Touching Information with DIY Paper Charts & AR Markers

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ABSTRACT

Fostering data literacy has largely been the domain of formal educational systems and export-oriented tools. Informal educational approaches, such as games or family activities, may overcome barriers to engaging with data by fostering data literacy through casual engagement. This work in progress explores how informal learning through creation and play with interactive data representations (physicalizations) can foster increased literacy and engagement with data. We outline a series of DIY paper charts using AR markers and everyday materials to help children interact and explore data through the creative process of making.

CCS CONCEPTS

• **Applied computing** → *Education.*

KEYWORDS

data physicalization, DIY, data literacy

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1 INTRODUCTION

Data literacy is a crucial life skill [18, 46]. Data is increasingly being interwoven into society, serving as an important element of civic engagement [2, 7] and information dissemination (e.g., economics [26], politics [12, 52], environmental sciences [39]). The COVID-19 pandemic has highlighted the importance of data literacy as experts and news outlets frequently use data visualizations to increase public awareness, to communicate public health decision making, and to drive action within different communities [41]. The public is now exposed to a deluge of new information about the pandemic in addition to the existing range of topics (e.g., crime statistics, political decisions, weather). However, many people struggle with data sensemaking due to their limited data literacy (i.e., the ability to constructively reason with data) [8, 34, 44]. The proposed work explores how informal learning through creation and play with interactive physical data representations (physicalizations) may foster increased action, literacy, and engagement with data for young children (ages 5–7).

Fostering data literacy has largely been in the domain of formal educational systems and expert-oriented tools. Informal educational approaches, such as games or family activities, may overcome barriers to engaging with data by fostering data literacy through casual engagement. We aim to engage children in making sense of data through physicalizations [25]. Specifically, this work in progress explains a series of activities that we have designed where children will design and craft interactive physicalizations using everyday materials.

While previous research has explored ways to teach children data visualizations through online platforms [3, 5, 6], we explore how interactive data physicalizations using accessible materials can foster data literacy. Data physicalization focuses on using physical objects to represent, visualization, and communicate data. This offers a simple and accessible way for others to understand and interpret data. This work in progress outlines the series of activities we have explored predominantly using paper and ARUCO markers [17, 38]. We constrain ourselves to using everyday materials as it enables us to focus on the engagement by keeping the data rooted in the child's local community. These activities are informed by our discussions with parents to better understand young children's interests and tying these interests to data-oriented activities.

2 RELATED WORK

Borner et al., [8] states the importance of data literacy, where data visualization literacy is defined as the ability "to comprehend and interpret graphs" as well as being able to create them [28]. Teaching data literacy, however, is challenging as it requires a multitude of skills including statistics, spatial reasoning, abstract thinking, and visual literacy. From analyzing educational materials [3, 29, 42], researchers find that data literacy can be improved in K-12 education in the United States as children struggle with interpreting visualizations. This finding supports investigations showing the

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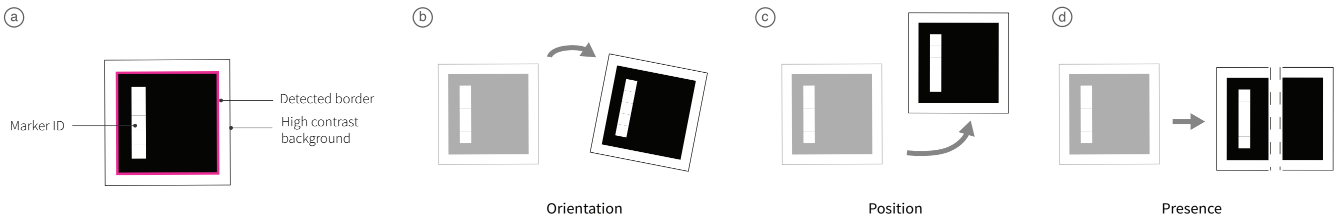

Figure 1: (a) Characteristics of ArUco markers [17, 38]. Demonstrating how markers can change according to its (b) orientation; (c) position; (d) presence.

general public often misunderstand visualizations due to their poor data literacy [8, 11].

