Toward a More Comprehensive Understanding of Visualization Literacy

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ABSTRACT

Researchers have proposed many definitions of *visualization literacy*, targeting various aspects of the term. But we have yet to fully capture what it really means to be literate in visualizations, which has important downstream implications, such as how to effectively teach visualization skills to younger generations. We ran a meetup at IEEE VIS 2022 that attracted over 30 researchers in the field, who discussed aspects of visualization literacy such as how we measure it, how we can improve it, how it develops, and how it relates to other literacies. ACM CHI has a track record of attracting researchers from various fields such as visualization, learning sciences, and design, advancing research through both quantitative and qualitative approaches in and around HCI. For this year's CHI, we propose to run a one-day workshop with the goal of further developing actionable research agendas to more comprehensively define, understand, and improve visualization literacy. By continuing critical discussions with diverse perspectives from the CHI community, we can deepen investigations of visualization literacy through multiple lenses, such as measurement, interventions, and pedagogy.[1]

CCS CONCEPTS

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

KEYWORDS

Visualization literacy, Workshop, Panel discussions, Group activities

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1 MOTIVATION

Information visualizations can enhance people's understanding of data and assist in important decision-making processes (e.g., visualizations designed to help people decide whether to wear a mask during the COVID-19 pandemic or hurricane forecasts designed to help people make evacuation decisions). However, the usefulness of these enhanced data displays in the wild relies largely on a viewer's *visualization literacy*, which has been defined across research efforts in various ways (e.g., [10, 13, 14, 26, 38, 48]). For instance, some definitions are based on a person's ability to do fundamental visualization tasks (e.g., retrieving values or making comparisons) [38], correctly interpret visualizations in the face of misinformation [26], or even create visualizations [13, 48]. Definitions of visualization literacy tend to either focus on certain aspects of this construct, or were created within boundaries of specific studies, and may not fully capture what constitutes being literate in visualizations. The growing, but scattered, momentum in visualization literacy research subsequently affects the comprehensiveness and effectiveness of measurements and interventions designed based on these definitions [4]. The propagating, and lasting, effects of this lack of a comprehensive understanding of visualization literacy necessitate deeper investigations of this construct.

Thus, our overarching question: **What is visualization literacy?** (assuming it—whatever *it* is—should even be called "literacy" in the first place [16]). The answer becomes more complex as we drill down to the underlying process of *interpretation*, which often involves a combination of low-level and high-level visualization tasks. Interpretations inevitably drive *decisions*, affecting a variety of stakeholders, further complicating our picture. This complexity multiplies again if we consider visualization *construction* to be part of visualization literacy, analogous to how writing is a component of textual literacy. Moreover, interpreting visualizations in the wild is often also context-dependent. For instance, different facets of visualization literacy may have varying levels of relevance depending on a viewer's background, task, occupation, and preferences. Such interactions with visualizations can also involve skills from other domains like statistics. Thus, to advance toward a more comprehensive understanding of all facets of visualization literacy, we must bring together researchers, practitioners, teachers, and students from various domains—not only human–computer interaction and visualization, but also fields like psychology, learning sciences, and education—to form a more holistic view of visualization literacy.

Although there have been previous IEEE workshops on related topics, such as visualization guidelines, pedagogy, and activities (e.g., [3, 31, 33, 36]), as well as CHI education symposiums on HCI more broadly (e.g., [20]), these prior efforts have not emphasized critical questioning of the visualization *literacy* construct itself. To pursue these critical discussions and include diverse perspectives on visualization literacy, a subset of organizers of this workshop ran an hour-long meetup at IEEE VIS 2022, drawing more than 30 attendees. Following a productive discussion, this meetup raised numerous significant research challenges that remain unaddressed, such as:

How can we more effectively measure visualization literacy? Prior works within the visualization community have proposed various ways of quantifying the ability to interpret visualizations (e.g., [11, 13, 17, 26, 38, 39]). Although these efforts serve as a solid foundation for measuring visualization literacy, they lack focus on a wider range of higher-level tasks (e.g., visualization construction): current measurements tend to focus on the *interpretation* of visualizations. It is important to identify skills, practices, and dispositions that have effects on visualization literacy, but are not yet part of measurement foci, and develop assessments for these.

How can we design and develop interventions for improving visualization literacy in broader audiences? Some existing interventions for improving visualization literacy take on game-based approaches [2] focusing on younger audiences (e.g., [1, 25, 32]) and low-level tasks (e.g., [9]). Other projects have evaluated approaches for online interventions with online communities (e.g., online learning [37]). Although these interventions have specific target audiences, we need to broaden the audience, content, and timing of interventions to support a wide range of creators, users, and learners' visualization experiences, including higher-level visualization tasks and activities that resemble those that people do with visualizations in their everyday lives. Examining what, how, and when interventions are most effective should also help us develop a more comprehensive understanding of visualization literacy as a concept and help guide literacy support efforts.

