Metaphors and 'Tacit' Data: the Role of Metaphors in Data and Physical Data Representations

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ABSTRACT

This paper explores (1) the role of metaphors in physical data representations and (2) the concept of tacit data: implicitly known data which are hard to uncover. In a semester course with twenty-three students, five teams explored how to represent self-chosen 'tacit data' in a visualisation, haptification, and dynamic physicalisation. Throughout these phases, our notion of tacit data evolved, resulting in a proposed working definition. Moreover, we noticed that metaphors played an increasingly important role. Based on analysis of students' work and interviews with them, we found that tacit data and physical data representations need metaphors. For haptifications and physicalisations, metaphors help to circumvent limitations, curate data, and communicate to the audience. As tacit data were seen as 'soft' and difficult to quantify, metaphors made the data workable. Furthermore, tacit data benefit from physical representations, which offer further dimensions to represent the feeling and intimate aspects of data.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; **HCI theory, concepts and models**; *Visualization theory, concepts and paradigms.*

KEYWORDS

data physicalisation, qualitative displays, data feminism, notion of data, tangibility

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1 INTRODUCTION

"We are entering into a dataverse"—although this is an intended hyperbole by Bowker [29], it cannot be denied that data increasingly play an important role in our daily lives. Aspects which previously were not associated with numerical representations, such as friendships and bodies, are now quantified and datafied [71]. This process of *datafication* [77] promises to enhance our knowledge and understanding of ourselves by revealing (invisible) patterns and correlations [39]. Key in doing so is quantification [64]. Through quantification, data receive their first layer of perceived 'smoothness' [18], as it washes away the messiness of the data [18, 71] and represents them in a *"familiar, standardized form"* [90]. This standardised form allows us to view the data from afar, without the need for personal knowledge and experience to understand the phenomenon [17, 51, 90]. The feeling that data are impersonal and the idea that *"numbers never lie"* [29] give the illusion that data are objective, clean, neutral, and abstract [20, 39, 51]. However, these perspectives are in stark contrast to how data are generated and how we encounter them in our lives [20]—which is messy [39, 71], local [68], and sometimes even emotional [35, 52]. Moreover, looking at how we make sense of information, most of it focuses on qualitative aspects rather than quantitative ones [64]. For example, when asking ourselves how tired we are, we typically do not answer with a number.

To explore these aspects of data, we organised a semester course which looked into the qualitative aspects of data, which we called 'hidden data' at the time (and later rephrased as 'tacit data'), and how to represent them. In total, five teams of students were tasked with tracking and representing a source of hidden data from their daily lives. To foster the exploration of a different kind of data, the course focused on the medium of *data physicalisation*: physical artefacts whose *"material and geometrical properties encode data"* [47]. Physicalisations enhance our engagement with data [47], can trigger emotional responses to data [37, 106], and since they are (often) a new medium to the viewer, every encounter with a physicalisation becomes a critical inquiry [84], because the viewer is

not trained in analysing them. These aspects make physicalisations a potential 'vehicle' for generating critical thought on what data are [84, 103], which motivated us to employ physicalisation for the exploration of 'hidden data'.

To work towards this goal and gain confidence in physically representing data, students first had to create a hand-drawn visualisation, then a haptification, and finally, a physicalisation. Seeing the developments, we noticed that metaphors –ways of understanding something in terms of something else [55]– played an essential role and that they became more apparent the more physical the data representations became. Although research has indicated that metaphors are commonly used in physicalisation (cf. [25, 40, 110]), it is not known why they are so prominent. Furthermore, we learned that our initial conceptualisation of hidden data was too limited. These observations motivated us to conduct an in-depth analysis, for which we analysed the written documentation that accompanied the data creations and conducted semi-structured interviews with eleven of the students.

Our analysis shows that metaphors were used to overcome the newness of physical data representations and offered ways of mapping data to something which is understandable to others. Moreover, a simple distinction between 'ordinary data' which are explicit and currently counted and represented, and 'hidden data' is too simplistic. Hidden data were seen as 'soft', intimate, and bound to technology. To capture this refined understanding, we renamed them *'tacit data'*: subtle and intimate phenomena, which either cannot be directly measured or meaningfully quantified, but of which we can have an implicit understanding (e.g., whether a lie had a good or bad intention). Similar to tacit knowledge, tacit data are hard to express and uncover. It is only through 'friction' that they can be uncovered [15, 89]. As physicalisations trigger reflection and critical enquiry [84], they helped students in grasping and representing tacit data—something for which visual representations are less suited, because our experience with visualisations makes that we use them for representing data efficiently and understandably. Metaphors play a crucial role in representing tacit data, as they are a method of making them workable and understandable.

The contribution of our work is twofold: (1) we show why metaphors are crucial in physical data representations and in particular for representing tacit data; and (2) we add to the discussion of what data are. We do so by introducing the notion of tacit data, explaining how our understanding of tacit data evolved, and reflecting on the potential of physical data representations to represent them. With this, we contribute to a better understanding of data, and of data physicalisation and haptification.

Although we specifically focus on hidden/tacit data in this paper, we want to acknowledge that all data (quantifiable or not) are situated, imperfect, and subjective [20]. In the following sections, we use both the terms hidden and tacit data. 'Hidden data' are used when acknowledging how we thought at the start of our process (e.g., when describing assignments given to students), whereas 'tacit data' are used when we are referring to our eventual refined understanding (e.g., what we learned from the interviews).

2 BACKGROUND

2.1 Diverse Perspectives on Data

Data are often associated with either maths and numbers, or diagrams and graphs [29, 51]. Associating data with numbers creates the illusion that data are factual and abstract [18, 29]; making them appear as the *"fundamental stuff of truth itself"* [29]. Therefore, in attempts to better understand ourselves and the world around us, *"impartial machines"* in the form of sensors and tracking technologies are tasked with datafying us [39]—something which is thoroughly embraced by the Quantified Self movement [18, 20]. However, as *"computers do not deal with 'soft' data"* [29], the qualitative aspects of our lives seem to be slipping away [29, 64] and data rewrite what counts as knowledge in the first place [39]: cold, hard, numerical facts. Yet, whereas facts cannot be changed ('a fact is a fact'), data are partial and have a position [20]—given certain data, certain conclusions might be proven right or wrong, or different arguments will be made [29]. The perceived factualness of data make them appear to be a given [24, 29], rather than something which has to be generated [20, 74]. Therefore, Drucker suggests using the term 'capta' –which means actively 'taken'– rather than 'data' (Latin, plural of *"that is given"*), to highlight that data are generated and need to be interpreted as data, for them to function as such [24, 29].

In line with the latter, and to challenge the quantification and factualisation of data, we initially came up with the term *hidden data*, to emphasise and explore data's qualitative aspects. Specifically, we focused on personal hidden data to highlight the assemblages (with other data, things, and humans) in which data are situated, and their liveliness [22, 71]—as done in *"Dear Data"* [69], a year-long project where two authors sent each other weekly postcards with creative data visualisations which illustrate the small, intimate, and interpretive nature of data [18]. Moreover, the focus on the personal gave us and our students the chance to explore that data need to be generated (in the sense of tracking your own data), allowing people to become aware of data's messy, plural, and heterogeneous nature, which needs rhetoric, biases, and editorial decisions to represent [20].

This brings us to data's second association: the alignment with visual representations [24, 29]. Generally, for a visualisation to be perceived as 'good' and 'trustworthy', visualisation designers follow guidelines, such as a lack of ornament, geometric shapes, and white space [20, 52]. These guidelines help to create graphical representations which look simple and legible, and hide the interpretive and generative nature of the data [24, 29]. These aspects have been criticised by researchers, who state that data representations should highlight the uncertainty and messiness of the data, their liveliness and relations to others, and their partiality [20, 24, 71]. Examples of data representations that aim to highlight these aspects are Drucker's humanistic interpretive graphics [24], qualitative displays [64], and autographic visualisations [83]. Furthermore, previous research has explored and created physicalisations which embody these aspects (e.g., [19, 50, 84]) and has shown that physicalisations expand our understanding of data [84, 103], as they highlight different perspectives of data by not focusing on efficiency and high-accuracy. Considering the mostly physical nature of qualitative displays and autographic visualisations, and the added

benefits of data physicalisations (e.g., changing our perspective on data and enhancing our engagement [47]), our work explores how data physicalisations can be used to represent hidden data (of which we later realised were actually tacit data).

2.2 Data Physicalisation and Data Diaries

Although qualitative displays and data physicalisations allow us to represent different aspects of data –and, as such, re-imagine our understanding of what data are– they bring new challenges with them as well [84]. Besides having an understanding of how to work with data, the creation of these physical data representations requires a skill set which combines material, technical, and design knowledge [103]. Moreover, whereas visualisations can be relatively easily controlled (they exist on a canvas), physicalisations exist in the material world, where it is harder to control every aspect of the representation [84]. For example, the context [96], scale [67], or light fall on the object influence our understanding of the representation.