Fostering data literacy has mainly been targeted towards adults with analytical systems focused on specific disciplines [15, 20, 21] and expert-oriented tools [9, 33, 40, 43]. Preliminary efforts focused on young children often consist of GUI-based technology-mediated practices to help children interpret and build visualizations [3, 5, 16, 24]. These tools typically adapt approaches designed for adults to children by reducing the volume and complexity of data and adding playful visual elements like icons. While these works teach children data visualizations in a playful manner, they are all digital, limiting children's ability to physically engage with data.

Recent work in data physicalization—using physical materials to represent data—offers techniques for bringing data out from the desktop and into the real world. Researchers have explored the means of developing visualization for adults through tangible interactions [22, 23] as a corollary of this effort. However, we lack similar resources for children, who require their own design methodologies [13, 14]. As such, the absence of physical data literacy tools creates an opportunity to see how physicalizations can actively help children.

Research has shown that children benefit from embodiment while making and working with physical objects [25]. This aligns well with Piaget's Theory of Development where he contends children in the Preoperational Stage (ages 2–7) are able to formulate representational thought through symbolic thinking (i.e., words and pictures) [19]. For instance, a theme of educational materials for children in this age range focus on helping children representing abstract notations of mathematics concretely (e.g., physical blocks [1]). This works in tandem with data visualization as physical objects can represent data. In addition, Piaget's model also support the notion that direct manipulation of an object supports the effective learning of young children: tangible interactions can increase playful learning, engagement, reflection, and manipulation of symbolic information. As such, physicalization is highly suited to the design and development of children's learning as it not only leverages physical artifacts, but also promotes critical thinking and hands-on learning [37]. Thus, we focus our efforts to create physical data literacy tools for children aged 5–7 as they are able to (i) concretely think about the world around them and (ii) see how data relates to the world they live in.

Another thread that differentiates our work, is our focus on using familiar, low-cost materials, such as paper. Paper is an accessible material with rich crafting affordances. Researchers have investigated how paper can create interactive books [10, 35], sensors [31, 48, 51], and even TUI's [27, 36]. We focus on constructing our interfaces out of paper for two reasons. First it enables us to broaden the participation of children from all socio-economic backgrounds. Cost-effective and scalable manufacturing is an integral part of "frugal science and engineering" [45]. Second, paper prevents children from becoming distracted by foreign materials and interfaces. Researchers [32, 50] demonstrate the various types of TUI's using printed ArUco markers [17, 38] and computer vision with no electronics. This minimalistic, scalable design helps children to focus on the set of tasks and partake in the making process. Our activities follow this same design principle by using paper and ArUco markers.

3 DESIGN

In this section, we provide an overview of our design process, methods, and explorations. All activities were designed to be part of a toolkit that can be sent to children (ages 5-7) and assembled at home. These activities first focus on how we can enable children to understand what data is, how data can be represented visually, and how to reason about data through data sensemaking and the creative process of making.

Learning Goals

Our activities focus on core learning goals from the Visualization Literacy Test [28] and related literacy assessments [30, 49]. Specifically, we focus on guiding children through elementary data tasks for extracting values from visualizations, with a specific emphasis on estimating individual values and comparing multiple values, and for basic sensemaking (i.e., turning data into knowledge). These activities are designed to help children:

- **G1: Read common visualizations** (bar charts, line graphs) to draw basic conclusions, such as making group comparisons and determining the range of the values in a chart.
- **G2: Update a visualization** to understand the relationship between data and shape as defined by the marks used to represent data.
- **G3: Use different techniques** for mapping data to visual elements to understand how data can be represented in different ways and how these differences can lead to different conclusions about data.
- **G4: Draw meaningful connections from everyday examples**. For instance, for many children the word "bar" will represent food, such as chocolate bar, and will understand

