The Candy Workshop: Supporting Rich Sensory Modalities in Constructive Data Physicalization

Carine Lallemand
Eindhoven University of Technology and University of Luxembourg
c.e.lallemand@tue.nl

Maud Oomen*
Eindhoven University of Technology
m.k.m.oomen@student.tue.nl

Figure 1: Constructive data physicalizations made out of candies during the candy workshop

ABSTRACT

Constructive data physicalization (i.e. the creation of visualizations by non-experts using physical elements) is a promising research area in a context of rapid democratization of data collection and visualization, driven notably by the quantified-self movement. Despite a prolific body of work developed to explore physicalization as a mean to communicate data to individuals, little is known about how people transform data into physical artefacts. Current research also falls short in studying constructive physicalizations using other sensory modalities than sight or touch. Building on the principles of data edibilization, we propose to use candies as a medium to study constructive data physicalization processes, due to their ability to leverage multiple sensory channels. We conducted a preliminary study (candy workshop) to gain insights into how people make use of various sensory modalities in the construction of data physicalizations. We hope to inspire new research using candies as accessible research material.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); User studies.

KEYWORDS

Constructive Data Physicalization, Physical visualization, Workshop, Sensory Modalities, Data Edibilization

*Both authors contributed equally to this work

CHI '22 Extended Abstracts, April 29–May 05, 2022, New Orleans, LA, USA

ACM ISBN 978-1-4503-9156-6/22/04.
https://doi.org/10.1145/3491101.3519648

ACM Reference Format:
Carine Lallemand and Maud Oomen. 2022. The Candy Workshop: Supporting Rich Sensory Modalities in Constructive Data Physicalization. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI '22 Extended Abstracts), April 29–May 05, 2022, New Orleans, LA, USA.* ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3491101.3519648

1 INTRODUCTION

A data physicalization (also called physical visualization) is defined as "a physical artifact whose geometry or material properties encode data." [8]. In the past decade, an important body of academic work has been developed to explore physicalization as a mean to communicate data to individuals. What is the potential of this approach and why would one want to physicalize data? A myriad of scenarios of use have emerged around data physicalization, the predominant ones identified in recent literature reviews [2, 4] being: (a) for the general public, simplifying the understanding of data, raising awareness or supporting decision-making, (b) for individuals, keeping track of personal data about tasks and activities for self-awareness, reflection or behavior change, (c) for individuals with specific needs, improving accessibility of data in various contexts, (d) as tools for educators, researchers and engineers.

Despite a prolific body of work developed to explore physicalization as a mean to communicate data to individuals, little is known about how people transform data into physical artefacts (i.e. constructive data physicalization [5]). Current research also falls short in studying constructive physicalizations using other sensory modalities than sight or touch [4]. Building on the principles of data edibilization [18], we propose to use candies as a medium to study constructive data physicalization processes, due to their ability to leverage multiple sensory channels. In this contribution, we report on a preliminary study to gain insights into how people make use of various sensory modalities in the construction of data physicalizations. With the candy workshop, we propose to use candies

as a medium to study constructive data physicalization processes encompassing multi-sensorial modalities.

1.1 Constructive Data Physicalization

In a context of democratization of visualization, Huron et al. [5, 7] introduced the notion of constructive visualizations to provide "means for non-experts to create visualizations that allow them to engage directly with datasets" [5]. The idea is defined [5] as "the act of constructing a visualization by assembling blocks that have previously been assigned a data unit through a mapping." (p. 436). In other words, looking at how people can craft visualizations by using familiar physical elements (aka tokens, basic units to which information or data has been mapped). The basic process of constructive physicalization consists of 4 steps: (1) the environment initialization, meaning choosing the space where tokens are assembled (e.g. a paper canvas), (2) the mapping of the data to tokens and data properties to token properties, (3) the assembling of the tokens, (4) the evolution over time, by updating the physicalization as needed. A key application area for constructive data physicalization is the exploration, manipulation and reflection on personal data [5, 17]. As activity trackers and sensors collect an ever-growing amount of information about people's daily lives, making sense of this data is a challenge that constructive physicalization can contribute to address through the act of active creation. Documented benefits of constructive physicalization are manifold. It allows novices to author visualizations [5], supports thoughtful exploration of data, increasing meaning-making and reflection [14, 17], the planning of future activities [17], and even showed pedagogical potential [3].