To overcome and ease into the challenges of data physicalisation, previous work has utilised the approach of *"Data Diaries"*: a set of assignments where participants track and represent their own personal data [103]. The assignments start with visualisations in order to ease into the activity of tracking data and representing them. Furthermore, since these visualisations are to be hand-drawn and cannot be based on traditional representations (e.g., graphs and charts), this exercise directs people towards the material world, as tangible tools have to be used. Then, new modalities –such as haptics and movement– are introduced to sensitise participants to the additional modalities of data physicalisation. This makes the *Data Diaries* a suitable method for the exploration of dynamic physicalisations [103]. Dynamic physicalisations (sometimes referred to as 'active physicalisations' [21]) can physically reconfigure themselves [23]. For example, they can change visual aspects, such as their shape [78, 95], or haptic qualities, such as force experienced by users [42]. Thus, dynamic physicalisations can update depending on the data or user's needs, for instance, hiding irrelevant data for a clearer view [100]. To accomplish the reconfiguration, dynamic physicalisations are often computationally actuated (and thus overlap with shape-changing interfaces [23]). As dynamic physicalisations can present real-time and dynamic data [71] (not just static data), the end goal of our course was to create a dynamic physicalisation. To work towards this goal, we used the Data Diaries approach, where we asked students to first create a visualisation, then a haptification, and finally, the dynamic physicalisation.

2.3 Metaphors and Data Representation

Media increasingly use the phrase *"data is the new oil"*, cf. [18, 65, 107]. This metaphor allows us to map an unfamiliar object (data) to a familiar object (oil) in order to improve our understanding of the unfamiliar [53, 101]. Although metaphors are often seen as a stylistic tool to enhance the aesthetics of text, they also guide our thoughts and behaviour [101]—influencing how we understand and make sense of the world [55]. This explains why metaphors are commonly used both in science and the arts for aesthetic and epistemic purposes [104].

The idea of metaphors helping us understand abstract concepts was introduced by Lakoff and Johnson, who coined the term *conceptual metaphors*. A lot of conceptual metaphors are rooted in image schemas: preconceptual structures which are established in our minds due to recurring bodily experiences (e.g., UP-DOWN) [31, 48]. As metaphors can never fully embody a concept –'this' cannot suddenly become 'that' [64]–, there always is some mismatch; the closer the mapping, the easier a metaphor is to understand [72]. This is reflected in the hierarchical order of metaphors [54, 56]. At the bottom are those conceptual metaphors derived from our experience called *primary metaphors* (e.g., MORE IS UP) [30, 56]. These primary metaphors can be combined to create *complex metaphors*, such as A PURPOSEFUL LIFE IS A JOURNEY [61]. Besides helping us to understand our world, metaphors serve various purposes, such as mnemonic [76], economic (less explanation is needed), and aesthetic functions [104]. To acknowledge these various functions, Pinker distinguishes between conceptual and *poetical metaphors* –which highlight (dis)similarities in an expressive manner, e.g., *"Juliet is the sun"*– [88], to acknowledge the aesthetic and emotional purposes as well [87, 104].

Metaphors have been highly influential in Human Computer Interaction (HCI) and interfaces. Conceptual metaphors used in interfaces are often based on aspects of a physical entity, but have their own behaviours as well (e.g., the desktop metaphor or a search engine) [91, 92]. Metaphors have been highly successful at making interfaces more familiar and easier to understand [72, 92]. However, metaphors can also be too constraining, creating conflicts with other design principles, or result in overly literal representations, which work poorly in the digital world [91]. When it comes to representing data, designers often use visual metaphors and image schemas to convey abstract information [59, 93, 111]. Although many images schemas and (primary) metaphors are visually oriented, they extend to the other senses [44]. Therefore, metaphors and image schemas can be found in multisensory data representations [38] and physicalisations as well. For example, for multisensory data representation, Nesbitt created the MS-taxonomy [80], which focuses on spatial, temporal, and direct metaphors. For physicalisations, Zhao and Vande Moere created a metaphor design space which introduces iconic, symbolic, and indexical metaphors [110], recent work of Dumičić et al. [25] labels metaphors used in physicalisations as abstract, associative, or literal. Hornecker et al. [40] also discuss how metaphors influence the viewer/user's experience of physicalisations.

However, despite the importance of metaphors in data physicalisation, little is known about why they are so essential. With our work, we contribute to a deeper understanding of this, as we show and discuss the various roles metaphors play, both in the creation of physical data representations and tacit data. Note that here we use a broad definition of metaphor (similar to [65]) to refer to various ways in which something can be understood in terms of something else.

3 TEACHING APPROACH AND PROCESS

The work presented here centres around an online taught class *'Data Physicalisation of Hidden Data'*. The 'hidden data' in the class' name refer to the concept later renamed as tacit data. During the

class, we explored what hidden data are, together with the students. When through our subsequent analysis a better definition and understating emerged, we deliberately renamed them 'tacit data', which we discuss in Section 5.1. The class had been advertised as exploring the hidden data in people's lives and how to represent them through (dynamic) physicalisation. The class was taught and designed by the authors of this paper as a collaborative effort between the Human-Computer Interaction programs of three geographically separated universities –Bauhaus-Universität-Weimar, Ludwig-Maximilians-Universität Munich (LMU Munich), and Augsburg University– in Germany. The course was offered to HCI Master students, but open for highly-motivated Computer Science Bachelor students as well, and offered a chance to explore what data are beyond the numerical (and often big) data that students within these programs usually work with. The course was part of the universities' project-based learning approaches, where students explore a practical or research challenge in smaller teams. Students from the three universities voluntarily chose to take part in the course.

Twenty-three students signed up, eight from the Bauhaus-Universität-Weimar, ten from LMU Munich, and five from Augsburg University. The course was taught in English, with most of the students studying in international study programs. Students had diverse backgrounds, with approximately two thirds of the students coming from Global North countries (Germany and Russia) and one third from other (mostly Global South) countries (including Egypt, Lebanon, Nigeria, India, Uruguay, and China). As we did not ask for gender identities, we have no clear information, but around half of the course participants (based largely on names) were women or feminine-presenting. Twenty students were HCI Master students (in course-based, taught Master programs) and three were Computer Science Bachelor students. Students were assigned to one of five teams, each team consisting of 4–6 students. Teams were mixed, so each had 1–2 students from each university. The class ran online, with weekly sessions. Sessions were split into two blocks of two hours each. The first block tended to focus on lectures that provided background on data, physicalisation, prototyping, and design processes. The second block was used for hands-on sessions, in which the students could ask questions regarding their designs and design process, and could work, present, and receive feedback on their progress in their team's breakout room. The topic of hidden data was introduced in the first lecture week, where they were described as *"the qualitative aspects of data which are difficult to communicate and represent due to lack of relations or language"*. For example, where 'ordinary' data concern the number of steps someone has taken, hidden data concern whether you –for example– enjoyed those steps, or whether it was a relaxing or stressful walk. Our definition was purposefully abstract and open, to allow students to develop their own understandings and together (with us) explore what they are. Besides lectures from ourselves, two guest speakers were invited for talks on prototyping and the user experience of multimodal data representations. During the course, students were to read several papers on physicalisation: [47, 62, 67, 98], and one paper on critical design ([73]) which was added to the reading list, given the initial hidden data concepts often bordered what is ethical and unethical. Therefore, we talked about ethics and introduced critical and speculative design to the students. The supplemental materials contain the course's complete curriculum, including the full assignment descriptions students received.

Based on the *"Data Diaries"* approach [103], three assignments built on each other, moving from the visual to the physical. To help students and provide some constraints, we instructed them to explore hidden data between two or more co-located people, as we assumed this context would allow for qualitative and more emotional aspects of data; thus, helping students find a source of hidden data. For the first assignment, each team was tasked to find a source of co-located hidden data and to track this for a week. Then, each team member had to create an individual visualisation. Similar to the Data Diaries, this was not allowed to be a standard depiction (e.g., a bar or line chart). Instead, students had to figure out new, creative ways to visualise the data. Students then had to send their visualisation, either digitally or physically, to someone in another team, who then had to interpret the data representation. This assignment aimed to (1) ensure each team picked a data source early on, (2) all students began to rethink what data can look like, and (3) to establish a connection between the teams, as each team was paired with another to send their visualisations to. To expand towards tangible data representations, the second assignment challenged each team to create a haptification –a data representation which communicates data via the sense of touch– based on their self-chosen hidden data. Based on the feedback teams received on their visualisations, this could be the same data set or an improved version. In practise, students either chose to work with the 'most complete' data set within the team or aggregated their data. The aim of the haptification assignment was to sensitise students to materials and the 3D nature of physicalisations. For the final assignment, each team had to create a dynamic data physicalisation of their hidden data, where at least one element changes over time (e.g., the movement speed or shape). As dynamic physicalisations often achieve their reconfiguration through computational elements [23], students used electronics and a microcontoller (e.g., Arduino) in this assignment. The exact assignment descriptions given to the students can be found in the supplemental materials. For all assignments, students could access their respective university lab. These labs were equipped with basic prototyping supplies (such as electronics, crafting materials, and soldering irons) and two of the three universities provided access to laser cutters and 3D printers.

