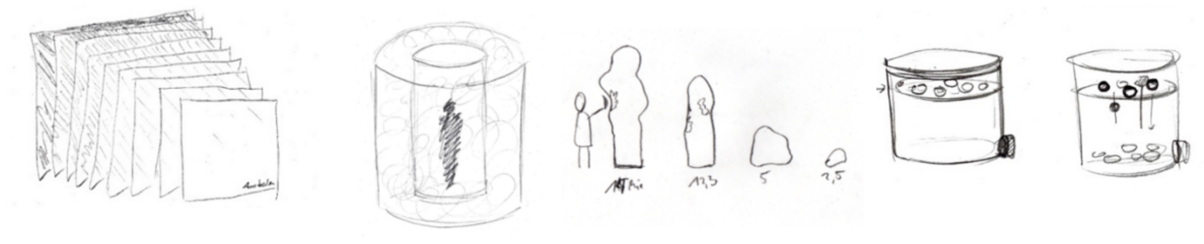
Dependent variable	**Items**	**Descriptive**		**Test results**
		Without	IS-Objects	
Design process	FSS: Flow	M = 5.10 SD = 0.90	M = 5.06 SD = 1.12	$t(21)$ = .138, p = .554, d = .029
Design process	FSS: Concern	M = 2.33 SD = 1.46	M = 2.49 SD = 1.52	z = .879, p = .819, r = .267
Design process	FSS: Task demand	M = 4.86 SD = 0.83	M = 4.91 SD = 97	z = .296, p = .655, r = .111
Design process	NASA-TLX: Mental demand	M = 11.23 SD = 4.02	M = 10.09 SD = 4.66	$t(21)$ = .946, p = .117, d = 202
Design process	NASA-TLX: Effort	M = 10.14 SD = 3.90	M = 9.27 SD = 5.22	$t(21)$ = .800, p = .216, d = 171
Design process	NASA-TLX: Frustration	M = 5.41 SD = 5.00	M = 5.14 SD = 4.70	z = .052, p = .490, r = .015
Design process	NASA-TLX: Performance	M = 6.55 SD = 3.64	M = 6.82 SD = 5.52	z = .000, p = .509, r = .000

Table 2
Effect of IS-Objects on the data physicalisation design activity.

objects encouraged them to explore unconventional ways of thought, to differentiate their ideas from the objects (P6, P8, P14). Furthermore, some participants (P6, P14, P16) expressed greater satisfaction with the ideas informed by IS-Objects. While some participants (P10, P15, P20) perceived the image schema names that accompanied the objects to be as or even more useful than the objects themselves, other participants (P19, P4, P3) placed greater value on the objects due to the visual support and the information, materiality, and properties, they provided. With regard to the dataset, the response of the participants once again demonstrated a divergence of opinions. While some (P6, P16) perceived the objects as facilitating their comprehension of the data, others (P5, P10, P13, P20) experienced difficulty in establishing a connection between the objects and the abstract data.

4.2. Design Outcome

Table 3 presents participants' and expert's evaluation of the generated design ideas using the proposed questionnaires. Sketches provided in Figure 2 represent some of the envisioned design ideas.



a) b) c) d)

Figure 2: Example design ideas generated without image schemas: a) big sheets of different shades of grey represent by their colour the CO2 emissions of different countries; b) a person stands inside of two concentric arranged glass cylinders, the amount of smoke between the two cylinders represents CO2 emissions. Example design idea generated with image schemas: c) abstract objects represent different age groups, physical interaction causes deformations which represents internet user data; d) mumbles represent countries' CO2 emissions by weight. A sorting mechanism reveals which countries have the highest emissions.

5. Discussion

In a within-subject-design study we investigated if the utilisation of IS-Objects facilitates a less demanding design activity and encourages to generate more innovative, intuitive, active, interactive, multimodal, and tangible, design ideas.