Studying constructive data physicalization involves the creation of a construction toolkit, an assemblage of elements to be used as tokens to map data attributes to physical properties. Of course, the toolkit content and underlying constraints or opportunities impacts the process. Initial toolkits were composed of building blocks or colorful wooden tiles [7, 19], before including a diverse set of tokens and craft material. Thudt et al.'s [17] toolkit contains beads, plasticine, pins, tape, thread (all in different colors and sizes) as well as labels, tape and foamboard. Similarly, Huron et al. [6] recommend in their workshop kit a variety of craft materials covering a range of material properties (e.g., bendable, pourable, malleable). They also emphasized the need of material that participants can easily engage with, without instructions nor practice.

1.2 Data Edibilization

In 2016, Wang et al. [18] introduced data edibilization (i.e. encoding and communicating data using attributes of edible materials) as a "novel approach to leverage multiple sensory channels to convey data stories". They identified several advantages of data edibilization: the multi-sensory experiences triggered by food can be used to encode data, are attention catching and make the data fun to explore and more memorable for the target audience. Food is also ideal to foster social interactions around data. The main challenges related to data edibilization is the difficulty to interpret the data as the implicit and intangible (e.g., cultural) attributes of food introduce complexity and ambiguity.

Of all human senses, smell and taste are less researched in the field. Remarkable examples using food to physicalize data include TastyBeats [10] and EdiPulse [9] where physical activity data is translated into energy drinks or 3D printed "activity treats" respectively. The more the user exercises, the more gratifying and beautiful the EdiPulse chocolates are. Similarly, Ryokai et al. [15] created tangible representations of laughter, including the poetic physicalization of laughter data of family members over multiple weeks using edible materials. While researching alternative sensory or multi-sensory physicalizations is high on the research agenda [2, 4, 8], a challenge already identified by Vande Moere in 2008 [13] is "how to map information values into non-visual sensations that somehow can be intuitively understood".

In this paper, we conducted a preliminary study in the form of a Data Physicalization Candy Workshop to gain insights into sensorial constructive data physicalization. Our approach is complementary to previous data edibilization studies [9, 10, 15, 18] where the data was typically physicalized by the designers and provided to target users to interpret and react on, or as a form of feedback. The singularity here is that the physicalization of the data is done by the participants themselves in a constructive process. Designing physicalizations using other sensory modalities than sight and touch was mentioned as an underexplored area deserving further research in 2016 [4] which still appears relevant today [2]. Our contributions are threefold. (a) Thanks to the nature of the candy material, we gather (preliminary) insights into how people make use of various sensorial modalities in the construction of data physicalizations (b) We shed light on the process of generating data edibilizations (c) We inspire new research using candies (or food) as an accessible and pragmatic research material to study multi-sensory constructive physicalization, including in-situ as part of a construction toolkit.

2 METHOD

In this study, we used candies as a research material to explore constructive multi-sensorial data physicalization. During a workshop, participants created physical representations of productivity data using a variety of candies (Figure 1). The candies thus acted as tokens, as per the definition of Huron et al. [5, 7] "basic units to which information or data has been mapped during the construction of the physicalization" (p. 2103). We investigate if people can construct a multi-sensorial physicalization using candies as tokens, how they do so, and what type of sensory modality they use to convey information.

2.1 Participants

The study involved 5 participants (1 men, 4 women), between 22 and 24 years old. Participants were all industrial designers or student designers, recruited via the authors' professional network. They all had normal color vision (important as it could influence the sight modality) and were purposively not visualization experts nor had any experience with data physicalization. The study was approved by the Ethical Review Board of the University, and informed consent was collected amongst participants.

