Dear Pictograph: Investigating the Role of Personalization and Immersion for Consuming and Enjoying Visualizations

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ABSTRACT
Much of the visualization literature focuses on assessment of visual representations with regard to their effectiveness for understanding data. In the present work, we instead focus on making data visualization experiences more enjoyable, to foster deeper engagement with data. We investigate two strategies to make visualization experiences more enjoyable and engaging: personalization, and immersion. We selected pictographs (composed of multiple data glyphs) as this representation affords creative freedom, allowing people to craft symbolic or whimsical shapes of personal significance to represent data. We present the results of a qualitative study with 12 participants crafting pictographs using a large pen-enabled device and while immersed within a VR environment. Our results indicate that personalization and immersion both have positive impact on making visualizations more enjoyable experiences.

Author Keywords
Visualization, Personalization, Immersion, Qualitative Study

CCS Concepts
•**Human-centered computing** → **Human computer interaction (HCI);** *Visualization systems and tools;*

INTRODUCTION
Most visualization research focuses on two major themes: data exploration and storytelling. Yet, Brehmer and Munzner [13] identify a third reason that motivates people to visualize data: *enjoyment*. Enjoying visualizations, while perhaps sometimes dismissed by the scientific community as insignificant, can potentially lead to deeper engagements with the data. For example, aesthetically pleasing visuals may entice people to read a visual story to its end, an important factor for storytelling as Amanda Cox from New York Times explained in a keynote [17]. Making data visualization a fun experience may motivate people to look at their personal data repeatedly and over long periods of time, promoting a deeper understanding of certain aspects of their lives, possibly increasing their well-being [22].

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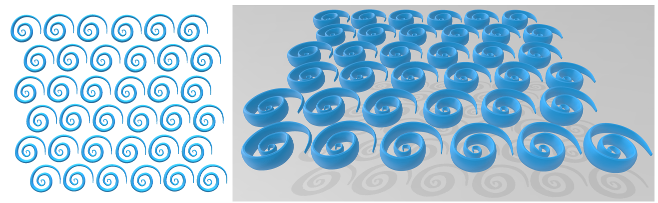


Figure 1. Consuming pictographs in 2D and VR

In this paper, we set out to investigate how we can make data visualization experiences more enjoyable. The first aspect we investigate, **personalization**, is inspired by the Dear Data project [28], a set of hand-drawn whimsical visualizations. We hypothesized that people would enjoy crafting their own visual representations of data. Making visualizations personal could be instrumental during storytelling, helping people to *relate to the data*, and useful for personal data visualization as well, to craft visuals that are *meaningful* to them.

The second aspect we studied, **immersion**, is inspired by Immersive Journalism [41]. We hypothesized that people would enjoy being immersed within the data in a virtual reality (VR) environment. This sense of immersion during a story could help people focus and *think about the data*, and for personal data visualization, to *reflect* on what the data mean about certain aspects of their lives.

To investigate whether these aspects make data visualization experiences more enjoyable, we conducted a qualitative study with 12 participants consuming pictographs (Figure 1). Since there are no established measures to assess enjoyment, we used a mixed methods approach collecting pre-defined objective measures, subjective self-ratings and conducting an open-coding of study observations and think-aloud transcripts.

Insights from our analysis reveals that personalization and immersion do not appear to have a negative impact on the estimation of quantities. Yet, they contribute to multiple aspects of enjoyment. Our results indicate that personalization promotes enjoyment by fostering a deeper thought process about what the data means for people and how to best represent it for themselves.

Data about immersion sheds light on what makes such experiences engaging. While novelty was a major factor in people enjoying these experiences, our results also reveal that immersion may trigger a deeper reflection mechanism, leading people to relate to data through their life experiences and real-world objects they encountered. Our data also indicate that immersive visualization experiences may be challenging to people. Such challenges can lead to frustration when, for example, executing an idea requires the user to dexterously manipulate unfamiliar controllers. However, it can also promote enjoyment by stimulating creativity in designing visuals in more than two dimensions.

Together, these insights contribute new knowledge on the role personalization and immersion play for enjoying visualizations. These insights lead to a set of implications for the design of authoring and consumption tools, as well as opening up new research directions. Study material and anonymized data is available in supplemental material and at `https://dearpictograph.github.io/Pictograph/`.

RELATED WORK

A considerable amount of work in visualization deals with the visual exploration and analysis of data for professional analysts and scientists. As the community turned its attention to the general public, e.g. the masses [43], the focus expanded on helping people extract insights from personal visualizations [20] and engage with storytelling media [38]. Motivation and tasks for these activities may differ from those of more professional users. In particular, a key motivation is to engage people by having fun and spending time with the data rather than gaining any particular insights.

This is a concept that Brehmer and Munzner [13] captured under the term *enjoy*, alongside *discover* and *present* in their taxonomy of visualization tasks. While enjoying a visualization may appear to be a superficial activity, it can actually foster deeper engagement with data by getting people's attention and keeping it [18]. Our motivation with this research is to investigate two aspects that could promote enjoyment: personalization and immersion. We first review the literature on measuring enjoyment and related concepts before delving into personalization and immersion in more depth.

Enjoying visualizations

Since the first edition of the BELIV workshop (Beyond Time And Errors: Novel Evaluation Methods For Visualization) [2], the visualization community has sought to have more insightful metrics other than just task completion time and number of errors [36]. As researchers assessed different storytelling techniques and authoring tools to craft them, several metrics relevant to enjoyment emerged [37, 5].

Memorability. Pioneering work by Bateman et al. [7] initiated an animated discussion in the community about the role of *visual embellishments*, considered at the time "chart junk", a term coined by Tufte, as they served no apparent purpose and were thought to interfere with the understanding of the data. However, Bateman et al.'s study results indicated that they did not seem to interfere with the visualization consumption and had an positive impact on the memorability of the chart. Borkin et al. [10] also used the same metrics, giving insights on elements that make infographics memorable such as colors and the inclusion of recognizable objects.