How can we improve visualization pedagogy? Researchers in the field have designed and developed toolkits or frameworks to cultivate literacy in and to teach visualization, both for novice learners and instructors (e.g., [5, 12, 45, 50, 52]). Prior work has also called for more targeted instruction on specific aspects of visualization literacy [15, 21] that can be applied in formal and informal instructional spaces. This reflects the notion that classroom instruction may need to be reassessed to incorporate contemporary understandings of visualization literacy.

1.1 Workshop Goals and Topics for Discussion

We aim to continue but not be constrained by these previous discussions. Starting with these seed questions as discussion points, we will use the workshop to brainstorm additional topics, form actionable agendas for research, and serve as a platform to foster collaborations. Our specific aims are:

- Serve as a platform for researchers, teachers, and students to share experiences of measuring visualization literacy skills, practices, and dispositions in classrooms, identify challenges in quantification, and brainstorm ways to improve measurement in practice.
- Develop and prototype intervention ideas during group activities.

- Surface teachers' and researchers' existing knowledge to reassess current teaching practices, identify areas for improvement that align with visualization literacy, and brainstorm classroom instructional strategies targeting learners at different stages.
- Redefine visualization literacy as informed by visualization usage in everyday life.
- Develop more concrete research agendas with existing and new collaborations targeting questions including:
  - How can we more effectively define and quantify visualization literacy?
  - How can we design and develop interventions that reach a broader audience?
  - How can we improve visualization pedagogy, both in terms of what skills to teach and how to teach them?
  - How can we draw from research findings in areas such as measurement, interventions, and pedagogy to support visualization literacy theory and practice?

2 ORGANIZERS

Our organizing committee spans a variety of topics around the workshop, including visualization literacy assessments (e.g., Kwon [38, 39], Ge [17, 26], Cui [17, 26], Ding [17], Harrison [17], Kay [17, 26], Joshi [22], Ottley [43]), interventions (e.g., Ding [9], Harrison [9], Joshi [23, 45], Kwon [37], Bach [19, 53, 54], Borkin [49]), and factors that can impact or be impacted by the interpretation of visual information (e.g., Ding [18], Harrison [18], Kay [18], Bonilla [18], Ottley [56], Bach [47], Rapp [28–30, 41, 55], Peck [44], Padilla [24, 42], Correll [16]). Together, we also span a variety of fields, including human–computer interaction, information visualization, learning sciences, psychology, and education.

2.1 Primary Organizers

Lily Ge is a Ph.D. candidate in Computer Science and a member of the Midwest Uncertainty Collective at Northwestern University. Within human–computer interaction and information visualization, her research is at the intersection of visualization literacy and misinformation. She has previously led the investigation of ways to assess people's susceptibility to visualization misinformation [26]. She also studies how to foster relevant skills for identifying misinformation and data-based reasoning with the support of visualizations.

Maryam Hedayati is a Ph.D. student in Computer Science + Learning Sciences at Northwestern University, and is a member of the Midwest Uncertainty Collective. She is interested in how visualization expertise develops, and the role of visualization literacy in people's daily lives.

Yuan Cui is a Ph.D. candidate in Computer Science and a member of the Midwest Uncertainty Collective at Northwestern University. He is interested in leveraging mathematical and quantitative tools to understand and measure visualization literacy. He has previously led the construction of adaptive assessments for visualization literacy [17]. In addition, he investigates how visual displays of arguments can debias people and designs statistical methods for racial disparity measurement.

Yiren Ding is a Ph.D. candidate in Computer Science at Worcester Polytechnic Institute. His research involves data visualization literacy and building tools for democratizing empirical studies. He has previously investigated modeling individual differences in graphical perception [18], as well as the utilization of animation to improve people's graphical perception [9]. He is also working on a comprehensive data visualization literacy platform, which allows the general public to learn and improve their data visualization literacy performance.

Karen Bonilla is a Postgraduate Researcher with the VIEW group at Worcester Polytechnic Institute. She is interested in visual literacy and how improvements can be made in how it is taught, such as at the middle school level. She has worked on research on individual differences in graphical perception [18].

Lane Harrison is an Associate Professor in the Department of Computer Science at Worcester Polytechnic Institute. Lane directs the VIEW group at WPI, where he and his students leverage computational methods to understand and shape how people use visualizations and visual analytics tools. He has organized successful IEEE panels and workshops on topics including visualization literacy for general audiences [34] and visualization for social good [6–8].