2.2 Procedure

The session took place in a controlled environment and lasted about an hour. After filling out a consent form and demographic questionnaire, we informed the participants that we were experimenting

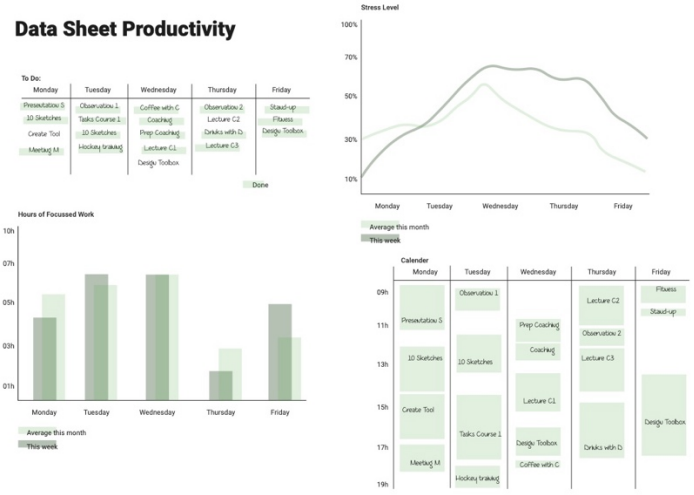


Figure 2: Fictional dataset provided to the participants of the workshop, composed of four visual representations of productivity data

with a new way to physically represent data. The participants were introduced to the fictional productivity dataset and they were asked to pick at least one data source to physicalize. They were given the task to represent this data using the material provided, namely any type of candy, or craft material provided (e.g., paper plates and wooden sticks). After 10 minutes, the participants wrote a description of their physicalization and how the data was mapped to the candies. A brief verbal explanation followed, after which the participants were asked to adjust the representation or create a new one, yet this time with an emphasis on multi-sensorial data representation. Again after 10 minutes, the participants wrote a description of their physicalization, followed by a brief verbal explanation. We transcribed the written descriptions of the physicalizations of each participant.

2.3 Material

2.3.1 Printed Dataset. The fictional dataset is an A4 sheet entitled "Data Sheet Productivity" (Figure 2), composed of 4 visual representations of productivity data: (a) a calendar to-do list visualizing the number of tasks done per day, (b) a corresponding timetable with the activities scheduled for each day of the week and their respective duration, (c) a bar chart representing the hours of focused work per day of the week, comparing the current week average to the month average, (d) a line graph representing the stress level per day of the week, comparing the current week average to the month average.

2.3.2 Candies. Twelve types of candies were chosen based on their qualities in relation to sensory modalities. Candies chosen in our toolkit come in different colors, shapes, and sizes in order to cover a heterogeneous and rich set of perceptions. There are different flavors, e.g., salty licorice, fresh peppermint, sour mats, or sweet marshmallow. Touch can be triggered in different ways by textured, rough, soft or hard sweets. Most candies also embody a strong and appealing smell component: think of licorice or marshmallow. Different sounds can be created, through touch (e.g., breaking pieces of edible paper), by shaking (e.g., a box of Skittles) or by biting (e.g., crunchiness of M&Ms).

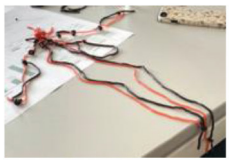
2.3.3 Craft Material and Working Area. To facilitate the assembly of candies, the following craft material was provided: A4 blank sheets, pens, paper plates, wooden cocktail sticks, rubber bands, tape, and scissors. The working area was left to the appreciation of the participants, in order not to constrain their use of space as a meaningful variable.

3 RESULTS

All participants were able to author a data physicalization within the given timeframe. Ten data physicalizations were produced in total during the workshop (two by each individual participant): five during the first round without precise instructions about how to map the data to the candies, followed by five during the second round (mostly incremental constructions based on the first round) where participants were explicitly asked to put an emphasis on alternative sensorial modalities beyond sight. To analyze the produced physicalizations, we looked at the type of candies used, how these were mapped to the data and which sensory modalities were triggered. Table 1 presents the outcomes of the data physicalization tasks for each individual participant.