Engagement. HCI researchers have studied engagement in the context of fluid interaction and have related it closely to aesthetics and having fun [42]. The community generally links engagement to a positive user experience, associated with being captivated and motivated to use an interface [33]. Engagement is a key metric in video game research [31, 45]. In this sense, engagement is perhaps most related to delivering an enjoyable experience. In the visualization community, measuring engagement is relatively novel and has been tackled from two very different perspectives. Boy et al. [11] gathered objective data on the number and quality of interactions during an in-the-wild study, hypothesizing that a strong engagement would lead to more interactions of higher quality with the visualization. In contrast, Amini et al. [5] designed and used a self-rating questionnaire, building it from video game research, to assess different levels of engagement and tease out the aspects that made data videos engaging.

These two approaches have advantages and drawbacks. On one hand, Boy et al.'s data is more objective, providing an ecologically valid environment and limiting the interference of the study experimenter and settings. However, the gathered data captured only a specific aspect of engagement, predefined by the authors, devoid of any insights on the emotions and thought processes of the users. On the other hand, Amini et al.'s data provides insights on multiple aspects of engagement and what participants found most engaging to them. However, the data gathered is highly subjective and potentially affected by the presence of an experimenter and the settings of the study. Our present study attempts to use multiple methods to gather both objective and subjective data, seeking to triangulate them [34] to shed light upon different aspects of engagement and enjoyment.

Enjoyment of Pictographs. Perhaps the most complementary work related to ours regarding the consumption of pictographs is Haroz et al. [19], describing a set of controlled experiments. Conclusions from their studies indicate that pictographs (of very small scale) do not impair viewers for perceiving the data. They also found that people are enticed, at least initially, to direct their attention towards pictographs (rather than more traditional visualizations or text), an effect they named *initial engagement* and measured via the number and order of clicks on blurred thumbnails. Boy et al. [12] explored a different aspect of engagement with pictographs. They investigated if employing anthropomorphic visuals could elicit *empathy* via a series of 7 studies, yet failed to capture any significant signal.

Our present work attempts to capture different aspects of engagement when consuming pictographs. Our results provide a complementary perspective by following a more qualitative approach than this previous work. Our study is also the first to report insights on how personalization and immersion may impact user enjoyment and engagement.

Personalization and Data Sketching

As data and visualization has become more ubiquitous in people's lives, numerous authoring systems have emerged to enable people to design and craft a personalized visual representation of data. To create expressive and unique visualizations, designers have used pictographs for decades, making visuals that closely align with the semantics of the data and

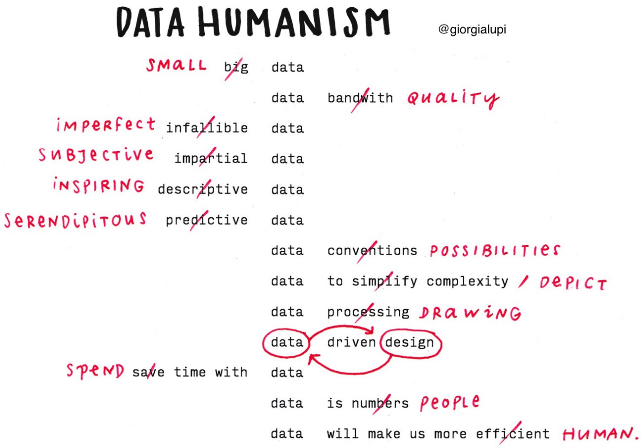


Figure 2. Principles of Data Humanism by Giorgia Lupi, co-author of the Dear Data project [29].

using advanced design tools [8, 9, 27]. Numerous off-the-shelf apps now offer this capability to a wider audience. For example, tools such as Visme [4] or Displayr [3] are available online to create pictographs in a few simple steps, and InfoNice [44] is one of the most popular plugins for Microsoft Excel.

The Dear Data project [29] is likely the most iconic project promoting the personalization of visualization. In her VIS keynote, Giorgia Lupi advocated for Data Humanism figure: 2, describing the potential that sketching data has to inspire people, foster their creativity and make them think more deeply about data. Certainly inspired by this project, researchers in visualization have developed authoring tools that enable people to sketch personal visualizations digitally such as DataInk [46] and DataSelfie [24], or even to create comics from data with DataToon [23]. However, to the best of our knowledge, there is no empirical evidence on the role that personalization and data sketching play for helping people engage with data in ways described by Lupi. This study is the first step towards gathering such empirical evidence.

Immersive Visualization

Immersion has been extensively studied in the virtual reality (VR) research community [35] and demonstrated as a positive engaging factor in immersive journalism [41]. The visualization community recently investigated the potential of immersive technology to provide new ways of representing, interacting and engaging with data [14].

So far, the motivations for creating immersive visualization experiences revolve around the investigation of the use of three dimensions to explore data [15], having a larger workspace than might be available with physical screen in order to visualize large amounts of data [21], or the potential of immersive technologies for collaborative analysis [16]. While designers have built VR experiences for storytelling [1], researchers have focused on the perceptual effectiveness of immersive data visualization [30] rather than study their impact on engagement with the data. This study is a first step towards shedding light on factors that make immersive visualizations enjoyable and engaging to people.

STUDY METHODOLOGY

To understand the role of personalization and immersion on enjoyment, We conducted a qualitative study using a within-subject design consisting of 3 (levels of personalization) x 2 (levels of immersion).

Data, Visualization and Task

As discussed in the introduction, storytelling and personal visualization are two key scenarios in which enjoyment of the viewer is important. For our study, we opted for a personal visualization scenario as it eliminated the issue of participants' particular interest (or lack thereof) in a specific topic. We told participants to imagine that they had collected a log of their thoughts and emotions for a week and assigned each entry to a positive, neutral, or negative category. We selected pictographs to visualize the data as such representations are popular in the wild [24, 6] and enable the easily personalization of the glyphs that compose them.

We used the simplest form of pictographs in this study, composed of three distinct types of glyphs to encode positive, neutral and negative categories organized in a grid. We kept quantities and proportions between them consistent through the study. We used a large set of 324 (18x18 grid), a medium set of 196 (14x14 grid) and a small set of 100 (10x10 grid), resulting in simple proportions. We explained the personal visualization scenario to participants instructing them to imagine this data was theirs and that their main goal was to enjoy looking at it multiple times. We told them that we would ask about the data but that it was to assess their general impression of the data quantities and proportions rather than seeking to have precise, numerical answers.