Matthew Kay is an Associate Professor jointly appointed in Computer Science and Communications Studies at Northwestern University. He works in uncertainty visualization, visualization literacy, and the design of human-centered tools for data analysis. He has organized successful CHI workshops and SIGs on various topics, including visualization grammars [46], transparent statistics [35, 51], designing for uncertainty [27], and health informatics [40]. He co-directs the Midwest Uncertainty Collective (https://mucollective.northwestern.edu/).

2.2 Co-Organizers

Co-organziers have advised on the content and structure of the workshop and will help in the juried paper selection process. They will also help disseminate the call for participation broadly within their varied research networks.

Alark Joshi is an Associate Professor in the Department of Computer Science at the University of San Francisco. His research focuses on developing and evaluating the ability of novel visualization techniques to communicate information for effective decision-making and discovery. He has organized successful IEEE workshops and panels on topics such as visualization pedagogy [33] and visualization for general audiences [34]. He directs the Visualization and Graphics Lab (VGL) at the University of San Francisco.

Alvitta Ottley is an Associate Professor of Computer Science and Engineering at Washington University in St. Louis. She is also the director of the Visual Interface and Behavior Exploration (VIBE) Lab (https://visualdata.wustl.edu/) and holds a courtesy appointment in the Psychological and Brain Sciences Department. Her research uses interdisciplinary approaches to solve problems such as how best to display information for effective decision-making and how to design human-in-the-loop visual analytics interfaces that are more attuned to how people think.

Benjamin Bach is an Associate Professor in Design Informatics and Visualization at the University of Edinburgh. His research designs and investigates interactive information visualization interfaces to help people explore, communicate, and understand data. He has organized successful IEEE workshops on various topics, including visualization education [36], activities [31], and guidelines [3].

Bum Chul Kwon is a research scientist at IBM Research, Cambridge, MA. His research goal is to enhance users' abilities to gain insights into data through interactive visualization systems. He is also interested in making machine learning algorithms more transparent, solving real-world healthcare problems, and improving data visualization literacy. He has successfully organized and been on the panel for visualization literacy for general audiences [34].

David Rapp is a Professor in the School of Education and Social Policy and in the Department of Psychology at Northwestern University. His research examines the cognitive mechanisms responsible for successful learning and for knowledge failures during text comprehension and visualization experiences. This has included examining the effects of reading inaccurate information, the evaluation of technologies intended to support formal and informal learning, the development of effective STEM visualization displays, and the iterative design of tools intended to support literacy.

Evan Peck is an Associate Professor of Information Science at University of Colorado Boulder. His research draws on the fields of Human-Computer Interaction and Information Visualization. He believes that improving the public's engagement, trust, and understanding of data is a critical societal challenge. His research focuses on the opportunities and barriers of both data representations and data tools when they are embedded within our public sphere. He has organized successful IEEE workshops and panels on topics such as visualization for social good [6, 7].

Lace Padilla is an Assistant Professor of Computer Science and Psychology at Northeastern University and a member of the Data Visualization Lab @Khoury (https://vis.khoury.northeastern.edu/). Her interests lie in the intersection between Information Visualization, Behavioral Decision Making, and Data Science. Her research on uncertainty communication explores how to align data visualizations of future events with human decision-making capabilities.

Michael Correll is an Associate Research Professor at Northeastern University's Khoury College of Computing and a member of the Roux Institute and NEU's vis lab (https://vis.khoury.northeastern.edu/). He is particularly interested in the ethical, accurate, and responsible communication of data, but he is also interested in graphical perception, text analytics, statistical graphics, and uncertainty visualization. His current research interests include data ethics, communicating statistics to mass audiences, and investigating biased or misleading data visualizations. He has organized successful IEEE workshops and panels on topics such as visualization for social good [6, 7].

Michelle Borkin is an Associate Professor at the Khoury College of Computer Sciences at Northeastern University. She works on the development of novel visualization techniques and tools to enable new insights and discoveries in data. She works across disciplines to bring together computer scientists, doctors, and astronomers to collaborate on new analysis and visualization techniques. She has also organized successful IEEE workshops and panels on topics such as visualization for social good [6–8].

3 PRE-WORKSHOP PLANS

As detailed in our call for participation (Section 8), we are inviting submissions in the form of 2-8 page papers targeting questions related to how we define, study, and improve visualization literacy. If the workshop proposal is accepted to CHI, we will plan to immediately release and publicize the call for participation through multiple channels, such as on our workshop website, social media, and communities of previous workshops on visualization literacy and education. Our organizing team has extensive connections across a variety of fields and institutions, and can therefore distribute the call to an international community of scholars with diverse backgrounds. Submissions will be due by February 22, 2024, and we will send notification of results by the middle of March.