5.1. Design Process

Previous studies showed that image schemas can be used in a variety of design methods [14], structure [11], and guide the design process [9, 10]. In this work, image schemas were applied to the idea generation process for data physicalisations and four strategies for utilising the tools were identified, what proved the IS-Objects to be flexible and to adapt to individuals' needs. Furthermore, our hypothesis expected that the IS-Objects foster a less demanding design process, in comparison to a design process without design tools. Lacking significant findings from the statistical analysis, the hypothesis cannot be confirmed. Previous research showing image schemas' inspirative power [12, 13, 9, 14, 15, 16, 11] is supported by participants' statements which revealed that IS-Objects provided inspiration and were helpful as a catalyst for thinking in unconventional directions. Other participants felt overwhelmed by the number and necessity to explore the objects or preferred the image schema names before the tangible objects. These contradicting results might be caused by the heterogenous group including design students as well as experienced designers. Perhaps participants with more design experience

Dependent variable	Items	Descriptive		Test result	Interview statement
		Without	IS-Objects		
Innovativeness self-rating	UEQ+: Novelty	M = 4.07 SD = 1.03	M = 4.75 SD = 1.58	z = 2.072, p = .020*, r = .529 corrected a-level: p = .040*	More creative (P6, P8, P10, P14, P15, P16, P17); More concrete (P19, P22)
Innovativeness expert-rating	UEQ+: Novelty	M = 4.06 SD = 1.24	M = 4.36 SD = 1.17	t(20) = .832, p = .208, d = .182 corrected a-level: p = .208	
Intuitiveness self-rating	UEQ+: Intuitive use	M = 5.42 SD = 0.96	M = 5.26 SD = 1.11	z = 89.000, p = .732 r = .163 corrected a-level: p = .732	
Intuitiveness expert-rating	UEQ+: Intuitive use	M = 4.73 SD = 0.77	M = 4.83 SD = 0.59	t(20) = .442, p = .331, d = .097 corrected a-level: p = .662	
Activity self-rating	Semantic differential	M = 3.50 SD = 1.66	M = 5.00 SD = 1.63	z = 2.651, p = .004*, r = .732 corrected a-level: p = .004*	
Activity expert-rating	Semantic differential	M = 2.67 SD = 0.97	M = 3.87 SD = 1.43	t(20) = 3.620, p <.001*, d = .790	
Interactivity self-rating	Semantic differential	M = 4.00 SD = 1.85	M = 5.41 SD = 1.71	z = 2.112, p = .018*, r = .567 corrected a-level: p = .036*	More interactive (P3, P11, P15)
Interactivity expert-rating	Semantic differential	M = 3.82 SD = 1.28	M = 3.63 SD = 1.47	z = 109.000, p = .720, r = .147 corrected a-level: p = .720	
Multimodality self-rating	Count	M = 1.56 SD = 0.49	M = 0.92 SD = 0.25	z = 109.000, p = .290, r = .138 corrected a-level: p >.999	More multimodal (P3, P14, P19)
Multimodality expert-rating	Count	M = 1.32 SD = 0.25	M = 1.29 SD = 0.26	t(20) = .378, p = .645, d = .082 corrected a-level: p >.999	
Tangibility self-rating	Semantic differential	M = 3.27 SD = 1.42	M = 4.73 SD = 1.86	t(21) = 3.269, p = .002*, d = .697 corrected a-level: p = .004*	
Tangibility expert-rating	Semantic differential	M = 3.71 SD = 1.27	M = 4.02 SD = 1.60	t(20) = .708, p = .244, d = .155 corrected a-level: p = .244	

*Significant difference

Table 3
Effect of IS-Objects on the generated data physicalisation design ideas.

benefited from the objects, while novice designers felt more overwhelmed by the task and the tools. To investigate this further, an analysis how the tools integrate in designers' workflows and thinking could provide insights.

5.2. Design Outcome

Participants' self-ratings of ideas' innovativeness provided significant evidence. It confirms our hypothesis that IS-Objects foster more innovative ideas compared to ideas generated without. Also, the expert rater experienced ideas developed with IS-Objects to be more innovative, but without significant evidence. Furthermore, participants stated in interviews that using IS-Objects enabled them to create more creative ideas. This study confirms previous work which showed that user interfaces created with image schemas are more innovative [14, 17, 11, 18] and shows that image schemas can also foster the generation of more innovative ideas for data physicalisations.