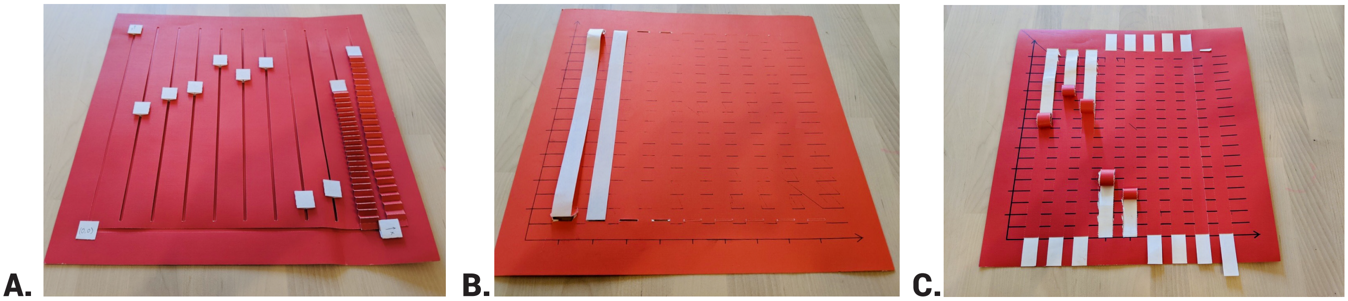

Figure 2: Series of DIY Bar Charts. (a) Sliding chart where markers are positioned according to the y-axis; (b) Pulling chart using paper strips; (c) Tearing chart where users tear off strips of paper according to the y-axis.

that a bar usually means a long rectangular shape. Thus, using colored, rectangular paper behind real objects can help children visualize "bar" when discussing bar charts.

Constraints

Existing approaches to engage children with visualizations either provide no embodied interaction [4] or are costly to produce [6]. To address these challenges and create literacy activities tailored to children, we design our activities to use:

- **Materials children can work with**, ensuring that any pieces were sufficiently large to support fine-motor skills for children between 5–7, that the materials were familiar to encourage play and creativity, and that any materials were non-toxic in case of inadvertent consumption.
- **Everyday materials** to keep the activities affordable for families and foster experimentation by making mistakes less costly (e.g., if a child tried something and did not like the results or made a mistake, they could simply start over).
- **Modular components** to help children update their visualizations as they accessed to new data. Modularity also supports our learning objectives by enabling children to move pieces of a design between activities.
- **AR markers** to create interactive free-moving token units. Each marker provides information based on its identity, position, orientation and presence. (Figure 1). These markers are detected when there is a high-contrast between the marker's border and its background, requiring to carefully consider the camera's visibility and positioning of the camera. The movement of these units should reflect the design of the activity (e.g., units on a line chart should mirror the movements of a line chart) and be easy for children to operate.

3.1 Activities

With these learning goals and constraints in mind, we explored a set of designs for the most familiar/fundamental data visualizations (i.e., bar chart, line chart, pie chart): (G3). The design for each chart explores how to best engage children to interact with the data representation and how to help differentiate each representation (e.g., a line chart is more useful to depict trends as opposed to bar charts [47]). Aligned with our constraints of everyday materials, the paper charts are constructed from a mix of 12×12 construction and letter size paper.

Bar Chart: Sliding Chart, Pulling Chart, Tearing Chart

We first explore creating interfaces that empowers children to playfully learn about bar charts. Bar charts help visualize quantities [47], and they are one of most rudimentary visualizations that children will come across. To help draw meaningful connections (G4), we explore three designs of a bar chart (Figure 2a-c) that use rectangular shapes that children can manipulate. Each iteration informed our design decision for the next prototype. Our first exploration is Sliding Chart (Figure 2a): an interface that is designed with a two-layer base with slots where sliding units can be attached. AR Markers are printed on the top side of each sliding unit. To be modular, we designed two types of attachable units (i.e., vertical accordion strips) where it can be used for bar charts in addition to line charts. While testing, we observed that the interface was unstable where sliding units could easily fall out after they deformed from a few rounds of interactions.