Participants used from 1 to 4 types of candies per physicalization (2 on average during round 1; 3.6 during round 2) out of a total of 12 candies type provided. Not all candies type were used (e.g., edible paper or salty licorice) and some were more popular than others (e.g., marshmallows used by all participants). Depending on their properties, some candies have the ability to be easily transformed (e.g., cut, compressed). Except for the laces being adjusted in lengths (e.g., by P2), candies were not altered by the participants in the process of mapping data to physical properties of the candies. In

Table 1: Outcomes of the data physicalization task for each participant

	Produced physicalization (round: top: 1 /bottom: 2)	Type of candies	Data mapping	Sensory modality
P1		Marshmallows Strawberry laces Licorice laces	The marshmallows represent the hours of focused work for each day of the week. The square marshmallows directly represent the data of this week, the twisted ones represent 'the average of the month. Days with a higher value are placed upfront and also indicated by a black or red lace.	Sight
		Marshmallows Strawberry laces Licorice laces	The marshmallows represent the hours of focused work (same as round 1). The red and black laces now represent the level of stress (low stress level in red, high in black). The red laces are thinner as compared to the black ones. A thin lace represents a low stress level and vice versa.	Sight Touch
P2		Haribo duo fruity Sour mats	The length of the sour mat represents the hours of focused work for each day of the week. At the start of a day, the length is proportional to the monthly average. The sour mat unrolls during the day based on the focused hours. If the candy inside the mat is visible, that day was more productive than the monthly average.	Sight
		Skittles Marshmallows Sour mats	The Skittles represent the hours of focused work. A low value is represented by a 'deep' positioned Skittle, which cannot be felt. A high value is represented by a Skittle that can be felt. If the hours of focused work of the day is higher than the monthly average, the Skittle becomes visible and touchable.	Sight Touch
P3		Strawberry laces Licorice laces	The hours of focused work for each day of the week are mapped to the length of the red laces. The length of the black laces represents the amount of tasks that need to be done on a day, as retrieved from the calendar graph.	Sight
		Strawberry laces Licorice laces Marshmallows Sour mats	The red and black laces represent the same data as in round 1. The balance between hours of focused work and the amount of tasks is mapped to the roughness of the laces. An unbalanced day feels rough and the laces are sloppily tied together. A balanced day is neatly tied and feels softer.	Sight Touch
P4		Haribo duo fruity (wooden sticks)	The level of stress is compared to the data from the calendar graph. The height of the wooden sticks represents the level of stress. The relative amount of study-related work, retrieved from the calendar, is mapped to the size of the red candies. The relative amount of spare-time activities are mapped to the size of the yellow candies.	Sight
		Haribo duo fruity Marshmallows Sour mats Strawberry laces	The amount of activities (retrieved from the calendar graph) is mapped to the height of the candies. The level of stress is mapped to the texture of the candies. A soft and flat candy represents a low stress level, a rough and hard candy represents a high level of stress. The red laces are decorative.	Sight Touch
P5		Marshmallows Sour mats	The five stacks of marshmallows represent the day of the week. The number of marshmallows used in every stack represents the amount of tasks that are done during a day. The sour mat represent the average hours of focused work (as in a line diagram).	Sight
		Marshmallows Sour mats Napoleons Skittles	The marshmallows and sour mat represent the same data as in round 1. Every day of the week is represented by a Napoleon candy, with a specific taste. The Skittles represent the average value of tasks, as compared to the average value of hours of focused work.	Sight Taste

one case, the craft material (wooden stick) was included as part of the mapping (P4/1st round). In all cases, the days of the week were used as a baseline point with 5 distinct structures (e.g. piles or stack) being created around them.