Our hypothesis expected IS-Objects to foster more intuitive ideas, cannot be verified. While some participants found the objects helpful in identifying visualisation options for abstract data, other participants found it difficult to make the connection. Also, statistical analysis provided no evidence. According to previous studies, interfaces created by using image schemas as a design strategy are more intuitive [19, 20, 21, 22, 14, 17, 10, 15]. This is not verified for the IS-Objects in the data physicalisation domain. The lack of evidence might be explained as previous methods identified image schemas in spatial location and motion [67] or retrieved them from analysing the context of use [9, 10] and then integrated them into interactive system designs. Users' mental models within specific domains of application were identified and subsequently incorporated into the design. In contrast, in our study, image schemas were selected because of their prospective value for supporting and addressing the underutilised possibilities of data physicalisation design, but without considering the context of the dataset. As mentioned in literature, using pre-existing selections, risks to ignore the affordances of a particular domain [25]. Furthermore, the way we introduced image schemas differed from previous approaches. There was no introduction or instruction; only tangible representations and the names of the image schemas were given. In previous research, image schema theory was deliberately introduced or training was conducted [67, 9, 14, 10, 11]. Furthermore, we provided image schemas without their metaphorical extensions. Nevertheless, the lack of intuitiveness could be an advantage for data physicalisation design. Data physicalisations aim to provide a richer experience [34, 35], in contrast to information visualisation that is frequently evaluated in terms of effectiveness and efficiency [37]. A more subtle approach of data encoding and representation may encourage more extended and intentional interactions with the data and its physicalisation, leading to a more enduring experience.

The fact that data physicalisations are often passive and lack interactivity is one of their main design challenges [40, 4, 3, 47]. Our hypothesis expected design ideas informed by IS-Objects to be more active and interactive than those created without. Quantitative data confirms this with significant results: Ideas informed by IS-Objects were rated to be more active by participants and experts. Additionally, participants experienced their ideas to be more interactive, what is supported by their interview comments. The expert rater may experienced the ideas lower in interactivity because the drawings and explanations did not accurately display the intended interaction. However, it needs to be stated, that one participant mentioned the interim questionnaire impacted the second design action. So, participants may have become more aware of these aspects and focused more on in the second assignment and evaluation. Therefore, the self-ratings might not be reliable. In future evaluations such possible confounding variables need to be removed. Furthermore, the effect of animated or more interactive versions of the objects, which might better capture the embodied and temporal nature of image schemas and foster more interactive designs should be investigated. Our hypothesis proposed IS-Objects to support more multimodal ideas. According to some participants, the objects encouraged more multimodal ideas (P3, P14, P19,) but no statistical evidence was found, and the descriptive numbers even suggest that ideas informed by image schemas appealed to less sensory modalities (self and expert-rating). Probably the objects demanded too much attention, so participants became aware of, but were not able to incorporate multimodality. Furthermore, the IS-Objects did not incorporate taste, smell or sound but simply provided a visual and tactile experience. The objects may need to appeal to a greater variety of sensory modalities to engage truly multimodal designs.

The ideas developed with IS-Objects were perceived to be more tangible by the participants and experts in descriptive numbers. Significant evidence supporting our hypothesis was only found in the participants' ratings. However, the questionnaires between conditions may have sensitised participants also regarding tangibility and confounded this result. Numerous research showed the importance of image schemas' form of representation and its influence on the design process [27, 28, 29]. The implementation of tangible image schema representations showed to enhance the development of more interactive, visual and tangible design ideas [60]. However, in this study a few participants indicated that the names of image schemas presented on little stands, were beneficial. It is challenging to discern the effects of the tangible representation from those of the labels. However, in general image schemas are promising to encourage a shift from visual towards tangible data representations. Here further research is required.

5.3. Limitations

The administration of questionnaires in between the two design assignments might influenced the subsequent design process. To assess innovativeness and intuitiveness the UEQ+ subscales Innovativeness and Intuitive Use were applied, which each consist of four bipolar items. In contrast, tangibility, activity, and interactivity were each assessed by a single-item-scale. These may had a more pronounced influence on participants. Another constraint was that participants scored all their design ideas at once. In contrast, the expert rater evaluated each idea on its own, what may enhanced expert's ratings. Contrary, as the expert was provided with the created sketches and succinct bullet point explanations, it is possible that the activity, interactivity, and targeted sensory modalities of the concepts were not represented adequately what could lead to lower expert ratings, compared to self-ratings.