To document their process, each team had to write three blog posts (one after each assignment) and publish these (with their consent) on our website: https://hide.medien.ifi.lmu.de/. The blog posts covered the design process and outcomes and were later used for the final report, which documented the complete design process. In using coursework (with students' consent) and interviews, our approach is similar to previous work in HCI (cf. [58, 103]).

3.1 Data Analysis

Our findings are based on four different resources: (1) the created artefacts (visualisations, haptifications, and dynamic physicalisations), (2) written blog posts, (3) written reports, and (4) post-hoc interviews with eleven students.

The blog posts and reports were analysed by one of the authors, who used reflexive thematic analysis (RTA) to construct themes [5]. RTA started with a distancing period of two months after the class

finished, to create some space between the experience of teaching and the created deliverables. After this distancing period, and following an inductive approach, the author started familiarising themselves with the data (the data representations and students' written work), by reading through it and performing an initial open coding. After two days of reflection, the author fine-tuned the initial codes and grouped them into initial themes. Then, the author refined the themes and created an initial thematic map. This map was finalised after another period of reflection, during which the themes were named, and the final thematic map was created. The insights were then presented to the other authors, whose feedback was used to finalise the initial RTA. Furthermore, the author reconstructed the design processes of each team, which were annotated with quotes from the blog posts and reports.

Based on this analysis, interview questions were developed and students were invited to take part in a semi-structured interview. Eleven students volunteered to be interviewed. Students from all three universities (five from the Bauhaus-Universität-Weimar, four from LMU Munich, and two from Augsburg University) and from four teams took part (two from Team 1, two from Team 3, four from Team 4, and three from Team 5) [1]. Interviews were conducted online due to the COVID-19 situation and geographic distance, and lasted on average 39 minutes (max. 74 minutes, min. 22 minutes). Students were asked: (1) how they experienced the three phases of the course (visualisation, haptification, and physicalisation); (2) whether one phase, in particular, helped them understand hidden data; (3) how their understanding of hidden data changed throughout the course; (4) how they would define hidden data; (5) how they came up with the metaphors used in their designs; (6) why they picked these metaphors; and (7) how their use of metaphors changed throughout the three phases. The interview data were transcribed and again analysed using RTA by two researchers, following a similar approach as described earlier.

3.2 Ethical Considerations

As this article is based on the creative work of students, we want to acknowledge that they are the creators of the artefacts that inspired us to conduct a meta-analysis and interview students that were interested. Consent for conducting the meta-analysis and for interviews was obtained after the course had been conducted and graded, as the course was initially not set-up with the idea of writing a publication.

Generally, for such a post-hoc analysis publication, there are two options: (1) obtain consent in advance or (2) after the course finished. Given the power dynamics of teaching, both come with ethical implications and issues. While asking for consent in advance would be the more standard approach, this could give the impression that the course only takes place to result in a publication for the benefit of the teachers (and not for students' learning). This might increase pressure to generate suitable deliverables and create fear regarding grading being based on the 'utility' of outcomes for a publication. This would risk losing the explorative space in which we –the lecturers– and students could explore what hidden/tacit data are and how to represent them. Therefore, so far in our teaching practice, we have always obtained consent after the course finished and deliberately waited until it was graded. Moreover, we have experienced that some students are very proud to see their work featured in publications. Thus, talking about the option for publication too early could result in disappointment, if the course does not lend itself to this (even if from a teaching and learning standpoint it was highly effective).

For this work, it was only after the course that we –as researchers– saw patterns that deserved further analysis. Upon this realisation, students were contacted via email, a couple of months after the course had ended and had been graded (the distancing period). In this mail, students were made aware of the meta-analysis, why it would happen, the possibility of a publication on the meta-analysis, and were asked whether they were interested in being interviewed. Students could object to their works being included and express any concerns. No concerns, questions, or objections to the usage of the data representations and quotes from the written work were received. Eleven students answered that they would like to take part in an interview and be acknowledged by name.

4 DATA REPRESENTATIONS AND DESIGN PROCESSES

To start, we showcase and explain selected data creations which highlight our observations. We start, in chronological order, with the visualisation, then the haptification, and we end with the physicalisations. Quotes either originate from the written work (reports and blog posts), or from the interviews. Interview quotes are indicated via participant numbers (e.g., *'P1'*), whereas quotes from written work are indicated with a team number (e.g., *'T1'*). When a quote or artefact originates from a particular team member, this is indicated with an index (e.g., *'T1-S3'* means team 1, student 3). Finally, quotes from written work are used verbatim. An overview of all creations as well as a more elaborate analysis can be found in the supplemental materials.

4.1 Assignment 1: Data Visualisation

Each team was tasked with selecting a source of 'hidden data'. Once the data tracking was complete, every team member individually created a postcard with a visualisation. Similar to *"Data Diaries"* [103], and the books *"Dear Data"* [69] and *"Observe, Collect, Draw!"* [70], visualisations had to be drawn or created by hand (i.e, without using software or programming) and not rely on standard visualisations (charts or graphs). This assignment resulted in twenty-three visualisations and five data sources: Team 1 chose the seven basic emotions [26], as: *"the source of emotion can only be described by the 'owner'"* (T1); Team 2 focused on lies; Team 3 explored the meaning emojis can communicate in online communication; Team 4 tracked their productivity efforts in the work environment; and Team 5 looked at emotions felt after physical interactions (e.g., a hug or handshake).

Analysing the representations, we noticed a mix of more standard visualisations (e.g., T5-S1's body map in Figure 1—possibly inspired by soma design [2]) and metaphorical visualisations. For example, T1-S1 mapped emotions to coloured flowers (Figure 1). Here, a red rose represents anger, whereas joy is represented through

[1] The acknowledgements list those students that allowed publishing their names. Given some of the represented data are personal and to ensure anonymisation of quotes, we do not reveal which of these students were part of which team.

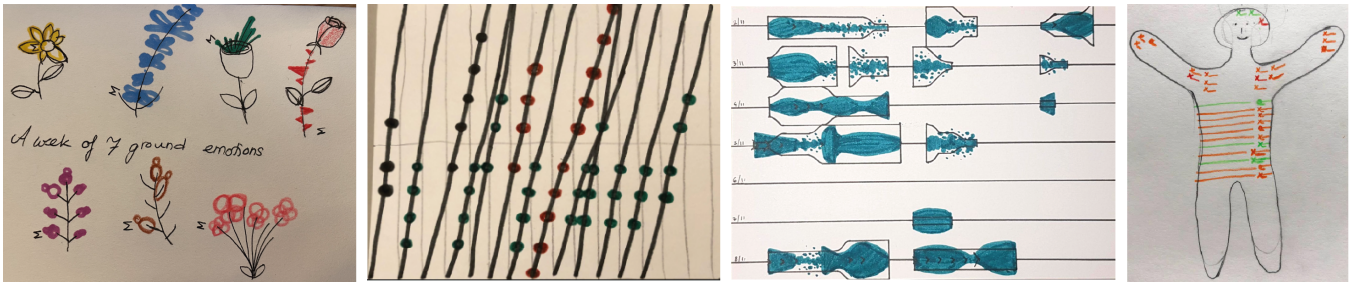

Figure 1: Left: T1-S1 used coloured flowers to represent emotions (e.g., purple represents disgust and pink surprise). The size of the petals, thorns, or leaves represents the emotion's intensity: bigger being more intense. The letter M stands for Monday, the starting day. Middle left: T2-S2 shows lies through the angle of each line (distance from the truth) and the colour of the dots (red is bad intention and green is good intention). The place of a dot –towards the bottom or top of the sheet– indicates who experienced the consequences of the lie (top indicates and effect on others and bottom an effect on them). Middle right: T4-S2 drew lines that represent the weekdays and containers for the amount of energy. Black arrows and their size indicate stress points. The coloured shapes represent productivity. Right: T5-S1 visualisation of emotions felt after a physical interaction. The location of the marks placed on the figure represent the interaction's location and the colour its affect (green is positive, orange neutral, and red negative). 'O' indicates that the interaction was initiated by them and 'X' by someone else. The length of the lines show the duration of interaction.

a yellow sunflower. Metaphors were especially used to represent lies: Team 2 used primary metaphors [41, 45] to encode the *"heaviness/weight"* of a lie and the *"distance"* from the truth. Moreover, in Team 4, both T4-S2 and T4-S3 used container metaphors to represent energy [55]. Figure 1 shows T4-S2's visualisation, where the size of shapes represents their perceived energy, with bigger shapes representing higher energy levels. They further use the dispersity of the blue fill colour to represent whether they were focused (solid fill) or distracted (blue dots) –mimicking their mental experience–, and the irregularity of the container represents the uncertainty and subjectivity of tracking this data.