A key observation during the first round of physicalization is that participants mostly relied on four properties to map data to the candies: the amount of candies used, their type, their shape and their color. Differences in quantity in the data were often represented by the amount of candies used (e.g., the piles of marshmallows in P5/1st round). Candies from the same family with differences in shape or color were used to represent the same data but on a different time scale (in P1/1st round - square marshmallows are used to represent the hours of focused work during the current week while twisted marshmallow represent the average of focused work during the month). Colors were used to bring a visual contrast between two related type of data. P3 used pink candies to show the hours of focused work, and black to for the hours of work that needs to be done: "This shows visually that there was less productive time than work" (P3). Similarly, P4 indicated the relative amount of work-related tasks in orange, and the relative amount of spare time in yellow. Not surprisingly, it was frequent for participants to physicalize data by somehow reproducing a classical visual chart or diagram with candies. While most participants created a static physicalization of the data provided, P2 interestingly included some dynamism in the data physicalization by planning that the sour mat would unroll progressively to represent the amount of focused work across the week. The same participant used the idea of visible/invisible element (the element is always present but made visible or not depending on the data) as an additional representation mechanism.

During the second round, participants were free to adjust their construction or create a new one. Except for P2 who abandoned one type of candy (Duo fruity) between round 1 and 2, all participants kept the candies of round 1 and added others to trigger another sense. Three participants out of 5 incrementally adjusted their structure, two created a new one.

Regarding sensory modalities, the dominant sense triggered in every physicalization created by our participants was sight. Making contrasts in shape, colors, or size visible was the intuitive way to map data to candies properties. Noteworthy, in one case, values were also mapped to physical properties using location in space, which can be perceived by sight. Hence, P1 placed marshmallows either in the back or the front of the plate depending on the value assigned to them. None of the five participants used another sense than sight during the first round of physicalization. Despite the diverse and rich nature of candy properties, smell, touch, sound and even taste were ignored, until the experimenter explicitly instructed the participants to take these into account. During round 2, four participants (P1-P4) implemented touch in addition to sight and one person (P5) used taste. The sense of touch has been triggered for instance by using rough (sour mat) vs. soft (marshmallow) textures to indicate the stress level of the day (P4/2nd round), or a soft (marshmallow) vs. hard (skittle) candy to represent the level of focused work (P2/2nd round). In this second output, P2 used the same visible/invisible mechanism as during round 1, yet this time making it touchable vs. untouchable. To describe their second physicalization, P3 mentions that "only when touching the data one can feel if it was a day with struggle or not". The sense of taste was only triggered by P5, who did rely on the same family of candies (Napoleon) yet mapping data to different tastes.

4 DISCUSSION

Using food as a material to physicalize data is an underexplored yet not novel idea, as it follows the data edibilization concept by Wang et al. [18]. We note the anecdotal use of popsicles and marshmallows in the workshop material suggested in [6]. Yet to the best of our knowledge, it is a first published contribution exploring the use of candies for data physicalization purposes, thanks to their sensorial and pragmatic properties (cheap and accessible material, with endless creative potential).

In our workshop, we observed that, similar to the second style of data edibilization described by Wang et al. [18], our participants initially simply reconstructed common data visualizations charts using candies. This is not uncommon in other constructive physicalization papers, especially when single tokens are used as a medium [7, 19]. As participants had no previous knowledge nor formal introduction to the data physicalization, this first round may have acted as an onboarding. The second part already showcased more creative outcomes with for instance the use of metaphors and some processing of the raw data into more meaningful interpretations (for P3 an "unbalanced" day felt rough with laces sloppily tied together vs. the soft and neatly tied feeling of a balance day). We can also wonder what impact did the time given for the task have on the creativity of the outcomes as it might have been short considering the 3 required sub-tasks. Participants had 10 minutes only to go through the following stages as defined by [6]: ideation of possible ways to represent the data, material selection of candies to encode the data, and building the physicalization by mapping the data to the material. Thanks to the data preparation stage being defined by the experimental protocol and the candies being pre-selected as working material, every participant was able to create a physicalization of data within this timeframe yet the depth of ideation might have suffered. In a one-day workshop format (with trained designers, including an introduction to data physicalization), Huron et al. [6] showcased physicalizations including more engaging qualitative properties. To keep an easy focus on the mapping of data to the candy material, we did not provide a usage scenario. Participants therefore understood the task as rather practical and self-centered. Building a physicalization to communicate an idea to others (or to "convince" or stimulate" [6]), might have triggered the use of other modalities or more consideration of the experience behind the physicalization.

