Supporting Data Visualization Literacy through Embodied Interactions

Elise Johnson
elise.johnson@colorado.edu
ATLAS Institute
University of Colorado
Boulder, CO, USA

S. Sandra Bae
sandra.bae@colorado.edu
ATLAS Institute
University of Colorado
Boulder, CO, USA

Ellen Yi-Luen Do
ellen.do@colorado.edu
ATLAS Institute
University of Colorado
Boulder, CO, USA

Figure 1: Embodied interactions enable a user to author their own bar graphs through a tangible input device. (a) The Figma board is where the user is able to create their visualizations. (b) Beholder library [11] tracks a fiducial marker on the authoring device and connects it to a keyboard interaction, which corresponds to an action on the Figma board.

ABSTRACT

Data visualization literacy (DVL) is increasingly important in navigating today's world. Young students are now required to develop data visualization skills (e.g., identifying patterns, collecting, organizing, and analyzing data). Past work focuses on cultivating children's DVL through playful and gamified approaches. However, these past solutions require hardware (e.g., smartphones) that is not readily replicable within standard classrooms. In addition, the extent of embodied interactions found in past solutions is fairly limited to large-scale interfaces. To address these challenges, we explore how to cultivate children's DVL through embodied learning that is more apt for a classroom environment. Using a standard Google Chromebook, we designed an interface that utilizes the tracking of a fiducial marker on a wooden arrow to allow a student to author their own bar graphs. We conducted Wizard of Oz tests (n = 3) to gather feedback on the functionality of our design. This project aims to display the benefits of giving students a mode to develop their own visualizations and broaden how they can interact with data.

ACM ISBN 979-8-4007-0180-1/23/06.
https://doi.org/10.1145/3591196.3596607

CCS CONCEPTS

• **Human-centered computing → Visualization theory, concepts and paradigms**.

KEYWORDS

data visualization literacy, embodied interactions

ACM Reference Format:
Elise Johnson, S. Sandra Bae, and Ellen Yi-Luen Do. 2023. Supporting Data Visualization Literacy through Embodied Interactions. In *Creativity and Cognition (C&C '23), June 19–21, 2023, Virtual Event, USA*. ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3591196.3596607

1 INTRODUCTION

Despite the importance of data visualization literacy (DVL), children are limited in how they can interact with visualizations. The predominant method is to interact with visualizations digitally [1, 5, 7, 13]. Though past methods are making strides toward improving DVL, they require multiple sets of hardware (e.g., smartphones [3]) that are not available within standard classrooms. In addition, these

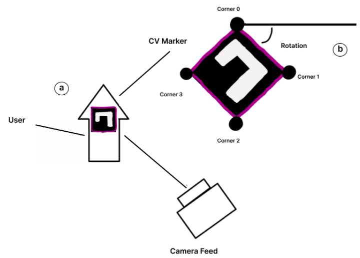

Figure 2: (a) Characteristics of ArUco markers [8, 17]. Demonstrating how a marker can change according to its (b) rotation to enable tangible interactions.

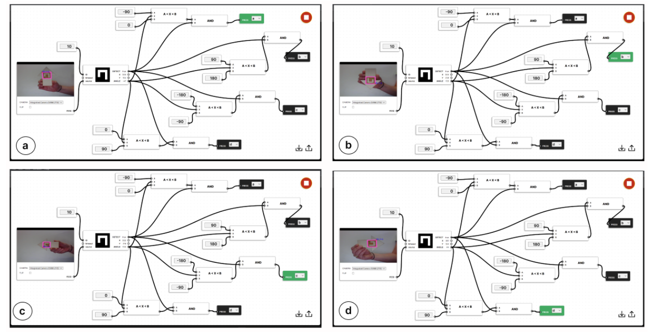

Figure 3: Screenshot of Beholder library. The orientation of the arrow correlates to a keyboard input, (a) up, (b) down, (c) left, and (d) right.