Immersion

We selected two different environments that provide different senses of immersion [35]:

[2D] In the non-immersive environment, participants used a Microsoft Surface Studio and interacted with the interface using pen and touch.

[VR] In the immersive environment, participants used a HP Reverb Virtual Reality Headset and interacted with the interface using head and body motion as well as 3D controller.

Personalization

We selected three levels of personalization:

[B] In the **B**aseline, participants could not personalize the visualization. Default shapes were a circle in 2D and a torus in VR. Default colors were orange, purple and blue respectively encoding positive, neutral and negative data categories.

[C] In the first level of personalization, participants could **C**hoose a shape for representing each data category from a limited set of examples.

[D] In the second level of personalization, participants could **D**raw a shape of their choice and given a limited set of colors to choose from.

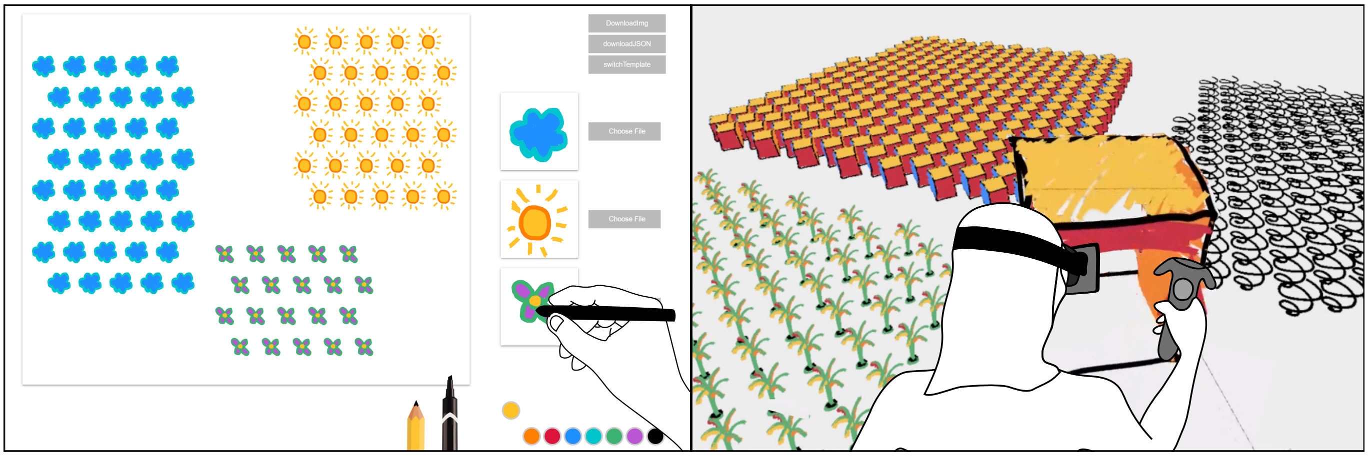


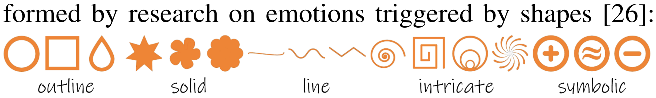
Figure 3. Screenshot of Drawing interfaces in 2D (left) and in 3D (right)

Interfaces

Figure 3 provides an illustration of the interface in two levels of immersion (2D on the left, VR on the right) and the interactions available for drawing glyphs. The companion video to this paper in supplemental material illustrates the interactions in each of the six conditions.

On the Surface Studio, participants used an application featuring the pictograph and glyph areas as illustrated in Figure 3 left. In the Baseline condition, each of these area is not modifiable and filled with a circle. Data categories are encoded by the color: orange, purple and blue, representing respectively positive, neutral and negative data categories.

In the Choice of shape condition, participants personalize each glyph with a shape of their choice among a limited set covering a range of characteristics (geometric, organic, symbolic, curved, angular, intricate) and informed by research on emotions triggered by shapes [26]:



Participants browse through a set of available shapes using a familiar file browsing component. Selecting a shape populates the pictograph. Participants could select different shapes in sequence to experience different pictographs.

In the Drawing condition, participants can personalize each glyph with a shape and color of their choice by drawing directly on each glyph area. Participants select a color among the 6 provided ones using the digital pen and then draw the design of their choice directly in the glyph area. One can turn the pen around to use the eraser and cross or tap on previous strokes to erase them. The pictograph is updated in real time as participants draw or erase them.

Wearing the VR headset, participants used an application featuring the pictograph on the ground in front of them. To provide an experience in which they could feel immersed within the pictograph, the entire pictograph did not fit in their field of view (as depicted in Figure 3 right). Instead, they need to turn their head to see the entire visualization. In the Baseline condition, participants see the pictograph composed of tori of different colors on the ground, echoing the 2D settings. Participants can walk around (to the extent that the headset cord and the space in the room allows). Note that the experimenter verbally stopped them in case they got close to an obstacle. The pictograph fills a 8m x 8m virtual surface. As the study was conducted in a 4m x 4m room, they could only inspect the edge of the pictograph.

In the Choice of shape condition, participants personalize each glyph with a shape of their choice among a limited set echoing the 2D set:

To minimize the use of the controllers, which require training, the application enables the user to change the shape of a data category currently in field of view by pressing a single button. Participants could repeat this button press to experience different pictographs.

In the Drawing condition, participants personalize the pictograph by drawing in 3D in a 1m x 1m cube placed in front of them. Participants use the controller trigger buttons to draw, select a color among a set of 6 (as in 2D) using the joystick, and erase with the grab button. The experimenter provided a clear option and changed the data category upon verbal prompting from the participant. As in the 2D condition, the pictograph updates in real time as participants draw.

Procedure

Participants signed the participation consent and filled up the demographics questionnaires. This questionnaire included past experiences with immersive environments, self-tracking activities and their affinity with drawing. The experimenter then introduced the personal data visualization scenario.

Participants completed six conditions (2x3). The order of Immersive conditions was counterbalanced between participants.