Regarding our purpose of using candies to support rich sensorial modalities in the physicalization process, we noted that sight was still the dominant sense triggered in every data physicalization by our participants. This is aligned with previous research, especially emphasized in reviews of data physicalizations [2, 4]. Out of 154 examples analyzed in Hogan and Hornecker's review [4], sight (n=151) and touch (n=144) were the predominant sensory modalities, far beyond any other sense (n=22 for hearing, and only n=5 for taste and smell). Even data edibilization artefacts produced in former studies relied a lot on the visible component, mainly the

amount and shape of the food [9, 15]. More than 50% of participants in the study of [18] chose "appearance as their first choice of properties to encode data if asked to design an edibilization" (p. 413). In that regard, candies in our study did provide an effective (and cheap to access) variety of colors, shapes, volumes, visual textures, which are easy to arrange and reconfigure. In the second round, candies supported triggering additional human senses, and served as carriers of additional messages from the data. Touch (mainly via texture) became the second dominant modality. While previous reviews of physicalizations have indeed shown touch as the second dominant sensory modality used [4], this came somewhat as a surprise in our case: if candies are known for their appealing and playful colors and shapes, their primary function as edible material comes through taste. Following Wang et al. [18], we might have expected more use of a data-ingredient fit in this context, similar to P5 who, in round 2, used the most acidic candy to represent the toughest day. Potential biases leading to touch being chosen before taste might include: the context of the Covid-19 pandemic and underlying hygiene measures, the idea that candies were used in a serious activity or an example given by the experimenter before round 2. All in all, we nevertheless saw that participants in round 2 started to use the rich sensory experience of candies to tell a more interesting story with data, rather than relying only on numbers. Candies fulfil [5]'s requirements of constructive visualization of being simple, expressive and supporting dynamics. Compared to physical building blocks, tokens or craft material often used in past studies [6, 7, 17, 19], they support the use of alternative sensory modalities. Candy as a material is easy and intuitive to engage with without instructions nor practice.

4.1 Limitations and Future Work

This first study using candies to investigate multi-sensorial constructive data physicalization processes encompasses several limitations. Besides the limited sample size (N=5), the profile of student designers recruited might have influenced the workshop outcomes. While we could see a pedagogical potential of the candy workshop to introduce data physicalization to student designers, follow-up studies should involve target audiences from the general population in order to explore how data physicalization can be produced by people in their idiosyncratic routines. While the use of a fictional and static dataset was convenient for standardization purposes to compare the outputs of several participants, it does not stimulate engagement and reflection. By using non-personal data, participants did not benefit from the documented impact of constructive physicalization on personal reflection that arise from active engagement with personal data [17]. In their study, Thudt et al. [17] hence observed that "by constructing visual mappings in line with their individual mental models of the data, participants engaged in an activity that can be related to an "expressive mode of learning". Similarly, experimenting in a controlled setting has the benefit of being able to observe the construction process and debriefing directly with the participants. Yet of course, an exploration of a longitudinal construction process, using real data in-situ during a diary study [11] as done by [17] uncovers different aspects of the experience [12].

In future work, we first intend to define more precise measures to study the constructive physicalization process besides the mere description of the outcome by the participants. Self-reported measures on perceived task difficulty, satisfaction, perceived accuracy of the physicalization to represent the data, perceived easiness to interpret the physicalization (for a person who was not involved in creating it) and actual interpretation are envisioned, based on previous literature [7]. On a practical side, our new lab protocol includes video recording the process in order to understand and map the different stages of constructive physicalization. In addition to the actions performed, we intend to collect users' thoughts and rationale behind their choices by pairing our participants as duos. Just like in paired user tests [16], we expect verbalization to occur spontaneously between the participants without the burden of requesting think out loud, often considered unnatural [1]. It will however create a specific dynamic of negotiation about how to map the data to physical properties. This differs from the context of quantified-self context which seems as a promising application area for constructive physicalization, and closer to a context of co-construction of physicalizations, which is currently underexplored. In-situ longitudinal studies would follow with a focus on engagement and personal reflection over the data.