4.2 Assignment 2: Haptification

After completing the visualisations, each team had to create a haptification (a data representation which communicates data through our sense of touch) of their chosen data source. This assignment challenged students to curate their data [105], as described by Team 4 who reduced the number of tracked dimensions, as it *"could get very hard or even counterproductive to squeeze too many dimensions of our data into one haptification"* (T4) and forces *"exploring one thing at a time, in this very moment being a human in your body"* (P1). Besides, the number of (poetical) metaphors increased. This is especially the case for the works of Team 1, 2, and 5.

Team 1's haptification represents the seven basic emotions felt over a week solely through metaphors (Figure 2). Some metaphors stem from specific haptics (e.g., toothpaste and cotton), others refer to bodily experiences, such as steel wool: *"sometimes people say they can't clearly think, because they're so angry."* (P11), or cultural conventions, such as ribbon: *"any gift that's nicely packaged in a ribbon [...] then it looks really like: Oh surprise!"* (P9).

To represent lies, Team 2's haptification (Figure 3—left) focuses on the intention of a lie (good or bad), the target (themselves, someone close, or a stranger), heaviness of the lie, and its distance from the truth. Lies are represented through balloons, as: *"like balloons, lies cannot be grasped easily and a lie can be busted like a balloon that explodes"* (T2). Team 2 used visual (size of the balloon and distance from the ground) and textural primary metaphors [41, 43]. For the latter, Team 2 used soft wool added to the balloon to represent someone close and rough surfaces for strangers. Further haptic metaphors were used for the lie's intention, represented through the felt temperature, as: *"warmth is usually associated with something comfortable and positive, cold usually is associated negatively"* (T2).

Lastly, Team 5's haptification represents the emotions felt during and after a physical interaction. Inspired by the separation between your inner feelings and how you present yourself to the outside world, Team 5 created small bags filled with materials (Figure 3—right). Just as Team 2, Team 5 used visual and textural primary metaphors: the outside material represents how you felt before the interaction and the inside represents the feeling after. The size of the bags represents the feeling's intensity, whereas the material's roughness indicates whether it is a positive or negative feeling [43]. To represent the feelings after, each bag's inside is filled with different materials. Here, the granularity of material encodes the interaction's impact (high granularity for small impact and vice versa) and its sharpness whether the lasting feeling is good (dull) or bad (sharp). The motivation behind the interaction was encoded based on whether the material was organic (*"natural"* interactions) or not (*"forced"* interactions). Finally, to indicate who initiated the interaction and what type of interaction it was, Team 5 added physical markers. A paper clip on the outside indicates that the interaction was initiated by themselves. For the type of interaction, Team 5 added an object inside the bag, e.g., a ring represents a hug. The aim was to make each cube a *"metaphor of one interaction"* (T5).

Although metaphors played an essential role in the haptifications, students initially struggled with the perceived subjectivity. To this end, Team 3 conducted additional interviews to: *"not just building (sic.) metaphors around what we think, but building metaphors around what maybe ten people say"* (P3). This helped them realise that: *"it*

Figure 2: Team 1 created a Christmas tree based on the time of the year. Each ring represents a day. Materials placed on the rings encode the felt emotions and their intensity (amount of material). The material itself metaphorically encodes one of the seven basic emotions, as described by the quotes (all from T1).

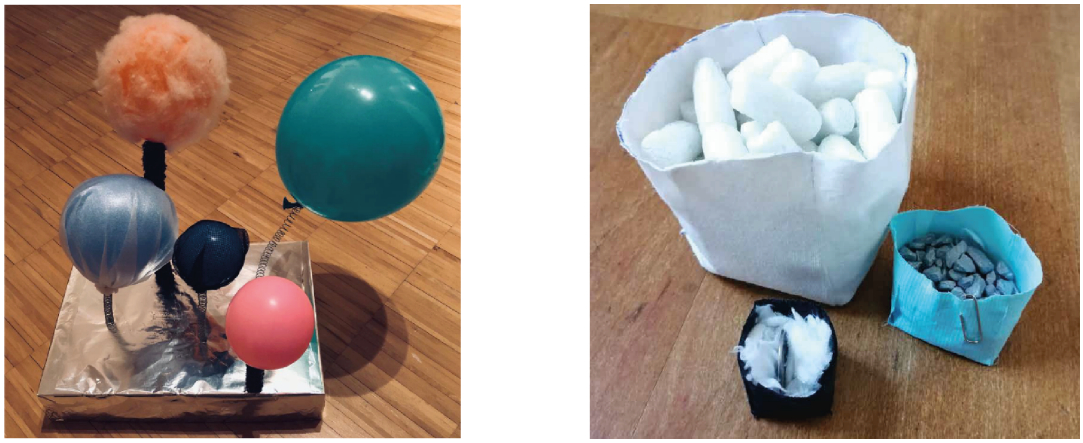

Figure 3: Left: A haptification of lies by Team 2 using balloons. The distance of each balloon from the ground indicates distance from the truth, its size the heaviness of lies. Texture and felt temperature of materials attached to the balloons represent at whom a lie was directed and its intention. Right: Team 5's haptification: Each square bag represents one physical interaction with another person. The outside material indicates the feeling before the interaction and the inside that after. Objects in the bag represent the type of interaction.

was not just the materials themselves that participants associated emotions with, but the characteristics or behaviour of the materials" (T3). For example, boiling water was suggested to represent anger, since someone can be *"boiling with anger"* (T3)—which aligns with the primary metaphor of *"anger is heat"* [41].

4.3 Assignment 3: Data Physicalisation

For the final assignment, each team continued working with their data set to create a dynamic data physicalisation. For this assignment, Team 1 created a bracelet that represents the wearer's emotions (categorised into the seven basic emotions), through metaphorical mappings where the vibration patterns and colour of LED lights represent the emotions (e.g., anger is represented through harsh vibrations and red light).

Team 2 developed a speculative design concept to explore the consequences of tracking and representing lies. In this concept, the front lawn of each home within a neighbourhood features a physicalisation that represents the lies of the house's inhabitants. Figure 4 shows a sketch of the idea. Team 2 also created a physicalisation based on their haptification (Figure 4—right). Keeping most of the haptification's mappings (e.g., distance to the ground represents the distance from the truth), Team 2 created an interactive artefact where this distance changes automatically. The encoding via material's temperature was replaced by light temperature emitted from LEDs inside the balloon, with blue (cold light) conveying bad intentions and red (warm light) good ones. Not only was light technically easier to implement, it also added the metaphor of light as: *"a symbol for the truth"* (T2).

Figure 4: Left: Team 1's bracelet. The LED's colour and the intensity of vibration patterns from the built-in vibration motor represent the wearer's emotional state (e.g., sad or happy). Right: A scenario sketch of Team 2's concept where each house in a neighbourhood has a physicalisation of lies. This way, people can assess the 'truthfulness' of the neighbourhood and individual households. The prototype consists of a balloon that can move up and down to indicate distance from the truth. Its colour represents the lie's intention and its size the heaviness (bigger is heavier).

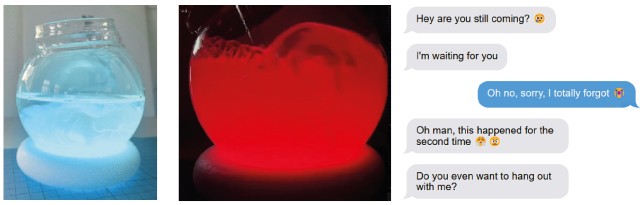

Figure 5: Team 3's physicalisation represents the emotional state based on emojis used in text communication through colour, water temperature, and behaviour (e.g., boiling or calm). Left: the ball in a happy state (blue, calm, and lukewarm water). Right: the ball in angry state (red and boiling water). The reason for this state is shown in the corresponding text messages.

Inspired by a fortune-teller's ball and the *"Remembrall"* from Harry Potter (a small glass ball which fills with red smoke if the user forgets something), Team 3 created a circular ball, filled with an opaque liquid (water and plant-based milk). Two conversation partners each own this object and based on their online communication and emojis, the physicalisation represents the emotional state (angry, happy, in love, or sad) of the relationship. To assess this information, the user has to touch the artefact, which Team 3 dubbed the *"touch to reveal" metaphor*. The temperature of the water (e.g., warm is love and cold is sad), its character (e.g., boiling is angry), and colour then represent the emotional state (e.g., black is sad). Since both anger and love were associated with the colour red, Team 3 added an extra metaphor for love: a pulsating light to mimic a beating heart. Figure 5 shows the physicalisation in action, next to the online communication.