solutions restrict children's creativity in exploring the connections between the various components of visualizations through embodied actions [18]. Embodied learning utilizes the body, through movement and gestures, to further understand complex topics (e.g., mathematics [9, 10], music [14], foreign languages [16]). Past work demonstrates how embodied learning can be transferred to visualization-related topics, such as exploring high-dimensional datasets [6] or authoring visualizations [3, 12]. Allowing young students to utilize their physical interactions and representations can empower them in ways that a 2D screen could not [4, 12]. Thus, we focus on promoting children to use embodied interaction to help them create, organize, and explore their own data. Specifically, we designed and built a computer application that uses the Beholder library [11] to track fiducial markers when authoring visualizations. Children are given an arrow device, which is etched with a fiducial marker, as a tangible input device. Children then use the tangible device to interact with the screen while authoring their visualizations (Figure 1a). Different angles of the arrow correlate to a different action on the screen. The one-to-one mapping can promote embodied learning, specifically enabling children to develop connections between their movements and what they see on their screens. We deployed the toolkit in a series of Wizard of Oz (WoZ) tests with field experts ($n = 3$). Discussion from field experts indicates further iterations to improve the efficiency of the overall system.

2 BACKGROUND

Past works have investigated how to cultivate children's DVL through embodied learning. Bae et al. [3] developed the *Data is Yours* toolkit which employs the constructionist approach. Students build their own toolkits and create common visualizations (e.g., bar, line, and pie) using paper and fiducial markers, which are accompanied by a smartphone. Their findings from workshops indicate that children felt a sense of ownership and empowerment. This positivity encouraged children to feel more comfortable around visualizations, even young children who had never encountered data visualization. Although this constructionist approach gave students confidence while engaging with data, it has limits in its applicability to a classroom. Specifically, Bae et al's approach required each student to have a smartphone, which is not readily reproducible. While our approach is most similar to Bae et al's in that we also focus on visualization authoring, we differ by focusing on technology that is already integrated into classrooms (e.g., Google Chromebook[1])

Similarly, Xin et al. [6] conducted a study where students (i.e., 3rd graders up to undergraduates) were instructed to embody data points for a high-dimensional dataset. Students were tracked with a motion capture camera, organizing themselves as the datasets, and observing changes based on their movements. This study found that embodied learning provided students with a way to quickly interpret and explore high-dimensional datasets. Similarly, our goal is to help students engage with data in a way that is both engaging and beneficial. By incorporating embodied actions, students will be able to have another way of understanding data visualizations. However, we differentiate from Xin et al's work by utilizing embodied learning through the use of a small-scale authoring device. Their approach requires a significant setup (e.g., motion tracking cameras) and physical space. In contrast, our approach allows students to engage in embodied interactions that can be readily fostered in a classroom setting. In this environment, students will be able to personalize their data and develop confidence in their own abilities.

3 METHODOLOGY

The goal of this research is to explore how to cultivate children's DVL through embodied learning in a classroom environment. Specifically, we aim to see how we can combine physical materials with digital feedback to enable dynamic data interactions when authoring a bar chart. Our approach uses Beholder [11], which is a software editor that allows us to map fiducial marker [8, 17] to keyboard interactions. We were inspired by various tangible interactions that printed fiducial markers enable [2, 3, 15, 19]. In our case, we have an arrow that is etched with a fiducial marker, which serves as a tangible input device. The fiducial marker provides information based on its identity, position, and orientation (Figure 2). Students hold the arrow toward the laptop camera at different angles, and Beholder recognizes the fiducial marker's angles to enable different keyboard interactions when authoring a bar chart (Figure 3). The visualizations are produced using Figma. The arrow design was chosen as it is an easily recognizable symbol for young children and accurately represents the actions occurring on the screen. For

[1]We interviewed with an educator at a local elementary school and learned that Boulder's school district uses the Chromebook 11 G9 EE.