Because the workshop will be driven by panel discussions rather than traditional paper presentations, we plan to use a juried selection approach to review the paper submissions and select a subset of submissions that workshop organizers can then use to help group participants into panels. Submissions are not required to be anonymous, and selection by a jury can better ensure the representation of diverse perspectives in reaching our goal of facilitating critical conversations on the notion of visualization literacy. The selection jury will consist of a subset of workshop organizers. We aim to accept a range of 10 to 20 submissions. The exact number of panels depends on the submissions we receive and the themes that arise from the submissions.

3.1 Website and Plans to Publish Workshop Proceedings

We will launch a website to distribute workshop related information such as the call for participation and the workshop goals, structure, and schedule. We will publish the accepted papers on the Open Science Framework (OSF) open-access repository and link the papers on the workshop website before the conference. Afterwards, outputs and artifacts generated as a result of the workshop will also be hosted on the website, which will help facilitate discussions before, during, and after the workshop.

4 WORKSHOP MODALITY

The workshop will be in-person only, because the workshop will be driven by panel discussions and group activities, which can be better supported when all participants are in one place.[2] On the day of the workshop, we would appreciate a room with AV equipment and an adjustable configuration of tables and chairs to facilitate panel discussions and group activities. Post-it notes along with collaborative technologies (Google Docs and Miro) will be used to support group activities (e.g., affinity mapping) and note-taking throughout the workshop. The outputs from these collaborative technologies can also be readily distributed online after the workshop, in widely accessible formats.

4.1 Asynchronous Engagement

Workshop materials from before, during, and after the workshop will be hosted on the workshop website to support asynchronous

[2] As per PCS, if CHI 2024 becomes fully virtual, this workshop would also be able to run virtual-only. In case that happens, participants would all be online, still participating in one (virtual) place.

engagement for interested individuals who cannot participate synchronously. Specifically, we will ensure that the accepted papers, notes taken during the panel discussions and group activities, and outputs from the group activities (e.g., affinity mapping, written artifacts) are publicly available on the website. We will also write a summary report on the workshop activities, which will be publicly posted on the website to further facilitate discussions and allow for asynchronous engagement.

5 WORKSHOP STRUCTURE AND ACTIVITIES

The workshop will be driven by panel discussions and group activities, rather than traditional paper presentations. We propose a workshop schedule below and detail the structure of the different types of sessions in the workshop.

This proposed schedule is subject to change in accordance with CHI 2024 schedule (e.g., exact times for breaks and lunch). Additionally, the exact topics for panel discussions will depend on the paper submissions we receive and the themes that arise.

- (9:00 - 9:30) Welcome and Introductions (all attendees)
- (9:30 - 11:00) Thematic Panels and Discussions
- (11:00 - 12:00) Group Activity - Affinity mapping
- (12:00 - 1:00) Lunch Break
- (1:00 - 2:00) Thematic Panels and Discussions
- (2:00 - 3:30) Group Activity - Brainstorm and share
- (3:30 - 4:00) Break
- (4:00 - 5:00) Group Activity - Revisit themes and draft research agendas (written artifacts)
- (5:00 - 5:30) Closing, reflection, and discussion of next steps

5.1 Panel Discussions

A tentative set of panel topics may include what is visualization literacy, measurements, interventions, and pedagogy surrounding visualization literacy. However, the exact topics of the panel discussions depend largely on the submissions we receive. For each panel, author(s) from each paper will serve as the panelists, with a maximum of five panelists to ensure more productive discussions. Notes will be taken during panel discussions and posted on the workshop website.

5.2 Group Activity: Affinity Mapping

One of the group activities will be affinity mapping based on the topics of the morning panel discussions. After the panel discussions, we will first assemble attendees into smaller groups, where they will use Miro to list ideas that emerged from the panel discussions and group them into themes. We will then form a large group with all attendees to synthesize themes from each smaller group into a shared document. The emergent themes will be saved and revisited later in the workshop, during the group activity with written artifacts (Section 5.4).

5.3 Group Activity: Brainstorm and Share

This activity will follow the afternoon panel discussions, focusing on brainstorming new ideas related to all of the panel topics. Attendees will be grouped into small groups based on individual topic interest. For instance, if the panel topic is intervention related, then the group could brainstorm and sketch out ideas about new interventions to improve visualization literacy. The small groups will then be merged into larger groups to allow sharing and prototyping intervention ideas with other group members. During the process of brainstorming and sharing, attendees will be encouraged to take notes through collaborative technologies and preserve artifacts that result from these activities.

5.4 Group Activity: Written Artifacts

During this group activity, all attendees will revisit the themes identified during affinity mapping (Section 5.2) and refine as necessary based on insights from the brainstorm and share activity (Section 5.3). Then, attendees will again assemble into small groups, depending on individual interest in the refined themes. In each group, participants will collaboratively draft a written artifact (e.g., research agenda) on a shared document (e.g., Google Docs) and outline actionable next steps. In the closing session of the workshop after this activity (see schedule above, in Section 5), groups will share these next steps and reflect on insights from the workshop as a whole.