4.2 Recommendations for the Use of Candies as a Material for Data Physicalization

More explorations of the use of candies as a material and replications of our workshop format are needed to derive a set of guidelines. At this stage, we can provide some initial insights. Regarding the choice of candies, we recommend to aim for a variety of candies, based on their qualities in relation to sensory modalities. A good candy toolkit includes different colors, shapes, and sizes in order to cover a heterogeneous and rich set of perceptions. Different flavors (e.g., sweet, salty, minty), textures (e.g., rough, soft, sticky, or hard sweets) and smells are essential. One can also consider the potential sounds that can be created through touch (e.g., breaking pieces of edible paper), by shaking (e.g., a box of Skittles) or by biting (e.g., crunchiness of M&Ms). Some candies have distinct features that might make them interesting as a material, either because they can be assembled or piled up easily (e.g., marshmallows), can be used to attach or bind things together (e.g., rainbow laces), are composed of many small elements that will allow to express granularity in the data (e.g., Skittles), are associated with specific memories or emotions (typically differs per culture and generations), or have a unique texture that one can easily shape (e.g., cotton candy). Additionally, we noticed that providing extra material that can help as a construction material (e.g., wooden sticks) or as a working surface (e.g., paper plates) can support the process.

In our exploratory workshop, we purposively did not instruct participants to explore the full range of sensory modalities in the first round of physicalization (because we were interested to see if and how they would do it). With a different research objective, it can be efficient and beneficial to immediately prompt participants to make use of the full potential of candies as a material. It is good to remember however that constructing a data physicalization is not a natural and easy process for non-trained individuals, and that

a first round of warm-up helps them to gain confidence and express themselves more creatively in the second round.

Finally, for researchers who would like to use the candy workshop format in their exploration of data physicalization processes, it is wise to consider whether the use of a fictional dataset can fulfil the research objectives: it is an option if one wants to compare several processes in a standardized way without exploring the personal meaning of the data for the participants. When the latter matters, one can invite participants to self-track personal data before the workshop so that they can physicalize and make sense of their own data [17].

5 CONCLUSION

In conclusion, we proposed to use candies as a medium to study constructive data physicalization processes encompassing multisensorial modalities. During a candy workshop, we gained initial insights on how people construct physicalizations using candies as tokens, and what type of sensory modality they use to convey information. Research about constructive data physicalization is still at its beginning and further studies are needed to consolidate existing knowledge. Our approach contributes new knowledge beneficial both to the constructive data physicalization and the data edibilization areas.

REFERENCES

[1] Obead Alhadreti and Pam Mayhew. 2017. To Intervene or Not to Intervene:An Investigation of Three Think-Aloud Protocols in Usability Testing. *Journal of Usability Studies* 12, 3: 111–132.

[2] Hessam Djavaherpour, Faramarz Samavati, Ali Mahdavi-Amiri, *et al.* 2021. Data to Physicalization: A Survey of the Physical Rendering Process. *Computer Graphics Forum* 40, 3: 569–598. DOI:10.1111/cgf.14330

[3] Trevor Hogan, Uta Hinrichs, Yvonne Jansen, *et al.* 2017. Pedagogy & Physicalization: Designing Learning Activities around Physical Data Representations. *DIS 2017 - Proceedings of the 2017 ACM Conference on Designing Interactive Systems*, Association for Computing Machinery New York, NY, USA, 345–347. DOI:10.1145/3064857.3064859.

[4] Trevor Hogan and Eva Hornecker. 2017. Towards a design space for multisensory data representation. *Interacting with Computers* 29, 2: 147–167. DOI:10.1093/iwc/iww015

[5] Samuel Huron, Sheelagh Carpendale, Alice Thudt, Anthony Tang, and Michael Mauerer. 2014. Constructive visualization. *DIS 2014 - Proceedings of the 2014 ACM Conference on Designing Interactive Systems*, Association for Computing Machinery New York, NY, USA, 433–442. DOI:10.1145/2598510.2598566.