Team 4 (Figure 6) created a modular physicalisation to represent workload, so it could be used in different scenarios (e.g., office garden vs. home office). Inspired by beehives: *"drawing inspiration from the collaborative work of bees and their hives, we chose a hexagon base for the object"* (T4), each module can either be used individually to represent the workload of one person, or connected to other modules to get an overview of how the team is performing. The shape and colour of the module represent the user's perceived capacity. A contracted shape (Figure 6—right) is mapped to a red warning colour, indicating that the user's capacity is overloaded. If the user thinks they can take on more work, the shape is *"relaxed"* and mapped to a cool, blue colour. Team 4 further added haptics to this to represent the 'actual' workload. Each module contains a spring and based on the height, the spring is compressed, which results in the physicalisation looking and feeling tense. This thus represents that the user cannot take on more work, or as Team 4 phrased it: *"less capacity to add on more weight (both physical and metaphorical)"*. Team 4 focused on this double mapping to have both an *"objective"* and *"subjective"* (T4) workload. Using a diaphragm, the objective and subjective encoding were linked to each other; representing that they exist simultaneously.

Finally, Team 5 created a *"bonsai tree"* (T5 and P8) as their physicalisation (Figure 7). The tree was chosen as a *"conceptual metaphor"*, as the data *"was rather emotional, we intended to proceed with a rather biomorphic and biophilic design to imply the fact that our physical interactions with others have influences on us and the influences will live with us in some way"* (T5). Inspired by this, Team 5 imagined the Bonsai tree to be placed in the home (e.g., on a table) for the user to explore it when they encounter the physicalisation. Cube-shaped 'fruits' made of epoxy resin hang from the tree. Each cube can emit light and vibrate: light colour represents whether the feeling after a physical interaction was positive or negative (green and red colour) and the brightness shows the intensity of this feeling. The type of interaction is communicated via vibration patterns. This data can only be accessed by touching and holding a cube, to symbolise the hidden nature of emotions. Finally, each cube can move up and down from the tree, where the distance from the tree branch represents the amount of body contact: short distances indicate short-lasting interactions and vice versa. To circumvent the limited number of cubes the tree can hold, data would *"die"* over time: *"the form also metaphorically presents that those influences fade with time, as the fruits and leaves come and go, and as we say, "Data dies""* (T5).

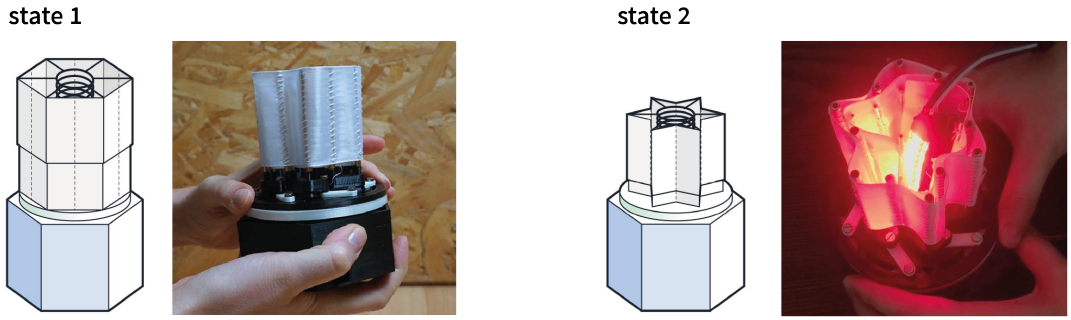

Figure 6: Team 4's physicalisation moves between two states to illustrate workload. State 1 shows a healthy workload: an open and relaxed shape, in a cool blue. State 2 represents a stressed user: the shape is contracted and tense-looking, and red emphasizes this. For haptic feedback, the physicalisation is at its maximum height and the spring inside is fully relaxed in State 1. In State 2, the height and spring are compressed, mimicking the tension one feels when being under stress.

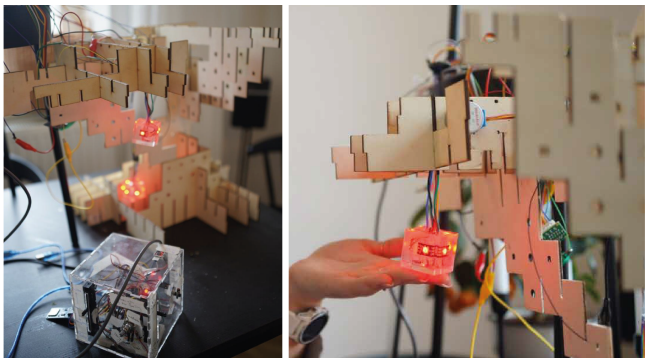

Figure 7: Team 5 designed a small tree, from which cubes hang that represent the data. Each cube represents the emotions felt after a physical interaction through colour (positive or negative effect), brightness (intensity of feeling), and vibration (interaction type). Vibration is only played when the cube is touched. The distance between tree and cube represents the amount of body contact. The cube (shown on the left) is the input device for entering these parameters.

4.4 Recap—Progression of Metaphors

Looking at the created data representations, metaphors play a crucial role in representing tacit data, even though the notion of metaphors had not been discussed or introduced in our course (see supplemental materials). In the first assignment, there was a mix of more traditional and metaphorical visualisations. Certain topics and elements seem to lend themselves more to metaphors. For example, it seems that lies (Team 2) cannot easily be represented in a literal way—thus need to be represented through metaphors. In contrast, emotions after physical touch (Team 5) could be represented well without metaphors. Although some initial complex and poetical metaphors can be seen (e.g., T1-S1's or T4-S2's representations), most are either colour or primary metaphors, possibly because these are commonly used in data visualisation [66, 108].

The usage of metaphors evolved when the teams had to create haptifications. While visualisations could be created without or only relying on colour and primary metaphors, the haptification required all teams to encode their data metaphorically. Even teams that used few metaphors in their visualisation (e.g., Team 5), created haptifications that centre around metaphors (Figure 3). Since the visual did not play a role in haptification –the data had to be communicated via touch– colour metaphors were not used. Instead, students created new material metaphors, for which they used the material itself (e.g., T1's twigs to represent sadness), type of material (e.g., T5's organic and inorganic materials to encode the motivation behind a physical interaction), its behaviour (e.g., T3's use of water), or haptics for texture metaphors (e.g., the outside of T2's balloons) [43]. Whereas for the visualisation assignment, only the work of T1-S1 focused on poetical metaphors, for the haptification this type of metaphor plays a more central role in telling the story of the data, as can be seen in the works of T1 and T5.

Even though all teams utilised metaphors, this was not always easy. As described in Section 4.2, Team 3 interviewed ten people, as they felt metaphors are a 'subjective' way of encoding data, for which you cannot verify whether this encoding is correct, as described during the interviews when discussing the haptification: *"there was (sic.) no metrics we could use to leverage an idea"* (P4).

Finally, for the physicalisations, metaphors play an important role on multiple levels, as these used primary and poetical metaphors, as well as metaphors which guide the user's interaction and help to tell the story of the data. Since visual elements were allowed again, all teams used colour metaphors. Besides being easy to implement (using LEDs), colour metaphors sometimes circumvented technical limitations. For instance, Team 2's initial idea was to use the balloon's temperature to indicate a lie's intention. However, as this proved too difficult to implement, Team 2 used light colour. This had a further benefit, namely fit with their story, given *"light is a symbol of truth"* (T2). In the physicalisation phase, using metaphors for storytelling in combination with metaphors to guide the interaction was common. Metaphors that fit the story were used by Team 3 (the Remembrall), Team 4 (the beehive), and Team 5 (a tree where data dies). Furthermore, both Team 4 and 5 used the *"touch to reveal"* (T4) metaphor, where the user has to interact with the physicalisation to retrieve the data. Lastly, colour and primary metaphors translated

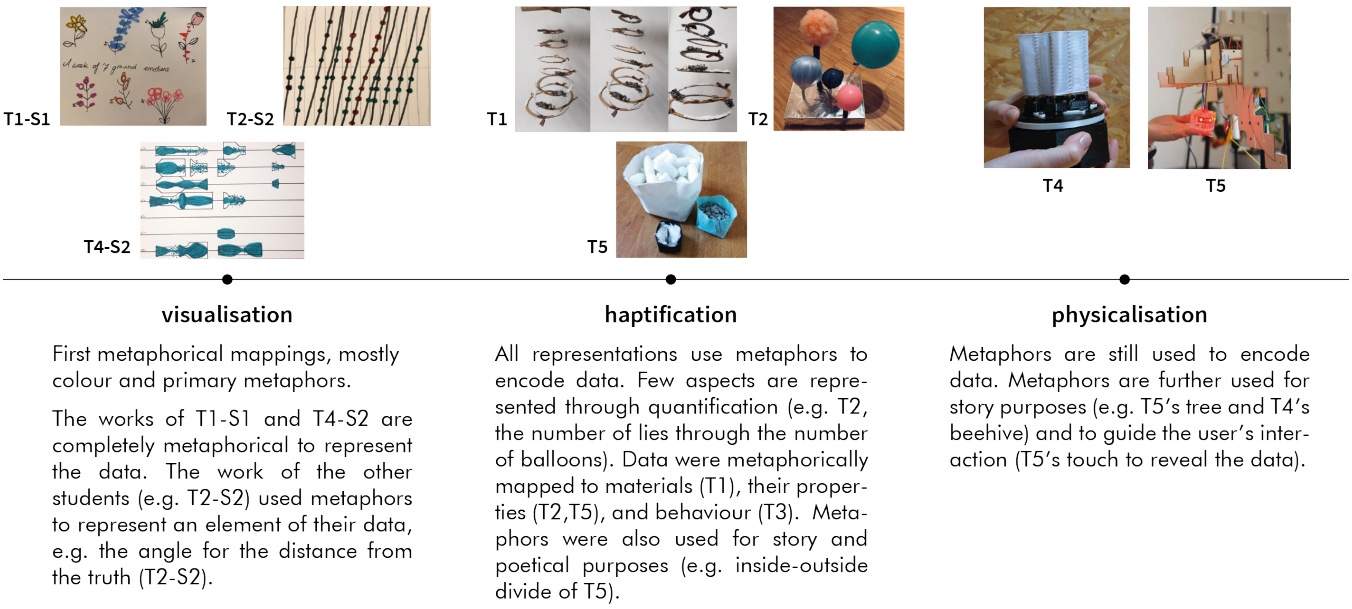

Figure 8: A progress overview of metaphors utilised.