For Personalization, participants always experienced the Baseline first, but we counterbalanced the order of Choosing and Drawing shapes. For these last two conditions, participants followed a short training to ensure proficiency with the interface. The experimenter verbally described interactions and asked participants to select or draw two to three shapes.

In each condition, participant could freely explore and interact with the visualization until they signaled the experimenter that they were done. They were instructed to talk aloud and describe their thought process and interactions during this phase. The experimenter then asked them to estimate quantities and proportions while still being able to experience the visualization. After each condition, participants then filled out a Likert-scale questionnaire.

After experiencing the six conditions, the experimenter conducted a semi-structured interview gathering the preferences and final comments. Participants then received their compensation. The entire session lasted about 90 minutes.

Hypotheses

H1. Participants will have difficulties with estimating quantities in pictographs composed of dozens of elements, and immersion will negatively impact these estimates as they lack overview.

H2. Participants will enjoy the highest level of personalization (Drawing shapes) most unless they dislike drawing, and thus favor selecting shapes instead.

H3. Participants will enjoy the highest level of immersion (VR) most, unless they suffer from motion sickness, which may be more pronounced in the drawing mode as it requires more interaction. We also hypothesized that novelty would be a major factor of engagement for people new to VR.

Data collection

We collected qualitative data from three different sources.

Objective measures

Objective measures refer to the data we collected from participants' comments that are unlikely to depend upon their subjective experience and self-reporting of conditions.

Estimation of proportions. The experimenter asked participants to estimate proportions between different categories. Participants answered verbally, in the phrasing of their choice (e.g. in percentage of the whole, in fractions or as ratios) while viewing the pictograph. We categorized as correct when proportions were correctly estimated between three categories, mostly correct for two, and incorrect otherwise.

Estimation of quantities. The experimenter asked participants to estimate quantities of each data category while seing the pictograph. We were interested in the general impression that participants would get from the visual as one would in a personal visualization scenario. Note that several participants had difficulties with this task and felt compelled to count. We categorized as correct when three quantities approximated the count (within a 10% margin), mostly correct when two quantities fell within the range and incorrect otherwise.

Memorability. Two business days after the experiment, participants received an email asking them to recall the glyphs used for each category and each condition. Participants answered wihtin two to seven business days. We computed a score from 0 to 6 for each condition taking into account the correct recall of glyph and color for each category.

Verbal cues. In addition to these measures, we also coded verbal expressions of enjoyment such as laughing or explicit comments denoting enjoyment; and verbal expressions of lack of enjoyment such as sighing or explicit comments denoting frustration or annoyance. We hypothesized that these cues could help to gain an objective impression of the participant's experience in contrast to self-reported measures.

Self-reporting measures

Participants completed a 7-point Likert questionnaire integrating engagement measures from game research synthesized in [5] and immersion measures from VR research [39]. Participants self-assessed the following aspects after each condition:

- **Confidence** in their estimation of proportion and quantities
- **Expressivity** of the glyphs used in the pictograph
- **Personal** feel of the pictograph
- **Memorability** of the pictograph
- **Aesthetics** of the pictograph
- **Positive Engagement** with the experience (e.g. fun)
- **Negative Engagement** with the experience (e.g. tedious)
- **Immersion** of the experience
- **Usability** of the experience
- **Physical comfort** of the experience

During the final interview we collected their overall **preference** for the most effective technique to gain an impression of the data, and the most enjoyable experience.

Open-coding

In addition to the measures above defined *before* conducting the study, we transcribed all verbal comments made by participants and used an open coding approach [40] to extract salient insights *after* running the study. The experimenter who ran, observed and transcribed all sessions identified ten recurring themes. A second experimenter independently coded 15% of the transcribed data. As the inter-coder agreement reached 90%, a single coder completed the rest of the coding.

- **Perception** includes comments pertaining to the perception of the pictograph during the experience. For example, "I don't like this [glyph] as a pattern [in the pictograph]" (P13)
- **Estimation Strategies** includes comments on the strategy used to estimate quantities or proportions. For example, *"I need to scope them all out [turning head]"* (P2)
- **Challenging Aspects** includes comments denoting actions or activities perceived as difficult to perform or achieve. For example, *"It is so hard, because it is an imaginary surface"* (P2) describing drawing in 3D.
- **Aesthetics Aspects** includes comments on the aesthetics of the pictograph (or lack thereof) *"I love the flowers, they look really pretty in purple"* (P13)
- **Personal Aspects** includes comments on aspects making the pictograph personal (or impersonal) to them *"It is personal because I am constructing it"* (P2)

The next five categories encode the ways participants related to the data or the visual representations.

- Reference to **Life Experiences**: *"a lot of these [positive data glyphs] would be times I am in the mountains"* (P6)
- Reference to **Physical World Objects**: *"I am looking for organic stuff. A flower. I'll add more petal to it"* (P12)
- Reference to **Physical Senses**: *"[looking a the polar star] painful to step on or touch"* (P7)
- Reference to **Abstract concepts**: *"[looking at the neutral category] happy but it's less energetic"* (P13)
- Reference to **Symbols**: *"I like the plus [sign] for the positive [category]"* (P9)

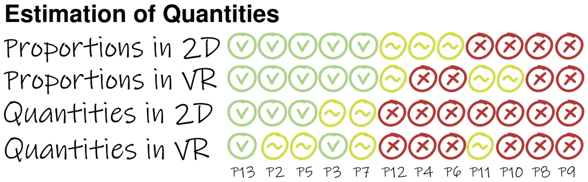
Participants

We recruited participants using several mailing lists in a large corporation. We screened participants to be right-handed. A total of 12 participants (7 males, 5 females) ranging from 22 to 49-years old (Mean=35) completed the experiment. Among them, 4 had never experienced VR and 5 reported disliking drawing.

STUDY RESULTS

Following the principles of triangulation [34], we used the different data collected above to shed light on the impact of personnalization and immersion on participants' perception of the data and enjoyment of the experience. We report these insights below. Note that Figure 5 and Figure 6 only report significant differences in ratings. Complete data and analyses are available in supplemental material and in our companion website https://dearpictograph.github.io/Pictograph/.