Through our next exploration, we designed the Pulling Chart (Figure 2b), a design that has slits at the top and bottom of the paper where paper strips are inserted strips. Each paper strip has a different color to help differentiate different attributes within a dataset (G1). However, we quickly noticed that this design causes the base of the bar chart to tear easily. This naturally led to the Tearing Chart (Figure 2c), a spin-off of the Pulling Chart where children can tear off the base of the paper and roll the strips together. The tearing motion exploits the rich qualities of paper where paper can be directed to tear along a line, but this design is limiting as it is irreversible once the paper is torn.

In all three designs, we focus on manipulating the paper (e.g., ripping and pulling strips of paper, moving a paper square mark) to accomplish data tasks. Manipulating the paper can elicit tactile feedback while helping children update their bar graphs (G2). Once a bar chart has been updated, children can be asked questions regarding the chart to evaluate their comprehension (G1).

Line Charts: Touching Trends

Line charts focus on conveying the trend of a dataset [47]. After exploring the modular design with the Sliding Chart, we developed a base for Touching Trends Figure 3 where two markers are printed at the ends of the y-axis (G3). The different combination of markers determines the range of the y-axis. Like the bar chart interface, we aimed in creating an interactive design where children are able to read and manipulate different aspects of the visualization when

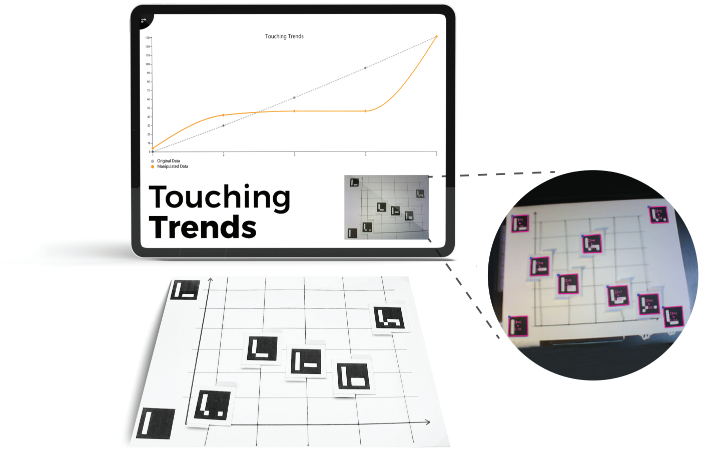

Figure 3: Overview of Touching Trends. Camera detection of the ArUco markers are exemplified in the circle.

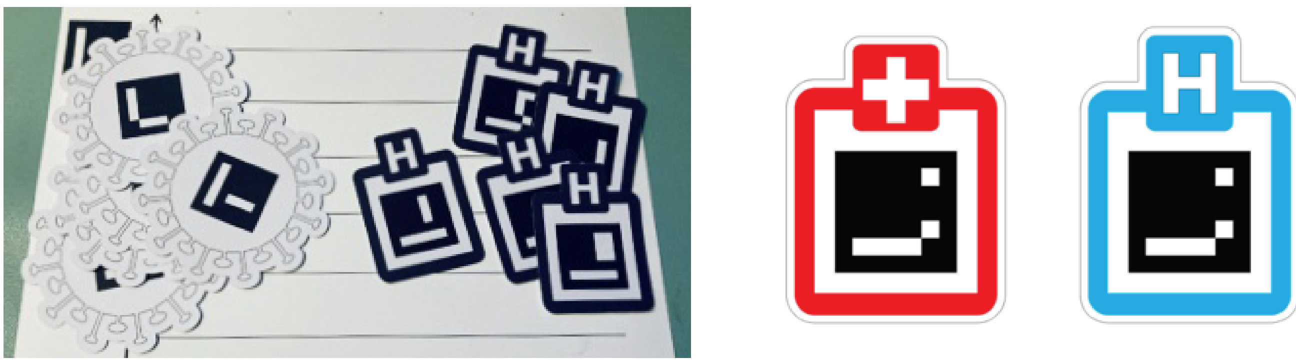

Figure 4: Graphical designs to add expressivity to the ArUco markers.

exploring a dataset, including the position of each point (G1, G2). To achieve this, we taped the AR marker between threads. From previous explorations, we focused on using threads rather than paper slots as this allows us to have a very stable base and limit the number of parts needed. After adjusting the size and shape of the movable units, we also came up with a variety of graphic designs (Figure 4) for the movable units to elicit playfulness and more meaningful connections to the chart (G4).