well from the visualisation to the physicalisation assignment. However, we note a contrast with the haptification assignment, where colour metaphors could not be used to represent data (as this had to be done via the sense of touch) and non-visual primary metaphors had to be relied on to communicate the data (e.g., ROUGH IS BAD rather than UP IS MORE). Figure 8 illustrates a visual summary of the described progress.

5 OBSERVATIONS AND INTERVIEW INSIGHTS

Based on these data creations, we conducted interviews with eleven students. Through the exploration of what 'hidden data' are, we learned that this term and its terminology were too broad. The data creations and interviews taught us that students considered three aspects to be crucial, which touch upon (1) data's relation to technology, (2) that they are difficult to quantify and measure, and (3) cover the 'soft' aspects of data—instead of hard, numerical values. To better reflect these aspects, we renamed our concept *'tacit data'*.

Since students saw tacit data as something different from 'ordinary data', visualising them did not contribute to improving their understanding of tacit data. According to students, visualisation focuses on making data understandable and presenting as much information as possible so it is easy to understand. This counteracted their attempts to capture the nature of tacit data, which benefited from tangible aspects present in haptification and physicalisation. These tangible aspects allowed students to represent data beyond accuracy [103], and in the case of emotions and feelings, the felt feeling could even be replicated haptically. Students had to use metaphors to encode the data in a physical representation and make tacit data 'workable'. Metaphors helped students understand what tacit data are, overcome (technical) limitations and the newness of haptification and physicalisation, and tell the story of the data.

In the following section, we first discuss the aspects of tacit data which helped us to create our final definition, followed by an explanation of why the visual does not suffice. This section ends with the role of metaphors. Note, as tacit data were introduced to students as 'hidden data', used quotes mention hidden data instead of tacit data.

5.1 Aspects of 'Tacit' Data

One of the aims of this article is to introduce the notion of tacit data and give insights in how to physically represent them. Although students were initially introduced to the term hidden data –*"the qualitative aspects of data which are difficult to communicate and represent due to lack of relations or language"*–, throughout the semester we stressed that this was not a definitive definition. Figure 9 shows how our (students' and researchers') understanding of tacit data evolved, to which the following three aspects were essential:

5.1.1 Soft and Subtle. The most popular view on tacit data was to refer to them as 'soft': *"I would call it soft data. Because it's not, it really requires you to ask, and it's really exploratory. It feels more exploratory than, you know, hard numbers"* (P2). Tacit data were seen as *"vague"* (P4) and *"something very subtle. It's something very emotional and inner"* (P8). Tacit data make you question why these data exist: *"it's really trying to understand why this data exists"* (P2). These labels ring similarity to tacit knowledge, which is often seen as *"esoteric"* [15]. This makes it difficult to use tacit data for interpersonal communication (our initial assignment), as tacit data serve small purposes, such as focusing on the self and reflection: *"the things that we made from the hidden [tacit] data [...] was (sic.) more*

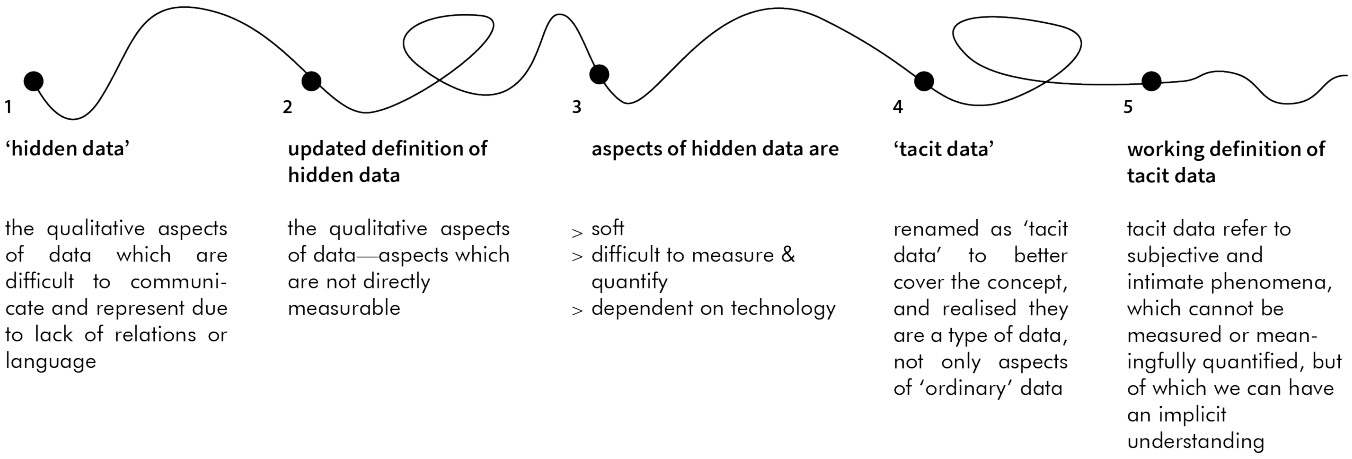

Figure 9: A visualisation of how the name and definition of tacit data developed over five stages: (1) at the start of the course; (2) at the end of the course; (3) aspects gained from the interviews; (4) reflection after the interviews; (5) during the write-up of this paper. The line is wobbly to indicate this was not a linear process.

of self-thought or like why does this data exist? It was more of a reflective kind of... Getting you to think or to ask questions" (P2).

5.1.2 Difficult to Uncover and Hard to Quantify. In alignment with the initial definition of hidden data, students stated that tacit data are hard to measure and perceive. However, students refined this understanding by describing that tacit data start at *"the point where [...] a human being lacks of perceiving this data"* (P3), that they are *"data that you have to really dig in"* (P2), and *"things that you wouldn't think of counting."* (P5). Since tacit data are difficult to uncover, it is only through *"specifically going for it or arranging something"* (P1), looking at multiple perspectives: *"[tacit data] is only describable by a combination of various factors"* (P11), and tracing the origin of the data: *"through [...] trying to get near to where they originate from, one can try to put a number on it"* (P4), that they can be 'uncovered'. A reason for why tacit data are hard to uncover, is the fact that they are difficult to quantify. This sentiment was described throughout the interviews, where students stated that tacit data cannot be labeled nor quantified: *"you can't just label it or something or put a number on it on a scale"* (P4) and *"how do you describe it? How to quantify it?"* (P8).

5.1.3 Technology and Tacit Data. Although tacit data are difficult to measure and quantify, students pointed out the relation to technology. Not only did some students expect technology to be able to uncover tacit data at points where humans cannot: *"that kind of thing like needed to be detected by a sensor"* (P10), students also indicated how our perspective of what constitutes tacit data changes through technology: *"100 years ago, body temperature would be perceivable (sic.) more hidden, because it was not like measurable [...] It was feel-able that [...] you have a fever or not. But there were no thermometers for that. Now we have thermometers"* (P3) and *"with these kinds of smartwatches [...] less and less is really hidden, but more and more is getting revealed"* (P4). Students expressed the temporal nature of tacit data, stating that we simply do not have the right technologies yet, but that these might be developed—as mentioned by P4 when discussing their idea of tacit data: *"things that are hard to measure, but that are still relevant and interesting. And that we are at a point where technology can help us measure these somehow, but is not there yet."*

5.2 The Visual does not Suffice

Besides these aspects, students stated that tacit data are completely different from 'ordinary' data: *"something totally different with [...] the explicit data"* (P8). This makes it difficult to visualise them, as described by the following reflection on the visualisation assignment: *"some things are really hard to visualise [...], because they're very subjective"* (P4).