6 ACCESSIBILITY

All paper submissions should comply with CHI 2024 accessibility guidelines, as emphasized in the call for participation (Section 8). We will also ensure that all workshop related materials used during the workshop and posted on the website after the workshop are accessible, such as necessary figure descriptions. Outputs generated with assistance from collaborative technologies (e.g., Google Docs, Miro) should ensure accessibility by the general public as well as adequate support for asynchronous engagement.

7 POST-WORKSHOP PLANS

We will collect interest after the workshop to build an online community for furthering conversations and facilitating potential collaborations. The format of this online community will depend on the preferences of participants, but could take the form of a Slack group or a mailing list. Soon after the workshop, we will post workshop materials on the website, which would include notes from panel discussions, outputs from group activities, a summary report reflecting on the workshop, and any established channels for post-workshop communication. Related workshop materials on the website will be disseminated to relevant communities (e.g., HCI, visualization, learning sciences, psychology, education) as an effort to broaden participation and engagement.

8 CALL FOR PARTICIPATION

This workshop aims to facilitate and deepen critical discussions about how to define, study, and improve *visualization literacy*. We welcome submissions targeting questions including, but not limited to:

- What is "visualization literacy"?
- How can we more effectively measure visualization literacy?
- How can we design and develop interventions to reach a broader audience?
- How can we improve the teaching of visualizations?

Submissions should be 2-8 pages (excluding references), in single-column ACM Master Article Submission Template, and comply with CHI 2024 paper accessibility guidelines. The workshop will be driven by participant panels based on submissions received, rather than traditional paper presentations. More details are on our workshop website: https://visualization-literacy.github.io/CHI2024/. To make paper submissions, please fill out this form https://forms.gle/URKJaYTLZbwEGRSZA by February 22, 2024 (AoE). Submissions will be reviewed by a jury of experts, who will select a subset of submissions that contribute to the goal of advancing diverse and critical discussions about visualization literacy. Decision notification can be expected around mid-March. Accepted papers will be published on the Open Science Framework (OSF) open-access repository.

At least one author of each accepted submission must attend the in-person workshop and register for the workshop and for at least one day of the conference. Outputs from the workshop, including panel discussions, group activities, a summary workshop report, and accepted workshop submissions will be made available to the public on our workshop website, facilitating further discussions within and beyond the CHI community.

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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] Lorenzo Amabili, Kuhu Gupta, and Renata Georgia Raidou. 2021. A Taxonomy-Driven Model for Designing Educational Games in Visualization. *IEEE Computer Graphics and Applications* 41, 6 (2021), 71–79. https://doi.org/10.1109/MCG.2021.3115446

[3] Benjamin Bach, Alfie Abdul-Rahman, and Alexandra Diehl. 2022. 4th IEEE Workshop on Visualization Guidelines in Research, Design, and Education. https://visguides-workshop.github.io/.

[4] Benjamin Bach, Mandy Keck, Fateme Rajabiyazdi, Tatiana Losev, Isabel Meirelles, Jason Dykes, Robert S. Laramee, Mashael AlKadi, Christina Stoiber, Samuel Huron, Charles Perin, Luiz Morais, Wolfgang Aigner, Doris Kosminsky, Magdalena Boucher, Søren Knudsen, Areti Manataki, Jan Aerts, Uta Hinrichs, Jonathan C. Roberts, and Sheelagh Carpendale. 2024. Challenges and Opportunities in Data Visualization Education: A Call to Action. *IEEE Transactions on Visualization and Computer Graphics* 30, 1 (2024), 649–660. https://doi.org/10.1109/TVCG.2023.3327378

[5] 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

[6] Leilani Battle, Michelle Borkin, Michael Correll, Lane Harrison, and Evan Peck. 2020. IEEE VIS Workshop on Visualization for Social Good. https://vis4good.github.io/panel2020.

[7] Leilani Battle, Michelle Borkin, Michael Correll, Lane Harrison, and Evan Peck. 2021. IEEE VIS Workshop on Visualization for Social Good. https://vis4good.github.io/workshop2021.

[8] Leilani Battle, Michelle Borkin, Emily Wall, Lane Harrison, and Narges Mahyar. 2022. IEEE VIS Workshop on Visualization for Social Good. https://vis4good.github.io/workshop2022.