Estimation of Quantities



Pictographs make estimation of quantities difficult

Participants commented on the overall difficulty in perceiving the quantity of pictographs laid out in grids, independent of the level of immersion or personalization. Results show that a third was mostly accurate, a third mostly inaccurate and a third in between. Out of 12, about five were less accurate when estimating quantities than proportions. Most of the participants commented that a pictograph felt like a *"texture"* (P4) or *"pattern"* (P13) making it difficult to assess the number of individual objects. Instead, they resorted to area comparison: *"I see the area covering the canvas to compare to the other one"* (P8). The difficulty in estimating and comparing quantities is reflected in the rather low self-reported confidence ratings. Participants were slightly more confident in their ability to make estimations of proportions (Mean=4.1) over estimations of absolute quantities (Mean=3.6), but few rated their confidence higher than average. Nine out of 12 participants found that estimating quantities was difficult, garnering almost a third of all comments on the challenging aspects of the study. P3 and P7 actually resorted to counting rows of objects in both 2D and VR, commenting that they felt, "compelled to count".

Immersion did not seem to impact quantities estimation

While confidence varied substantially between participants (e.g. P2 had ratings above 6, while P13 had ratings below 3), participants were generally more confident in their ability to make estimations in 2D (Mean=4.1) than in VR (Mean=3.5). However, contrary to our hypothesis (H1), results did not reveal consistent differences on the accuracy of these estimations based on the level of immersion. For example P13 rated her confidence as 1 to 2 points lower in VR but was accurate in all conditions. Similarly P4 and P10 rated their confidence lower in VR but consistently underestimated quantities in all conditions. Half of the participants commented on the particular challenge in the VR condition which lacked an overview in contrast to 2D: *"I had to shift my head all the way around. It was uncomfortable to compare the ones far apart"* (P11). However, P11 actually performed better in VR.

Personalization did not seem to impact quantities estimation

With respect to the level of personalization, while several participants commented that different shapes made estimating quantities and proportions somewhat harder, results did not reveal any substantial differences in accuracy between conditions. Several participants, however, commented on the importance of selecting shapes with similar *"visual footprint"* (P4) to be able to compare categories more accurately. For example, in VR, P4 commented that he wanted to pick shapes that appeared to occupy a similar volume in space to be comparable *"for me, the problem is the bias of the volume of stars versus teardrop". In 2D, P10 commented on this same concept, noting that spirals and concentric circles "kind of go together, because of the weight of the lines".*

On the impact of personalization

Personalization appears the most enjoyable factor

Every single participant chose a condition that incorporated higher levels of personalization as the most fun and engaging. Contradicting our hypothesis (H2), even most of the participants who initially expressed that they did not like drawing, selected a drawing condition as the most engaging and enjoyable in the final interview (4 out of the 5).

Our collection of verbal cues of enjoyment confirmed these self-ratings. We collected a total of 70 verbal expressions of enjoyment across all conditions, as well as 34 verbal cues expressing a lack of enjoyment (e.g. frustration and annoyance). Enjoyment cues collected included behaviors such as walking like a robot (P5), sounds such as laughing (P2, P3, P5, P6, P7, P11, P10, P13) or humming songs (P5) and explicit comments said with an excited tone, such as, *"oh wow! I like it"* (P8) or *"Oh jeez. so much fun"* (P13). Frustration and annoyance cues collected included behaviors such as low or no interaction with the system, sounds such as sighing (P5, P7, P13) and explicit comments said with a sad or frustrated tone, such as, *"I don't know. I am not doing a good job"* (P12), *"oh jeez. that's hard"* (P13). While several participants were more expressive than others during the study, we gathered cues of enjoyment and frustration for every single participant.

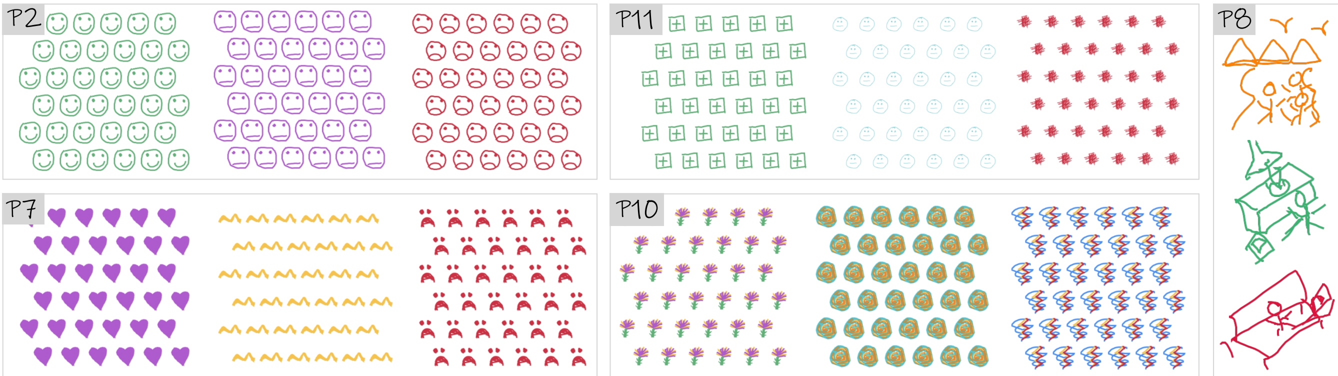


Figure 4. Sample glyph choices drawn by participants. Note the preponderance of symbols (smileys, positive and approximate sign). After experiencing immersive conditions, P10 replicated her exact design and P8 sketched life scenes she started describing in VR.

The majority of enjoyment cues (87%) occurred during the drawing conditions. Aesthetics did not appear to be a major factor for enjoyment. While participants consistently rated their selected or hand-drawn shapes as more appealing than the baseline, several expressed the lack of visual appeal of their outputs. *"Yikes!"* (P3 in VR-D) *"No idea if I can pull it off without making it look awful"* (P5 in 2D-D). Open-coding of verbal comments and self-rated measures appear to point out that **making representations meaningful to people** was a key factor for participants independently of the level of immersion they were in.

Personalization makes visuals meaningful to people

Participants expressed (through comments and self-ratings) that personalization helped to make the representation more meaningful to them. They reported a higher satisfaction with shapes representing the different categories when choosing or drawing them over the baseline (Figure 5). Participants consistently rated a higher level of personalization as more engaging, enabling them to make data more personal.