A potential reason for this is visualisation's focus on making data understandable: *"in the visualisation phase [...] we focus more on how to make the data understandable"* (P10), by compressing information in something which is easy to consume—as explained by P2 when discussing the visualisations: *"the main learning under the visualisation part was [...] compressing information into symbols"* and seeing *"how they took a large chunk of information and just made it into something small and easy to consume"*. Using their standard tools: *"I don't think about how I would visualise it, I just have my three-four tools"* (P4) and visualisation principles, students saw this step as *"relatively easy"* (P1), since they are used to visualisations: *"We have (sic.) so much used to dealing with it, that we don't even have to think about it"* (P1). Therefore, it seems that visualisation did not help students understand what tacit data are, as mentioned by P8 whilst discussing this assignment: *"that like made me [...] not understand the hidden [tacit] data, because I didn't see that much difference between hidden [tacit] data and the so-called normal data. Because at the end of the day, we need to visualise it, then what's the difference?"*.

5.2.1 Physical Data Representations Offer More. Since the conventional way of representing data does not suffice for tacit data and is too simplistic: *"it's too simple to only try to visualise data, [...] a lot of information gets lost when you only try to show it in 2D space"* (P11), students stressed the importance of the tangible. Not only do

physical-tactile data representations (the haptification and physicalisation) contain a lot of information: *"there's a lot of meaning attached to [...] the tangible part"* (P11), they also offer the freedom of exploring other values than accuracy: *"maybe the tactile perception is the best one, because sometimes if it's a hidden [tacit] data you don't [...] need a scale there, right? So you don't want a very accurate value"* (P8) and exploring the meaning of data: *"in the second phase [the haptification], we not only focus how to make the data understandable, but also the meaning behind the data"* (P10). This echoes previous research [84, 103], which showed that physicalisations focus on other qualities, such as storytelling.

Moreover, the physical offered 'rich' ways of expressing data, where people feel the experienced data: *"information gets lost when you try to describe it in words or if you try to paint it. But if you can show somebody by touching a surface [...], I think that's probably the best way to represent it, because you can try to map the feeling you're having on the inside, you can try to recreate somehow that experience by touching a surface"* (P11).

5.3 The Role of Metaphors.

As tacit data demand new ways of representation for which physical data representations seem to be an option, we need new mapping techniques, as mentioned by P1: *"'I want this thing to be red. Because I can.' No! you can't do this anymore. You are pushed to [...] make this mechanism of physicality and your mental model to match."* This has been indicated by previous research as well [28]. To create these mappings between data and representation, students resorted to metaphors. Here we discuss how metaphors were needed for tacit data and physical data representations.

5.3.1 Tacit Data Demand Metaphors. Because of the nature of tacit data, students stressed that *"everyone has different experiences to especially something that doesn't have to do with numbers, something that has to do with experiences and people's perception of life"* (P2). As discussed in Section 5.1.2, this makes tacit data difficult to quantify. Therefore, new ways of making the data workable had to be found, for which metaphors played a role, as stated by P4: *"with these metaphors, we put this hidden [tacit] data from being something we feel, into something we can work with."*. Metaphors allowed students to 'objectify' the tacit data: *"these metaphors helped us to make this hidden [tacit] data somehow more objective"* (P4) and anchor [14, 49] them into something 'concrete', as indicated by P9 when discussing their use of twigs as a metaphor for sadness: *"when we were thinking of the sadness, we couldn't really think of anything concrete, but then we thought: 'okay, when it's winter time [...] when the leaves are no more, it's just branches. It's just very gloomy and kind of depressing'. So we were like: then it's sad"*.

Moreover, metaphors allowed students to communicate the essence of their data. As explained by P8, who mentioned that it is impossible to compare tacit data: *"you cannot tell today if I'm not happy, if I'm happier, [or] if I'm slightly happier than yesterday—it's something not comparable"* and thus, a high level of accuracy does not make sense. Here metaphors play a crucial role, as they convey the main message: *"[metaphors] exactly abandoned those redundant, redundant information: the accuracy—but keep the stem [...] of the feeling"* (P8).

5.3.2 Physical Data Representations Demand Metaphors. Although it is known that physicalisations often use metaphors to encode and communicate data (e.g., [25, 80, 110]), to our knowledge no work offers an explanation for why they are so dominant. As discussed in Section 4.4, metaphors played a quintessential role in the physical data representations. This was also acknowledged by P6, who speculated that metaphors were needed to overcome the newness of these types of data representation: *"we used a lot of metaphors in our design, so I guess you could say that we were using more and more. Maybe because it's also like something new, so you try to anchor it in things that you know. And maybe that's why we used more metaphors"*.

Moreover, students reflected that metaphors resulted from limitations imposed by physical data representations: *"the metaphors were born mostly through limitations"* (P1). Since these data representations prohibited students' from using their regular tools, students had to figure out new ways of representing data: *"[with visualisation it is like] you have 10 actors to make a movie, you would not like bother to go into the metaphors, because you have a person who can like express emotion and say things. [...] And it was exactly the same way here. So at first phase, we had all the visuals possible [...] that we don't even have to think about it"* (P1). Furthermore, metaphors helped students find solutions for how to represent their data: *"it was more like a ping pong of, between fulfilling requirements and finding solutions. And yeah, in this process metaphors helped us to find this solution"* (P3). A final given reason was that physicalisations offer more dimensions that can be used for metaphorical encoding: *"in the last phase, because we also add the interaction, so there is one more dimension that we have. [...] So you have more actions and behaviours, and this can also be used to build metaphors"* (P10).

6 DISCUSSION

Although we initially set out to explore 'hidden data', we soon learned that this notion did not fully and adequately capture what we had in mind. A distinction between quantitative aspects of data which are counted and thus explicit, and qualitative aspects which are not accounted for –thus being hidden– is too simplistic. Therefore, a new name (tacit data) and working definition were needed. Moreover, as tacit data were seen as being different from 'ordinary' data, which focus on subjective, intimate, and perhaps consciously unaccounted aspects, our work indicates that visualisation does not suffice for representing tacit data. To cover these aspects, physical/tangible aspects seem to be promising, as they move beyond highly accurate representations with the aim of making data easy to understand. Instead, they allow you to relive a feeling and offer more dimensions to express elements of the data. However, to represent data in the physical realm, new representational methods are needed. Here we see the importance of metaphors, which were used to overcome the 'hard to quantify' nature of tacit data and newness of physical data representations, and to make sense of tacit data. In this discussion, we reflect on the evolution of our understanding of tacit data, the role of metaphors in physical data representations and tacit data, and the possibilities for physical/tangible data representations. We end with the limitations of our work.

6.1 Evolution to Tacit Data

We align ourselves with data feminism and believe that all data are plural, messy, subjective, and situated [20]. Within this understanding, we set out to explore 'hidden data': qualitative aspects which are difficult to communicate and represent. Through the course, interviews, and working on this article, we realised that this initial definition and terminology did not suffice. For example, the term hidden data makes it seem as if the data should 'only be invisible' or, as Onuoha uses it [85], be systemically excluded. Although part of tacit data is that they are often unaccounted for –as they are hard to measure/quantify (see Section 5.1)– they constitute more and go beyond qualitative aspects: they are their own type of data (Section 5.2). 'Ordinary data' tend to be used as a way to turn inarticulate phenomena into articulate knowledge (often through quantification) [10]. Although this works (well enough) in many instances, tacit data start at the boundary where this process stops making sense and acknowledges that not *all* inarticulate phenomena can be turned into articulate knowledge. Tacit data embrace this 'fuzziness'; they are 'soft', intimate, and technology-bound. They serve smaller purposes than 'ordinary data', such as communication with yourself, reflexive questioning, and demand that you really 'dig in' the data to uncover them: requiring patience and craft-like approaches [15]. Based on this and the data sources used by our students (e.g., lies and emotions), we renamed our concept *tacit data*. Similar to tacit knowledge [82, 89], tacit data are not formal and codified; they are difficult to express and uncover, and thus more difficult to communicate (resulting in some students labelling them as *'vague'*). We then developed a working definition: *"tacit data refer to subjective and intimate phenomena, which cannot directly be measured or meaningfully quantified, but of which we can have an implicit understanding"*. As our working definition suggests, tacit data can be quantified. However, quantification defeats the purpose of tacit data, as it eliminates all meaningful and essential complexity. For example, quantifying the 'badness' of a lie does not improve our understanding. On the contrary, it only leaves us wondering why it would be quantified!

Although our proposition of tacit data is new, unquantifiable or difficult to quantify elements are not; in data science *unquantifiable uncertainty* [86] refers to uncertainties which are difficult to quantify and which can only be expressed *qualitatively* [86, 102]. Here we see similarities to tacit data which are better expressed qualitatively or through metaphorical quantification (just as tacit knowledge [89], see also [10, 79, 81]), as we discuss in the next section.