[9] Ryan Birchfield, Maddison Caten, Errica Cheng, Madyson Kelly, Truman Larson, Hoan Phan Pham, Yiren Ding, Noëlle Rakotondravony, and Lane Harrison. 2022. VisQuiz: Exploring Feedback Mechanisms to Improve Graphical Perception. In *2022 IEEE Visualization and Visual Analytics (VIS)*. IEEE, Oklahoma City, OK, USA, 95–99. https://doi.org/10.1109/VIS54862.2022.00028

[10] Jeremy Boy, Ronald A. Rensink, Enrico Bertini, and Jean-Daniel Fekete. 2014. A Principled Way of Assessing Visualization Literacy. *IEEE Transactions on Visualization and Computer Graphics* 20, 12 (2014), 1963–1972. https://doi.org/10.1109/TVCG.2014.2346984

[11] Jeremy Boy, Ronald A. Rensink, Enrico Bertini, and Jean-Daniel Fekete. 2014. A Principled Way of Assessing Visualization Literacy. *IEEE Transactions on Visualization and Computer Graphics* 20, 12 (2014), 1963–1972. https://doi.org/10.1109/TVCG.2014.2346984

[12] Vetria L. Byrd and Nicole Dwenger. 2021. Activity Worksheets for Teaching and Learning Data Visualization. *IEEE Computer Graphics and Applications* 41, 6 (2021), 25–36. https://doi.org/10.1109/MCG.2021.3115396

[13] Katy Börner, Andreas Bueckle, and Michael Ginda. 2019. Data visualization literacy: Definitions, conceptual frameworks, exercises, and assessments. *Proceedings of the National Academy of Sciences* 116, 6 (2019), 1857–1864. https://doi.org/10.1073/pnas.1807180116 arXiv:https://www.pnas.org/doi/pdf/10.1073/pnas.1807180116

[14] Katy Börner, Adam Maltese, Russell Nelson Balliet, and Joe Heimlich. 2016. Investigating aspects of data visualization literacy using 20 information visualizations and 273 science museum visitors. *Information Visualization* 15, 3 (2016), 198–213. https://doi.org/10.1177/1473871615594652 arXiv:https://doi.org/10.1177/1473871615594652

[15] Jorge D. Camba, Pedro Company, and Vetria L. Byrd. 2022. Identifying Deception as a Critical Component of Visualization Literacy. *IEEE Computer Graphics and Applications* 42, 1 (2022), 116–122. https://doi.org/10.1109/MCG.2021.3132004

[16] Michael Correll. 2018. What Does "Visualization Literacy"' Mean, Anyway? https://medium.com/multiple-views-visualization-research-explained/what-does-visualization-literacy-mean-anyway-22f3b3badc0.

[17] Yuan Cui, Lily W. Ge, Yiren Ding, Fumeng Yang, Lane Harrison, and Matthew Kay. 2024. Adaptive Assessment of Visualization Literacy. *IEEE Transactions on Visualization and Computer Graphics* 30, 1 (2024), 628–637. https://doi.org/10.1109/TVCG.2023.3327165

[18] Russell Davis, Xiaoying Pu, Yiren Ding, Brian D. Hall, Karen Bonilla, Mi Feng, Matthew Kay, and Lane Harrison. 2022. The Risks of Ranking: Revisiting Graphical Perception to Model Individual Differences in Visualization Performance. *IEEE Transactions on Visualization and Computer Graphics* (2022), 1–16. https://doi.org/10.1109/TVCG.2022.3226463

[19] Alexandra Diehl, Elif E. Firat, Thomas Torsney-Weir, Alfie Abdul-Rahman, Benjamin Bach, Robert Laramee, Renato Pajarola, and Min Chen. 2021. VisGuided: A Community-driven Approach for Education in Visualization. In *Eurographics 2021 - Education Papers*, Beatriz Sousa Santos and Gitta Domik (Eds.). The Eurographics Association, The Netherlands, 8 pages. https://doi.org/10.2312/eged.20211003

[20] EduCHI. 2022. 4th Annual Symposium on HCI Education. https://educhi2022.educhi.org/.

[21] Elif E Firat, Alark Joshi, and Robert S Laramee. 2022. Interactive visualization literacy: The state-of-the-art. *Information Visualization* 21, 3 (2022), 285–310.

[22] Elif E. Firat, Alark Joshi, and Robert S. Laramee. 2022. VisLitE: Visualization Literacy and Evaluation. *IEEE Computer Graphics and Applications* 42, 3 (2022), 99–107. https://doi.org/10.1109/MCG.2022.3161767

[23] Elif E. Firat, Colm Lang, Bhumika Srinivas, Ilena Peng, Robert S. Laramee, and Alark Joshi. 2023. A Constructivism-based Approach to Treemap Literacy in the Classroom. In *Eurographics 2023 - Education Papers*, Alejandra Magana and Jiri Zara (Eds.). The Eurographics Association, The Netherlands, 8 pages. https://doi.org/10.2312/eged.20231016

[24] Steven L. Franconeri, Lace M. Padilla, Priti Shah, Jeffrey M. Zacks, and Jessica Hullman. 2021. The Science of Visual Data Communication: What Works. *Psychological Science in the Public Interest* 22, 3 (2021), 110–161. https://doi.org/10.1177/15291006211051956 arXiv:https://doi.org/10.1177/15291006211051956 PMID: 34907835.