We gathered many comments about making shapes and colors meaningful. Colors were perhaps one of the more commented upon aspect of personalization, and varied much between participants. *"I like purple, one of my favorite colors - so that is my happy color"* (P5), *"Orange is positive"* (P6), *"The colors are not symbolizing well these emotions [...] green is more memorable for happy"* (P7), *"associating happy with yellow"* (P9) *"I like the red [for positive]. So vibrant"* (P13).

Many participants associated shapes with either symbols, concepts and experiences that were meaningful to them (Figure 4). For example, over 7 selected smiley faces akin to emojis, or plus and negative mathematical signs: *"I can see the symbols [mathematical signs +, - and approximate] and I don't have to think to what they are"* (P9), describing these conventional representations as the *"natural metaphor"* (P6). Participants also related shapes to more abstract concepts and experiences that they associated with different data categories *"Peace water sky [for neutral emotions]"* (P13), *"Positive for me is nature and growth and things like that. [...] like a multi color flower"* (P10). We delve more into the contrasts we observed between different levels of immersion for making these associations later in this paper.

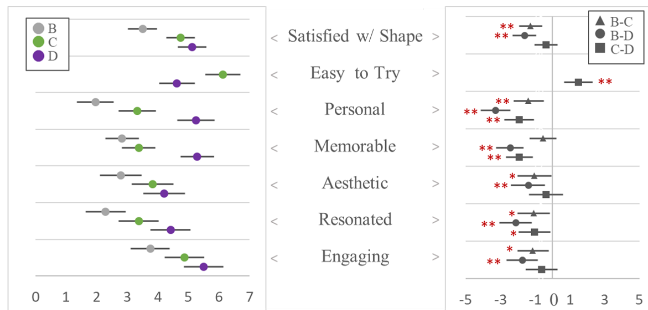


Figure 5. Participants' mean rating for Personalization with significant differences indicated by * (error bars are 95% Confidence Intervals).

While participants consistently rated the visuals they sketched as more memorable (Figure 5), our results did not indicate significant differences across participants between a simple design using a single simple shape (B) and a drawing (D). Meaningful visuals may prove more memorable for some participants. Four (out of eleven) indeed had a better recall for the drawing conditions than any others. Among these, P5 emphasized the difficulty of remembering visuals that did not mean anything for her "[...] remembering that the default 2D negative color was purple which was confusing to me since I associate purple with positive things".

Personalization makes people think about the data

We found evidence that personalizing the visual representations makes people think more about the data and what it represents for them. Comments suggest that the process itself played more of a role rather than the output: *"It does make it more personal because I am constructing it"* (P2). *"Mine [in VR-D] looked like 2 year old did it. I enjoyed the process more than the outcome"* (P4).

We also gathered comments indicating that participants thoughts about what the data category meant for them during this process: *"Neutral is the hardest because you don't feel anything, it's neutral. How do I represent that?"* (P9). This process led participants to verbally express **what the data actually encoded for them**. For example, P11 commented on an *"an expressionist representation [...] combines frustrated and [...] emphatic."*

Beyond thinking about the data categories, several participants also considered their **experience when consuming the resulting visualization**. While personalizing the visuals, they became aware of the impact of different visual properties on their perception of the data. For example, P4 commented on how perception can be affected by volumes of individual objects in space, selecting the larger or bolder ones for representing positive emotions: *"I want to feel good about these positive moments, having them a bit larger is great"*. P11 made a similar comment in 2D *"positive experiences should outweigh the neutrals [by using a thicker outline]"*.

Participants reflected on how they would react to consuming the visualizations, and expressed the desire **to influence their future interpretations** when consuming visualization: *"I would pick something geometric but really small [for representing negative emotions]. I want to know but I don't what them too strong. I never want to see how negative I was, I want to see how positive I was instead, even if I had some negative that week."* (P13). *"To better understand my feelings, but also to feel good, I want to bias it"* (P4). It led some of the participants to formulate what they want to see out of the visualization *"I want flowers and birds in my life"* (P5).

On the impact of immersion

Immersion may help grasp the scale of data

During the post-study interview, 11 out of 12 participants rated the 2D conditions more effective for estimating quantities. However, several participants commented that a higher level of immersion helped them gain an understanding of scale rather than help them being accurate on perception of quantities. P10 contrasted the two levels of immersion: *"[In VR], I felt that at one point I was, like, oh wow! that's a lot of positivity and I feel like* ***I could almost emotionally feel it*** *when it was physically in space"*. P11 noted that: *"I think this is the core value of seeing data in VR... Understanding the vastness of a larger dataset by seeing things like the converging lines towards the horizons and that kind of things, that are not that easy in 2D. A different perspective on the scale. Not necessarily a more accurate perspective but* ***a more dramatic understanding of the scale****"*. Coupled with comments made during the study during the estimation questions such as *"a sea of positive this week"* (P11) or the use of the term *"field [of shapes]"* (P3, P5, P9, P13), these results suggest that immersion may provide a more visceral sense of scale of quantities like standing in the physical world, surrounded by objects.

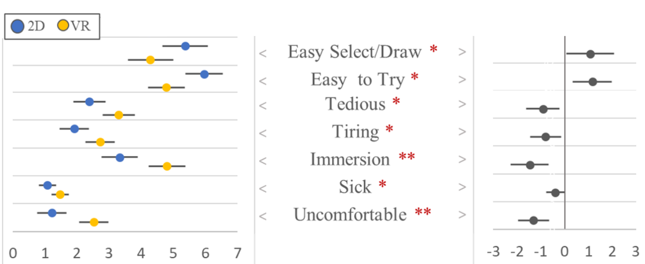


Figure 6. Participants' mean rating for Immersion with significant differences indicated by * (error bars are 95% Confidence Intervals).

Immersion is enjoyable

As expected, participants rated the level of immersion significantly higher in VR (Mean=4.806) than in 2D (Mean=3.333). As we hypothesized (H3), the majority of participants (9/12) preferred VR overall, the remaining three reporting motion sickness (P7 and P12) or depth perception issues (P8). Self-ratings revealed surprising results: participants rated VR conditions significantly more tiring, more uncomfortable, more tedious and more difficult to use on average than 2D experiences (Figure 6). These results may suggest that immersion is so fun for participants that, unless they have physical discomfort, they may be willing to overlook its negative aspects.