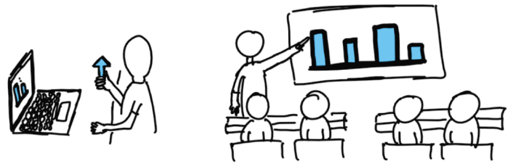

Figure 4: Future vision of integrating it into the school's curriculum.

example, when authoring a bar graph, the arrow pointing upward will grow the bar that is chosen, while when it points down it will shrink. The arrow pointing left or right will move between different bars.

4 RESULTS

Currently, we have conducted preliminary tests using WoZ with the system ($n = 3$). All participants are Ph.D. students specializing in either tangible interactions, learning technology for children, or data visualization. These preliminary tests enabled us to explore how a student would potentially interact with our design. After we conducted the WoZ, we interviewed the participants in order to gather their feedback. The main feedback was that the system needed a playful narrative so young students would feel engaged while using it. Participants noted the importance of providing students with a reason to feel motivated to use our device. Otherwise, students would resort back to using paper and a pencil to draw their graphs. From these WoZ, we gained preliminary insights on how to further improve our device to make it a successful teaching aid for a classroom.

5 CONCLUSION

Data visualization plays an integral part in our society. We all engage with data of some form throughout our daily life, whether it be in classes, games, articles, or the news. It is key that we foster a data-literate society. In order to ensure this, we must increase children's exposure to data in terms of frequency and diversity (e.g., qualitative, geographic, categorical, temporal). The increase in exposure would allow students to become more comfortable around data and develop confidence in their reasoning abilities. By presenting data in an exciting way, we hope that students will look forward to learning and potentially grow their interest in pursuing data-related fields later in their life (Figure 4). A limitation of this project is the lack of evaluation of the actual end-users (i.e., children), which can be resolved with future work. We hope that this product is utilized in the classroom as a tool to enhance learning.

ACKNOWLEDGMENTS

The authors appreciate the guidance, support, and intellectual contribution from the ACME Lab. We also thank CU Boulder's Discovery Learning Apprenticeship (DLA) program, the Engineering Excellence Fund, and Jonathon Warshaw from Foothills Elementary School. This material is based upon work supported by the National Science Foundation under Grant No. IIS-2040489 and IIS-1764089.

REFERENCES

[1] Basak Alper, Nathalie Henry Riche, Fanny Chevalier, Jeremy Boy, and Metin Sezgin. 2017. Visualization Literacy at Elementary School. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 5485–5497. https://doi.org/10.1145/3025453.3025877

[2] Sandra Bae, Ruhan Yang, Peter Gyory, Julia Uhr, Danielle Albers Szafir, and Ellen Yi-Luen Do. 2021. Touching Information with DIY Paper Charts & AR Markers. In *Interaction Design and Children* (Athens, Greece) *(IDC '21)*. Association for Computing Machinery, New York, NY, USA, 433–438. https://doi.org/10.1145/3459990.3465191

[3] S. Sandra Bae, Rishi Vanukuru, Ruhan Yang, Peter Gyory, Ran Zhou, Ellen Yi-Luen Do, and Danielle Albers Szafir. 2023. Cultivating Visualization Literacy for Children Through Curiosity and Play. *IEEE Transactions on Visualization and Computer Graphics* 29, 1 (2023), 257–267. https://doi.org/10.1109/TVCG.2022.3209442

[4] S. Sandra Bae, Clement Zheng, Mary Etta West, Ellen Yi-Luen Do, Samuel Huron, and Danielle Albers Szafir. 2022. Making Data Tangible: A Cross-Disciplinary Design Space for Data Physicalization. In *Proc. CHI.* Article 81, 18 pages.