[25] 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

[26] Lily W. Ge, Yuan Cui, and Matthew Kay. 2023. CALVI: Critical Thinking Assessment for Literacy in Visualizations. 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 815, 18 pages. https://doi.org/10.1145/3544548.3581406

[27] Miriam Greis, Jessica Hullman, Michael Correll, Matthew Kay, and Orit Shaer. 2017. Designing for Uncertainty in HCI: When Does Uncertainty Help?. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI EA '17)*. Association for Computing Machinery, New York, NY, USA, 593–600. https://doi.org/10.1145/3027063.3027091

[28] Scott R. Hinze, David N. Rapp, Vickie M. Williamson, Mary Jane Shultz, Ghislain Deslongchamps, and Kenneth C. Williamson. 2013. Beyond ball-and-stick: Students' processing of novel STEM visualizations. *Learning and Instruction* 26 (2013), 12–21. https://doi.org/10.1016/j.learninstruc.2012.12.002

[29] Scott R. Hinze, Vickie M. Williamson, Mary Jane Shultz, Ghislain Deslongchamps, Kenneth C. Williamson, and David N. Rapp. 2014. Spatial Ability and Learning from Visualizations in STEM Disciplines. In *Space in Mind: Concepts for Spatial Learning and Education*. The MIT Press, Cambridge, MA. https://doi.org/10.7551/mitpress/9811.003.0006 arXiv:https://direct.mit.edu/book/chapter-pdf/2113623/9780262321730_cae.pdf

[30] Scott R Hinze, Vickie M Williamson, Mary Jane Shultz, Kenneth C Williamson, Ghislain Deslongchamps, and David N Rapp. 2013. When do spatial abilities support student comprehension of STEM visualizations? *Cognitive processing* 14 (2013), 129–142.

[31] Samuel Huron, Benjamin Bach, Georgia Panagiotidou, Mandy Keck, Jonathan C. Roberts, and Sheelagh Carpendale. 2021. IEEE VIS Workshop on Data Vis Activities. https://visactivities.github.io/.

[32] 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

[33] Alark Joshi, Eytan Adar, Enrico Bertini, Sophie Engle, Marti Hearst, and Daniel Keefe. 2017. IEEE VIS Workshop on Pedagogy of Data Visualization. https://vgl.cs.usfca.edu/pdvw/2017/.

[34] Alark Joshi, Katy Börner, Robert S Laramee, Lane Harrison, Elif E Firat, and Bum Chul Kwon. 2021. Visualization literacy for general audiences-can we make a difference?

[35] Matthew Kay, Steve Haroz, Shion Guha, Pierre Dragicevic, and Chat Wacharamanotham. 2017. Moving Transparent Statistics Forward at CHI. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI EA '17)*. Association for Computing Machinery, New York, NY, USA, 534–541. https://doi.org/10.1145/3027063.3027084

[36] Mandy Keck, Samuel Huron, Georgia Panagiotidou, Christina Stoiber, Fateme Rajabiyazdi, Charles Perin, Jonathan C Roberts, and Benjamin Bach. 2023. EduVis: Workshop on Visualization Education, Literacy, and Activities. https://arxiv.org/abs/2303.10708.

[37] Bum Chul Kwon and Bongshin Lee. 2016. A Comparative Evaluation on Online Learning Approaches Using Parallel Coordinate Visualization. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 993–997. https://doi.org/10.1145/2858036.2858101

[38] Sukwon Lee, Sung-Hee Kim, and Bum Chul Kwon. 2017. VLAT: Development of a Visualization Literacy Assessment Test. *IEEE Transactions on Visualization and Computer Graphics* 23, 1 (2017), 551–560. https://doi.org/10.1109/TVCG.2016.2598920

[39] Sukwon Lee, Bum Chul Kwon, Jiming Yang, Byung Cheol Lee, and Sung-Hee Kim. 2019. The correlation between users' cognitive characteristics and visualization literacy. *Applied Sciences* 9, 3 (2019), 488.