We attempted to identify specific aspects of immersion participants enjoyed from the comments. We surfaced two possible factors that P6 summarized well during the final interview: *"It's a new experience and kind of doing anything in it takes some time and mental effort. You basically have to work at it"*.

1. Engagement may be due to novelty. While 8 participants had experienced VR before, drawing in three dimensions was a novel experience for all of them. Half of the participants compared the interaction to decorating a cake with icing (P5, P9, P10 and P11) and spray painting (P2, P3), which they referred to as fun and enjoyable experiences. Seven participants selected immersive drawing as the most engaging condition overall, thus novelty may be a key factor as we hypothesized (H3). Note that participants who had not experienced VR before specifically commented on novelty as a factor of engagement *"Legitimately cool and novel"* (P9), one of them referring to the novelty of VR experiences as a whole: *"any of the VR is not boring. It is still novel."* (P2).

2. Engagement may be due to the challenge of 3D design. Drawing in VR was definitely challenging for participants and constituted about 40% of all comments made on difficult aspects of the study. Participants also spent much longer in VR than 2D when drawing (Figure 7).

Comments revealed that negative aspects dealt with **executing** what they had in mind: *"It's a challenge to make something look good in 3D when I don't have practice with the pen"* (P9) and expressed disappointment of their mastery of the tool: *"Mine looked like a 2-year old did it"* (P4). However, we also gathered comments on positive engagements regarding the challenge of **designing** a 3D representation. Participants seemed inspired by the potential of 3D for encoding the data: *"I was immediately thinking of other dimensions that we could map"* (P2), *"More to work with there. On 2D it was limiting in term of the space that you had"* (P10), *"Trying to come up with something that would fully utilize the 3D space [...] maximize the opportunity that it offers"* (P3).

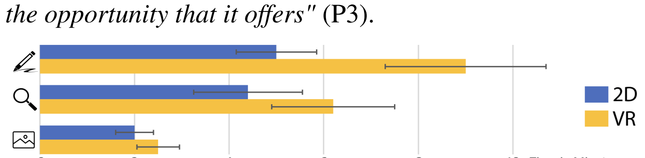


Figure 7. Indicative task time in minutes for each condition.

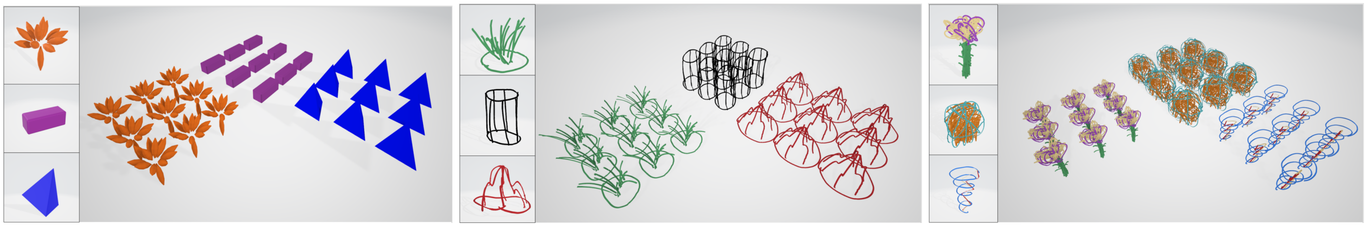


Figure 8. P12 used a lotus flower for positive emotions and a pointed pyramid painful to the touch for negative ones, using a less salient neutral shape for neutral emotions. P9 created grass to represent growth of positive emotions, a red angry mountain of negative emotions, and used a geometrical, empty shape for neutral ones that do not make him feel anything. P10 drew a tall flower for positive emotions and a storm for negative ones.

How Immersion Impacts Personalization

Perhaps one of the more unexpected insights from this study is the evidence indicating that participants tend to think and relate to data via life experiences and representations of real-world objects when immersed in VR in contrast to more abstract concepts and symbolic representations in 2D.

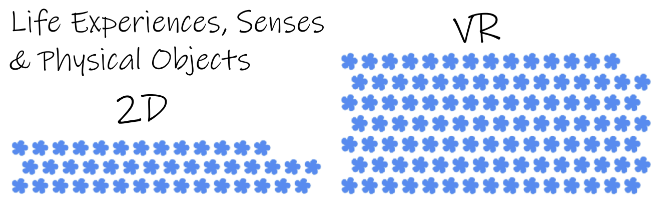
Relating to data through life experiences in VR

All participants except one (P4) referred to at least one life experience when immersed. In contrast, a single participant (P8) referred to life experiences in 2D. While we noted earlier that participants referred to life experiences to describe the immersive drawing interaction (e.g. like frosting a cake), more interesting observations are references to life experiences and real-world objects to relate to data. For example, when selecting shapes for representing negative emotions in VR, P12 commented that the pyramids reminded him of the objects in a public park, placed on benches so homeless people don't spend the night. For positive emotions, P6 commented *"a lot of these would be times that I am in the mountain"* and proceeded to draw a mountain for the 3D shape (Figure 1right).

These comments indicate that these participants used salient experiences they encountered or saw as a source of inspiration for representing the data. P8 explicitly commented on this reflection process when thinking about a design for negative emotions in 3D: *"going back to my experience [...] it's like a rough road or a rose with lots of thorns"*. During this process, participants related to the data and identified a representation that would be meaningful to them.

In addition to life experiences, participants made 75 (out of 102) references to real world objects and senses were expressed by participants in VR conditions. For example P11, considering 3D stars for negative emotions, commented that 3D stars would be adequate because it looked like every single one would hurt if touched or stepped on. P8 touched the ring she was wearing to describe how she would represent positive emotions: *"like a real diamond"*.

Beyond associating an experience with a visual representation of the data, participants also related the consumption of the visualization to their past experiences. For example, P13 explained what an increase of neutral emotions in the visualization would mean for her: something to watch for, potentially announcing a general drop of mood. She expressed this by referring to her past experience with her children: *"it's like when you see a kid and he is starting to have a rash and then you know what's coming next"*.