[5] Fearn Bishop, Johannes Zagermann, Ulrike Pfeil, Gemma Sanderson, Harald Reiterer, and Uta Hinrichs. 2020. Construct-A-Vis: Exploring the Free-Form Visualization Processes of Children. *IEEE Transactions on Visualization and Computer Graphics* 26, 1 (2020), 451–460. https://doi.org/10.1109/TVCG.2019.2934804

[6] Xin Chen, Jessica Zeitz Self, Leanna House, John Wenskovitch, Maoyuan Sun, Nathan Wycoff, Jane Robertson Evia, Scotland Leman, and Chris North. 2018. Be the Data: Embodied Visual Analytics. *IEEE Transactions on Learning Technologies* 11, 1 (2018), 81–95. https://doi.org/10.1109/TLT.2017.2757481

[7] Johannes Gäbler, Christoph Winkler, Nóra Lengyel, Wolfgang Aigner, Christina Stoiber, Günter Wallner, and Simone Kriglstein. 2019. Diagram Safari: A Visualization Literacy Game for Young Children. In *Extended Abstracts of the Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts* (Barcelona, Spain) *(CHI PLAY '19 Extended Abstracts)*. Association for Computing Machinery, New York, NY, USA, 389–396. https://doi.org/10.1145/3341215.3356283

[8] Sergio Garrido-Jurado, Rafael Munoz-Salinas, Francisco José Madrid-Cuevas, and Rafael Medina-Carnicer. 2016. Generation of fiducial marker dictionaries using mixed integer linear programming. *Pattern Recognition* 51 (2016), 481–491.

[9] Susan Goldin-Meadow. 2005. *Hearing gesture: How our hands help us think.* Harvard University Press.

[10] Susan Goldin-Meadow, San Kim, and Melissa Singer. 1999. What the teacher's hands tell the student's mind about math. *Journal of educational psychology* 91, 4 (1999), 720.

[11] Peter Gyory, S. Sandra Bae, Ruhan Yang, Ellen Yi-Luen Do, and Clement Zheng. 2023. Marking Material Interactions with Computer Vision. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 478, 17 pages. https://doi.org/10.1145/3544548.3580643

[12] Samuel Huron, Sheelagh Carpendale, Alice Thudt, Anthony Tang, and Michael Mauerer. 2014. Constructive visualization. In *Proceedings of the 2014 conference on Designing interactive systems.* 433–442.

[13] Elaine Huynh, Angela Nyhout, Patricia Ganea, and Fanny Chevalier. 2021. Designing Narrative-Focused Role-Playing Games for Visualization Literacy in Young Children. *IEEE Transactions on Visualization and Computer Graphics* 27, 2 (2021), 924–934. https://doi.org/10.1109/TVCG.2020.3030464

[14] Marc Leman and Pieter-Jan Maes. 2014. The role of embodiment in the perception of music. *Empirical Musicology Review* 9, 3-4 (2014), 236–246.

[15] Lijuan Liu, Jiahao Guo, Chao Zhang, Zhangzhi Wang, Pinqi Zhu, Tuo Fang, Junwu Wang, Cheng Yao, and Fangtian Ying. 2021. ElectroPaper: Design and Fabrication of Paper-Based Electronic Interfaces for the Water Environment. *Electronics* 10, 5 (2021). https://doi.org/10.3390/electronics10050604

[16] Manuela Macedonia and Thomas R Knösche. 2011. Body in mind: How gestures empower foreign language learning. *Mind, Brain, and Education* 5, 4 (2011), 196–211.

[17] Francisco J Romero-Ramirez, Rafael Muñoz-Salinas, and Rafael Medina-Carnicer. 2018. Speeded up detection of squared fiducial markers. *Image and vision Computing* 76 (2018), 38–47.

[18] Margaret Wilson. 2002. Six views of embodied cognition. *Psychonomic Bulletin & Review* 9, 4 (01 Dec 2002), 625–636. https://doi.org/10.3758/BF03196322

[19] Clement Zheng, Peter Gyory, and Ellen Yi-Luen Do. 2020. *Tangible Interfaces with Printed Paper Markers.* Association for Computing Machinery, New York, NY, USA, 909–923. https://doi.org/10.1145/3357236.3395578