[40] Mark Matthews, Erin Carroll, Saeed Abdullah, Jaime Snyder, Matthew Kay, Tanzeem Choudhury, Geri Gay, and Julie Kientz. 2014. Biological Rhythms and Technology. In *CHI '14 Extended Abstracts on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI EA '14)*. Association for Computing Machinery, New York, NY, USA, 123–126. https://doi.org/10.1145/2559206.2559230

[41] Matthew T. McCrudden and David N. Rapp. 2017. How Visual Displays Affect Cognitive Processing. *Educational Psychology Review* 29, 3 (2017), 623–639. http://www.jstor.org/stable/44956393

[42] Lace M Padilla, Sarah H Creem-Regehr, Mary Hegarty, and Jeanine K Stefanucci. 2018. Decision making with visualizations: a cognitive framework across disciplines. *Cognitive research: principles and implications* 3, 1 (2018), 1–25.

[43] Saugat Pandey and Alvitta Ottley. 2023. Mini-VLAT: A Short and Effective Measure of Visualization Literacy. *Computer Graphics Forum* 42, 3 (2023), 1–11. https://doi.org/10.1111/cgf.14809 arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1111/cgf.14809

[44] Evan M. Peck, Sofia E. Ayuso, and Omar El-Etr. 2019. Data is Personal: Attitudes and Perceptions of Data Visualization in Rural Pennsylvania. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300474

[45] Ilena Peng, Elif E. Firat, Robert S. Laramee, and Alark Joshi. 2022. Evaluating Bloom's Taxonomy-based Learning Modules for Parallel Coordinates Literacy. In *Eurographics 2022 - Education Papers*, Jean-Jacques Bourdin and Eric Paquette (Eds.). The Eurographics Association, The Netherlands, 9 pages. https://doi.org/10.2312/eged.20221042

[46] Xiaoying Pu, Matthew Kay, Steven M. Drucker, Jeffrey Heer, Dominik Moritz, and Arvind Satyanarayan. 2021. Special Interest Group on Visualization Grammars. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI EA '21)*. Association for Computing Machinery, New York, NY, USA, Article 162, 3 pages. https://doi.org/10.1145/3411763.3450406

[47] Xinhuan Shu, Aoyu Wu, Junxiu Tang, Benjamin Bach, Yingcai Wu, and Huamin Qu. 2021. What Makes a Data-GIF Understandable? *IEEE Transactions on Visualization and Computer Graphics* 27, 2 (2021), 1492–1502. https://doi.org/10.1109/TVCG.2020.3030396

[48] Mara Solen. 2022. Scoping the future of visualization literacy: A review. https://osf.io/eypgm.

[49] Uzma Haque Syeda, Prasanth Murali, Lisa Roe, Becca Berkey, and Michelle A. Borkin. 2020. Design Study "Lite" Methodology: Expediting Design Studies and Enabling the Synergy of Visualization Pedagogy and Social Good. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376829

[50] Yuzuru Tanahashi, Nick Leaf, and Kwan-Liu Ma. 2016. A Study On Designing Effective Introductory Materials for Information Visualization. *Computer Graphics Forum* 35, 7 (2016), 117–126. https://doi.org/10.1111/cgf.13009 arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1111/cgf.13009

[51] Chat Wacharamanotham, Matthew Kay, Steve Haroz, Shion Guha, and Pierre Dragicevic. 2018. Special Interest Group on Transparent Statistics Guidelines. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI EA '18)*. Association for Computing Machinery, New York, NY, USA, 1–4. https://doi.org/10.1145/3170427.3185374

[52] Chaoli Wang. 2022. VisVisual: A Toolkit for Teaching and Learning Data Visualization. *IEEE Computer Graphics and Applications* 42, 4 (2022), 20–26. https://doi.org/10.1109/MCG.2022.3176199

[53] Zezhong Wang, Harvey Dingwall, and Benjamin Bach. 2019. Teaching Data Visualization and Storytelling with Data Comic Workshops. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI EA '19)*. Association for Computing Machinery, New York, NY, USA, 1–9. https://doi.org/10.1145/3290607.3299043

[54] Zezhong Wang, Lovisa Sundin, Dave Murray-Rust, and Benjamin Bach. 2020. Cheat Sheets for Data Visualization Techniques. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376271

[55] Elizabeth A.H. Wilson, Gregory Makoul, Elizabeth A. Bojarski, Stacy Cooper Bailey, Katherine R. Waite, David N. Rapp, David W. Baker, and Michael S. Wolf. 2012. Comparative analysis of print and multimedia health materials: A review of the literature. *Patient Education and Counseling* 89, 1 (2012), 7–14. https://doi.org/10.1016/j.pec.2012.06.007

[56] Caroline Ziemkiewicz, Alvitta Ottley, R. Jordan Crouser, Krysta Chauncey, Sara L. Su, and Remco Chang. 2012. Understanding Visualization by Understanding Individual Users. *IEEE Computer Graphics and Applications* 32, 6 (2012), 88–94. https://doi.org/10.1109/MCG.2012.120