Relating to data through abstract concepts in 2D

In contrast to the immersive environment, a large portion of comments (60%) coded as abstract concepts such as "peace" (P13) to describe neutral emotions or "turbulence" (P8) to describe sad ones occurred when participants worked with 2D representations. References to symbolic concepts and conventional representations such as smileys or emojis and mathematical symbols occurred more than twice as often in 2D representations than in immersive environment. Overall, 18 out of 24 pictographs created by participants in 2D conditions contained at least one symbol.

Immersion may set a frame of mind

It is possible that immersive environments set people into a specific frame of mind, in which people relate to real-world objects and their life experiences. For example, P6 initially started drawing an object in perspective in 2D and stated *"thinking to do a perspective thing. Only because of what we had done previously [in VR]"* and P10 also replicated the same design (Figure 4 and Figure 8). A particularly salient example of this are P8's unique results in the 2D drawing condition, representing each data category with a hand-drawn life scene (Figure 4). P8 made multiples references to her own life experiences when drawing these scenes restating what she had said in VR and sharing her memories: *"To make myself happy I cook. I'll be looking at a recipe. Try to talk to people, reach out to my mom."*

DISCUSSION

As with all qualitative studies, the insights reported in this paper are rich and thought-provoking for the community, rather than generalizable empirical evidence demonstrating a specific claim. This paper aims at starting a conversation around the enjoyment of visualizations, fostering research on how to measure it and identifying factors impacting it positively or negatively. Our small sample of 12 participants is not representative of the larger population. Findings reported denote proof of existence but require a validation via a series of complementary studies.

Limitations of this study

While we spent substantial time and effort to make 2D and VR experiences as consistent as possible, there were inherent differences to both experiences that may have impacted our results. VR lacked overview and participants walked in a pictograph on the ground whereas they could see it entirely on a vertical screen in 2D. While these settings did not appear to impact quantities estimation, they may have impacted ratings.

Another limitation of this study is the longer time that participants spent in VR conditions, especially in the Drawing condition. There was just more to do in VR: turning the head, possibly standing and walking, drawing a glyph with a controller required larger physical motions than with a digital pen in 2D. This likely impacted the number of comments gathered (roughly 40/60 ratio between 2D and VR) and may have impacted the number of references to life experiences, real-world objects and senses made in VR compare to 2D. A third, and perhaps the most important limitation of our study, is the fact that participants did not visualize their own data. This certainly impacted most their engagement with the visualization.

Considerations for future work

Our study suggest several implications for the design of enjoyable visualization experiences compelling for storytelling and personal visualization scenarios.

Personalization appears a strong factor of enjoyment

Our study suggests that personalization contributes to enjoyment of visualization in many ways. We gathered some evidence that having people choose visual encodings for the data may **elicit thinking** about what the data means for them as well as how they would interpret the resulting visualization. These findings relate to previous work studying the benefit of having people predict what a visualization would look like [25] in the sense that people become more active and reflect on what they think and what they want to see. The process itself appears enjoyable, especially when coupled with real-time impact of people's interactions.

These benefits do not seem to come at the price of misinterpreting the data quantities or proportions, at least in pictographs. From our observations, participants were consistent in their ability to make estimations, independent of variations in shapes and colors. Despite this consistency in interpreting the data, several participants thought that the "visual footprint" (e.g. shapes and colors) was impacting their impression of quantities and proportions. However, this turned out to be a positive aspect as participants felt **empowered** by personalization. They either sought to control for this effect by selecting shapes of equivalent visual saliency (e.g. three solid shapes), or thought to influence their future interpretations of the visualization by deliberately selecting shapes of different visual saliency (e.g. selected larger bolder designs for positive emotions and smaller lighter designs for negative ones). Personalization may not necessarily result in a visualization that participants find visually appealing nor did we find evidence of better memorability. However, discrepancy between objective and subjective measures indicate that participants believe they are more personal and thus more memorable, warranting further investigation.

Immersive visualization may be worth it

In contradiction with our hypothesis, we did not collect any evidence that participants' estimations of quantities and proportions were less accurate in VR than in 2D. This result is surprising especially as participants did not get an overview of the entire visualization in VR. However, it might be explained by the fact that humans are not very good at estimating large quantities (over 20 items) or areas in the first place and that our VR settings echoed real world situations in which humans have the most experience.

Our study also raised a few intriguing questions about the potential value of VR for visualization. In particular, the sense of immersion that VR provides appeared to elicit a visceral sense of the scale of data, and foster references to people's life experiences and physical objects encountered in their life. Our findings on the positive engagement of challenging aspects of VR aligns with previous research [32] findings that spending time and effort increased the perceived value of artifacts. These observations could be instrumental for stimulating people's self-reflection and having them **relate more deeply to data**, critical for personal visualization and self-tracking.

While more research is needed to confirm any of these findings, the small amount of evidence we gathered about a potential order effect have interesting implications as well. It raises the following question: what if experiencing VR, even once, even for a short period of time, before interacting with a 2D interface could trigger this particular frame of mind in which people recall and relate to their life experiences and physical senses? This possibility opens numerous avenues for making storytelling about data deeply compelling to people.

CONCLUSION

We set out to investigate the role that personalization and immersion play for enjoying visualizations. We conducted a qualitative study triangulating multiple sources of data: objective measures such as estimation of quantities, self-ratings such as confidence in estimations and aesthetics as well as observations and think-aloud transcripts.

Our study generated substantial data and rich insights. Our findings suggest that personalization may have aan impact on enjoyment, leading to deeper engagement with data. The process of personalizing visuals elicits thinking about the data and the resulting visuals may prove more meaningful to people even if not aesthetically pleasing. Immersion also appears to play a role in enjoyment, eliciting self-reflection and stimulating people to relate to the data via their life experiences.

While a series of studies is needed to validate, compare and contrast these findings, this paper aims at starting a conversation in the research community about the value of crafting visualization experiences that are highly enjoyable. Especially in storytelling and personal visualization contexts, making visualizations enjoyable may prove as important than making them perceptually accurate and efficient.

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