Pie Charts

Lastly, we also experimented designing interfaces for another familiar visualization: the pie chart. Compared to line and bar charts, pie charts can help children better understand the proportional relationships within a dataset. We used playful designs (e.g., a watermelon paddle in Figure 5) to help children ground the pie chart into a more familiar context (G4). From here, the watermelon design can be used in data-driven activities where children can be asked to use the interface as an input to match the proportional relationship within dataset. Based on the interface, a system can ask questions about the input data, such as "Today, 33% of the food you ate were cookies and 66% were pizzas. Is that correct?". The validation can help learners be critical with their visualization and develop their visualization literacy skills as mentioned in the learning objectives (G1–G3). Using a circular paper structure, the pie chart can be rotated easily and allows markers to hidden. Our current design supports 6 sections, but more sections can be added as needed. The colored sections helps children distinguish between the different sections while not affecting AR marker recognition. However, a limitation of this design is it requires a certain amount spacing and high contrast. This is further elaborated in Section 4.

4 DISCUSSION

We note three discussion points. First, while designing these activities, we observed how the camera setup also plays a role. From discussion, we observe how there are three possible options: (1) using an overhead camera, (2) using the laptop's built-in camera, and (3) using a docking station to point the camera upwards. The current designs listed in this work assume the camera will be pointed downwards. But we recognize the need to experiment with different camera positions (e.g., upward) based on room lighting, contrast, and feasibility. To ensure the activities can work in various room conditions, we will explore how the design the design of these activities will need to change so that the AR markers can be printed on both sides and with different cameras, such as a smartphone.

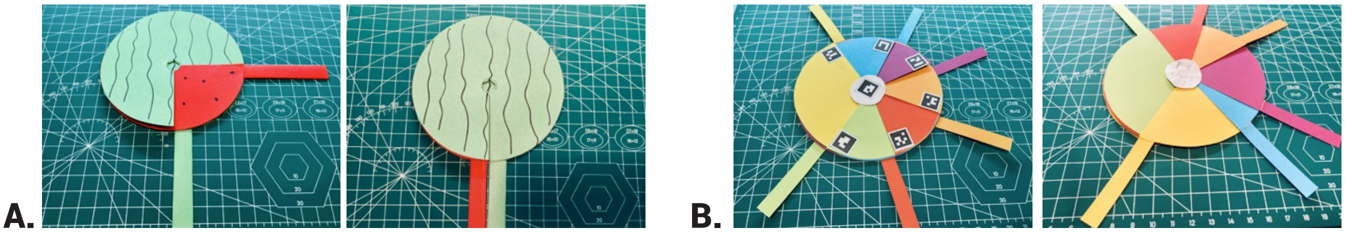

Figure 5: Pie Chart. (a) Playful watermelon design (b) Pie chart with 6 sections.

Variations in the environment and even the camera hardware itself can complicate the marker detection. Lighting in particular poses a huge challenge since the ArUco algorithm identifies the marker squares based on its contrast to the background (Figure 1). For our prototype we chose to use an IR camera as it helps emphasize dark and light areas of the image. Our camera model includes a ring of IR leds as a light source as well which enables us to place the camera in environments without light. Another hardware challenge of certain cameras as well is barrel distortion. This causes minor errors in the positioning of markers towards the edges of the image. These errors can cause issues when detecting markers over a larger space, so we limit the detection area to the center of the camera and allow for lack of precision of the marker positions when programming applications.

Lastly, our activities are not tested with our target audience. As part of future work, we aim to distribute these activities as a kit to local families to get their input and test whether the informal learning and creative process can help improve children's data literacy.

5 CONCLUSION

We present a series of interactive DIY paper physicalizations using everyday materials. We focus on how informal learning through creation and play can actively engage children in working with and making sense of data through physicalization. As part of future work, we will focus on how further integrate future features as well distribute these kits to families for evaluation.

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