6. Conclusion

To investigate the influence of IS-Objects on the data physicalisation design activity and the resulting ideas, we conducted an evaluation study. Although the artefacts were perceived as inspirational, there was no significant evidence to confirm their influence on the design process. This work showed that participants perceived their concepts envisioned using IS-Objects to be more innovative. Experts and participants evaluated the concepts as being more active. Overall, the objects received mixed responses. A series of suggestions and insights with a view to applying the IS-Objects to the data physicalisation design process were collected. In the next step, the IS-Objects are integrated into a toolkit.

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Declaration of Generative AI

The author(s) have not employed any Generative AI tools.

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Appendix

A. Instructions
Task 1: Develop design ideas or concepts for data physicalisations that represent the provided dataset. Develop as many ideas as possible. Sketch the ideas and feel free to add notes to the sketches. The working time is 20 minutes. If you finish earlier, let the experimenter know.

Task 2: Develop design ideas or concepts for data physicalisations that represent the provided dataset. Use the available objects for inspiration. You may touch and interact with the objects. Develop as many ideas as possible. Sketch the ideas and feel free to add notes to the sketches. The working time is 20 minutes. If you finish earlier, let the experimenter know.

B. Datasets
C02 emissions worldwide by country 2020
CO2 emissions: countries by share of global CO2 emissions in 2020

- China 30.65 %
- U.S. 13.54 %
- India 7.02 %
- Russia 4.53 %
- Japan 2.96 %
- Germany 1.85 %
- Canada 1.54 %
- South Africa 1.30 %
- Australia 1.13 %

Internet users by age group in Germany by 2021
Number of internet users by age group in Germany in the years 2003 to 2021 (in millions)

	Age 14 to 19	Age 20 to 39	Age 40 to 59	Age 60 and older
2003	5.00 m.	14.70 m.	12.30 m.	2.50 m.
2012	5.20 m.	19.30 m.	20.80 m.	8.10 m.
2021	4.70 m.	20.00 m.	23.10 m.	18.8 m.

C. Questionnaires
Demographic Data
Please answer the following questions about your education and prior experience:

- How old are you?
- Which subject are you studying?
- In which semester are you studying?
- What is your Major?
- Prior to your current studies, have you had any other design-related education/study/job? If yes, which one?
- How much design experience do you have in years?

Now that you have completed the design task, please evaluate the design ideas and concepts you have developed. Further, please evaluate how you experienced the ideation process you just went through.
UEQ+: Novelty
In my opinion, the idea/the design of the data physicalisations are:

- dull – creative
- conventional – inventive

- usual – leading edge
- conservative – innovative

UEQ+: Intuitive Use
In my opinion, using the data physicalisations (reading the data or interacting with it) is

- difficult – easy
- illogical – logical
- not plausible – plausible
- inconclusive – conclusive

Self Developed Scales
The data physicalisations are:

- passive – active
- not interactive – interactive
- visual – tangible

FSS Flow Shortscale
During the ideation process, I felt:
Flow:

- I felt just the right amount of challenge.
- My thoughts/activities ran fluidly and smoothly.
- I didn't notice time passing.
- I had no difficulty concentrating.
- My mind was completely clear.
- I was totally absorbed in what I was doing.
- The right thoughts/movements occurred of their own accord.
- I knew what I have to do each step of the way.
- I felt that I had everything under control.
- I was completely lost in thought.

Concern:

- Something important to me was at stake here.
- I wasn't allowed to make any mistake here.
- I was worried about failing.

For me the requirements were ... too low – just right – too high
NASA-TLX
Now indicate for each of the dimensions below how much stress you felt. Please mark on the following scales to what extent you felt stressed or challenged by the task in the dimensions mentioned:

- How mentally demanding was the task? (low – high)
- How hard did you have to work to accomplish your level of performance? (low – high)
- How successful were you in accomplishing what you were asked to do? (failure – perfect)
- How insecure, discouraged, irritated, stressed, and annoyed were you? (low – high)

D. Interview Questions
After task 1 and 2:

- Have you sketched all your ideas or could you have thought of more ideas?
- If yes: How many more ideas could you have sketched?
- –Presenting Ideas–

After task 2:

- How would you rate the difficulty of the two datasets on scale of 1 (easy) to 7 (difficult)?
- How did the objects influence your idea generation?
- Would you rate your ideas from the first or second task as more creative? Why?
- Did you feel more positive about the idea generation process from the first or second task? Why?