[6] Samuel Huron, Pauline Gourlet, Uta Hinrichs, Trevor Hogan, and Yvonne Jansen. 2017. Let's get physical: Promoting data physicalization in workshop formats. *DIS 2017 - Proceedings of the 2017 ACM Conference on Designing Interactive Systems*, Association for Computing Machinery New York, NY, USA, 1409–1422. DOI:10.1145/3064663.3064798.

[7] Samuel Huron, Yvonne Jansen, and Sheelagh Carpendale. 2014. Constructing Visual Representations: Investigating the Use of Tangible Tokens. *IEEE Transactions on Visualization and Computer Graphics* 20, 12: 2102–2111. DOI:10.1109/TVCG.2014.2346292

[8] Yvonne Jansen, Pierre Dragicevic, Petra Isenberg, *et al.* 2015. Opportunities and challenges for data physicalization. *Proceedings of the 2015 CHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery New York, NY, USA, 3227–3236. DOI:10.1145/2702123.2702180.

[9] Rohit Ashok Khot, Deepti Aggarwal, Ryan Pennings, Larissa Hjorth, and Florian Mueller. 2017. EdiPulse: Investigating a playful approach to self-monitoring through 3D printed chocolate treats. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery New York, NY, USA, 6593–6607. DOI:10.1145/3025453.3025980.

[10] Rohit Ashok Khot, Jeewon Lee, Deepti Aggarwal, Larissa Hjorth, and Florian Floyd Mueller. 2015. Tasty beats: Designing palatable representations of physical activity. *Proceedings of the 2015 CHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery New York, NY, USA, 2933–2942. DOI:10.1145/2702123.2702197.

[11] Carine Lallemand. 2012. Dear Diary: Using Diaries to Study UX. *User Experience* 11, 3: 18–20.

[12] Carine Lallemand and Vincent Koenig. 2017. Lab Testing Beyond Usability: Challenges and Recommendations for Assessing User Experiences. *Journal of Usability Studies* 12, 3: 133–154.

[13] Andrew Vande Moere. 2008. Beyond the tyranny of the pixel: Exploring the physicality of information visualization. *Proceedings of the International Conference on Information Visualisation*, IEEE469–474DOI:10.1109/IV.2008.84.

[14] Bettina Nissen and John Bowers. 2015. Data-Things: Digital Fabrication Situated within Participatory Data Translation Activities. *Proceedings of the 2015 CHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery New York, NY, USA, 2467–2476. DOI:10.1145/2702123.2702245.

[15] Kimiko Ryokai, Noura Howell, Elena Duran, Ji Won Jun, and Dina Bseiso. 2017. Celebrating laughter: Capturing and sharing tangible representations of laughter. *DIS 2017 Companion - Proceedings of the 2017 ACM Conference on Designing Interactive Systems*, Association for Computing Machinery New York, NY, USA, 202–206. DOI:10.1145/3064857.3079146.

[16] Tara Shrimpton-Smith, Bieke Zaman, and David Geerts. 2008. Coupling the users: The benefits of paired user testing for iDTV. *International Journal of Human-Computer Interaction* 24, 2: 197–213. DOI:10.1080/10447310701821558

[17] Alice Thudt, Uta Hinrichs, Samuel Huron, and Sheelagh Carpendale. 2018. Self-reflection and personal physicalization construction. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery New York, NY, USA, 1–13. DOI:10.1145/3173574.3173728.

[18] [Yun Wang, Xiaojuan Ma, Qiong Luo, and Huamin Qu. 2016. Data edibilization: Representing data with food. *Extended Abstracts of the 2016 CHI Conference on Human Factors in Computing Systems (CHI EA '16)*, Association for Computing Machinery New York, NY, USA, 409–422. DOI:10.1145/2851581.2892570.

[19] Tiffany Wun, Jennifer Payne, Samuel Huron, and Sheelagh Carpendale. 2016. Comparing Bar Chart Authoring with Microsoft Excel and Tangible Tiles. *Computer Graphics Forum* 35, 3: 111–120. DOI:10.1111/cgf.12887