Even though tacit data offer a way of expressing and communicating implicitly known data (e.g., *data hunches* [60]), it is important to note that there are ethical implications as well. As tacit data are dependent and affected by technology (with technology making more-and-more tacit data perceivable, see Section 5.1.3), it is easy to imagine how technology can be used to unethically monitor people's tacit data. As tacit data are intimate phenomena, uncovering these data and representing them could expose what we might want to keep hidden. Therefore, it sometimes might be best to keep tacit data unaccounted for. Because there is still much that needs to be learned about tacit data –from what they are, where they end, their ethical impact, and how to better define them– we invite other researchers to join our quest to understand and define tacit data.

6.2 Metaphors in Tacit Data and Physical Data Representations

In Section 4.4 we showed that metaphors were central in our course, that certain topics (such as lies) lent themselves easily to metaphors, and by moving towards the physical, the number and types of metaphors increased—especially the number of poetical metaphors [88]. From our work, it seems that both physical data representations and tacit data need metaphors to represent the data. Starting with tacit data, we note that tacit data were deemed difficult to measure and quantify (Section 5.1.2). Therefore, students expressed that they needed new ways of working with the data, for which they used metaphors. This echoes the concept of *ontological metaphors*, where unbounded or non-discrete entities –such as emotions and activities– are viewed as substances or entities (e.g, *"inflation is lowering"*) [55]. This way, ontological metaphors make it possible for us to deal *"rationally"* with our experiences, partly because they allow metaphorical quantification (e.g., *"a lot of patience"*) [55]. This was often used in the context of tacit data. Moreover, as quantification can be described as *"a technology of distance"* [90], quantification might not be the best tool for soft and intimate data. As metaphors originate from our bodily experiences and embodied being in the world [55], it seems that they are better suited to capture these aspects of tacit data.

Another reason why tacit data demanded metaphors can be seen in students' acknowledgement of the partiality of the data. As students developed their own understanding of tacit data, they realised that everyone's experience would be different for their chosen topic. This made them aware that there might not be one correct way of representing the data. Since metaphorical connections only emphasise some aspects of a phenomenon, but never the whole [55, 72], they never perfectly match—there will always be components missing, properties that do not exist, or structures that cannot be compared [72]. As such, metaphors are *"neither true nor false"* [92], which means that they can only illuminate the target through a limited isomorphism. Thus, the 'imperfectness' of metaphors might suit the partiality of the tacit data, making them a good fit to represent them.

However, this is not the only effect of the imperfections of metaphors: it fosters ambiguity which triggers critical thinking, which can, in turn, foster new understandings of how we see certain things [1, 11, 32, 75, 92]. This could explain why metaphors were needed for tacit data, as they helped students grasp the concept and move beyond their initial understanding of data as something numerical, objective, and universal.

At the same time, the partiality of metaphors suited the physical data representations. Previous work has shown that data physicalisations demand reduction and data curation [105], and indicate that their main purpose is not accuracy, but to tell a story with the data [103]. Therefore, metaphors could have helped students to both curate and focus on communicating their data. Moreover, as the physical data representations were a new medium, students mentioned that metaphors were used to overcome the limitations

they faced, communicate the data, and make use of the extra dimensions these media afforded. This aligns with the purposes of metaphors in design, where they are used to inspire the design of new interfaces [65], create a shared vision and frame the problem at hand [1, 12, 33], and enhance the aesthetics, intuitiveness, and evocativeness of the product [14, 16, 33, 34].

As stated by Petrenko et al. the presence of metaphors *"isn't accidental or purposeless, but trying to reduce them to a single function would be hopeless."* [87]. Accordingly, we acknowledge the plural roles metaphors play in tacit data and physical data representations. The above-mentioned reasons might be only some of the possible reasons. Therefore, more research exploring the role of metaphors for diverse understandings of data and data representations is needed. Moreover, our work shows that metaphors helped students grasp the concept of tacit data, change their understanding of how data should be represented, and to embody the unique aspects of tacit data. A reason for this could be that metaphors require the rejection of an absolute truth [55], and thus allow mappings beyond sole rational thought [87]. Therefore, we believe that metaphors could be a powerful tool in exploring and helping people understand different perspectives on data beyond the current status quo, such as feminist perspectives (e.g., [13, 20]). Future research should explore whether this hypothesis holds up.

6.3 Beyond the Visual

According to our students, the visual did not suffice for tacit data. This aligns with previous work speculating that data physicalisation could be a vehicle for channelling critical thought on what data are [4, 84, 103]. In our exploration of tacit data, we found that tacit data require touchable aspects to be able to represent the 'feel' and perspectives of the data. As materials have a meaning of their own, independent of users and context [46, 94, 97], they offer added dimensions which can be used for encoding. As put by Offenhuber, physicalisations: *"are not abstracted and contain unquantifiable amounts of information"*. These dimensions do not necessarily focus on the qualities of visualisation (such as efficiency) but do allow us to embrace new aspects of data [103], such as expressivity [99]. Moreover, our findings and that of previous work [57, 63] indicate that physical data representations are suited for representing qualitative data (aspects). These findings would explain why many physicalisations –especially those which can be assigned to Offenhuber's epistemological/relational and ontological/relational quadrants [84]– focus on non-traditional, numeric data sources, but instead focus on the narratives of the data and the data experience, cf. [40, 50]. Therefore, we believe that more research is needed on how physical data representations change and influence our understanding of data.

Looking at the created data representations, we note that haptics were often used to represent feelings, such as stress or emotions. As explained by one student, the haptic modality allowed felt experiences to be replicated in a way that others could experience them as well. This suggests the potential for data haptifications. Currently, haptifications have mainly been used to create representations for people with visual impairments [6–8], as immersive alternatives to visualisations [7, 27, 109], or for data representations with low cognitive load [3, 9]. Based on our findings and previous research, which indicates that people respond more emotively to data represented haptically (cf. [36, 37]), we believe there is an opportunity for haptifications to represent felt and emotional experiences. Future research should explore the potential of this.

Finally, we want to acknowledge that students' opinions regarding the need for physical aspects to represent tacit data might be influenced by the course's assignment. We asked students to create a haptification and physicalisation, which would explain why they gravitated towards the tangible aspects and not other modalities, such as sound or taste—even though these were introduced in the lecture of week 6. Because of this, we believe future research should explore the possibilities of representing tacit data through other sensory channels, to see whether our findings hold, and to explore the strengths these modalities have to offer. Although this could be seen as a limitation of our work, we believe our findings indicate the potential strengths of physical data representations, which adds to a growing body of work that tries to understand this type of data representation (e.g., [25, 47, 96, 106]).

6.4 Limitations

As our work is based on an online semester course for HCI students (predominantly with a Computer Science background), we surmise that this influenced our findings. For example, the ideas and faith in technology (Section 5.1.3) can result from this, just as students needed to overcome the new challenges of working with creative materials. This can also be seen in students often using colour to represent their data in their final physicalisations, rather than using the potential of materiality and the dynamic nature of the physicalisation. This would probably be different for students with an art or design background. Nonetheless, considering that our students feel comfortable working with numerical data and traditional data visualisation, it could be a strength to see that this audience used metaphors and focused on the different perspectives of data. Furthermore, we acknowledge the Global North, Western perspective of this work. The course took place in Germany, with all teachers/authors being situated in Western Europe. Although the students had various nationalities, some of the metaphors used are culture-dependent, such as colour metaphors, where Team 5 used red to indicate a negative feeling. Therefore, further research with more diverse samples, gender identities, and research locations, and other research methods are needed to deepen and validate the generalisability of our findings. Moreover, the initial assignment (used to provide some constraints) of finding data in a co-located setting between two or more people influenced the data sources students selected. Therefore, the data sets presented in this paper only cover a small range of possible sources of tacit data. More work is needed to explore the vastness of tacit data. Lastly, the representations often used 'ultimate' encoding (e.g., red is anger and blue is sad). Considering that the data sources (e.g., emotions) often require more nuance, these representational techniques ideally would offer a gradient of options between 'anger' and 'sadness'. Within the time constraints of this semester course, the full potential of creating nuanced mappings could not be explored. More work is needed exploring how to represent the complexity of tacit data.

7 CONCLUSION

To explore the diversity of data, this work introduces the notion of *'tacit data'* and examines how to represent them through data physicalisation. Based on an online semester course with twenty-three students –in which students created a visualisation, a haptification, and a physicalisation– our work shows the importance of metaphors: both in physical data representations and for tacit data. In physical data representations, metaphors help to overcome limitations, curate the data, guide interactions with representations, and communicate the data to the audience. For tacit data, metaphors were used instead of quantification to make the data workable, anchor them in something known, and communicate the essence of the data. This was needed as tacit data were seen as difficult to summarise in numerical values, and focusing on 'soft', intimate, and subjective aspects of data. Because of these qualities, data visualisation does not suffice. Students expressed the need for more dimensions which allow you to express how the data felt, suggesting that physical data representations are better suited for this type of data. Our work adds to the current discussion of what data are by introducing the notion of tacit data, the role metaphors play in understanding different perspectives of data, and shows why metaphors are so central in physical data representations (including physicalisations).

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