Embracing Disciplinary Diversity in Visualization

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***Abstract*—Visualization is inherently diverse and is employed in countless domains to enable meaningful interactions with data. There is tremendous opportunity in embracing disciplinary diversity to widen the pool of contributions to visualization design, research, and practice. We describe a few examples of diverse approaches: scientific method, design studies, tool building, participatory research and co-design with communities, data storytelling, and autographic design. We discuss opening the aperture, pushing back on what we, as a community, deem acceptable and rigorous, and what can be gained through greater inclusivity of approaches.**

Introduction

Visualization (VIS) is often discussed as both an art and science. A myriad of contrasting approaches accompany the diversity of VIS applications, yet we often limit ourselves to familiar methods. Here we aim to celebrate epistemic, practical, and disciplinary diversity of approaches in VIS, which we collectively refer to as *disciplinary diversity*. We acknowledge differences in research processes, share some examples we appreciate in VIS research, and suggest ways we, the VIS community, can strive to be more inclusive. We hope to inspire visualization researchers and designers to explore unfamiliar approaches, celebrate the creativity they bring to our community, expand our mutual respect, and embrace collaboration among disciplines. Our hope is that by opening the aperture of what is possible, the VIS community can partake more richly and more fully unlock the potential of data.

We draw attention to research approaches that go beyond what is often seen in the VIS literature and argue that this diversity of perspectives will spur innovation. We want to emphasize that we are not suggesting these as new paper types, but rather as examples of the many research approaches in active use in VIS and other fields. We then discuss actions the VIS community might take to better encourage, embrace and celebrate diverse contributions. Our work contributes a small step towards the greater goal of broader disciplinary diversity within the VIS community.

Variations in Research Approaches

To present our viewpoint, we present six examples of research approaches, three familiar and three, perhaps less familiar. Rather than an exhaustive list of approaches, this should be considered a sampling to illustrate the diverse possibilities. We encourage the reader to embrace the unknown and consider what may be possible by looking at problems through different disciplinary lenses. There is validity in approaches that were matured in other disciplines and that can be adopted and borrowed in a visualization design context.

Keep in mind that, though we describe the approaches separately, these processes and their outputs are often not mutually exclusive. Approaches can overlap and merge, mirroring the unique ways in which visualization design unfolds differently in each project.

Each approach is accompanied by a sidebar containing publications that employ the approach or resources for further information. Though these are not intended to be used as templates, the reader can take a deeper look at each approach through these examples.

Scientific Method The scientific method (Fig. 1) is a research process common in the computer science oriented visualization communities (e.g. IEEE VIS, EuroVis) because of the natural sciences backgrounds of many of their members. It begins with observing an event, phenomena, or data, which leads to research questions. A scientist then creates hypotheses and designs experiments to prove or disprove the hypotheses. The data is analyzed, a conclusion is formed, and the research is disseminated. Results of one study often drive observations and questions for future studies and the process continues. These types of research studies represent a preponderance of visualization research and are foundational to the visualization community historically.

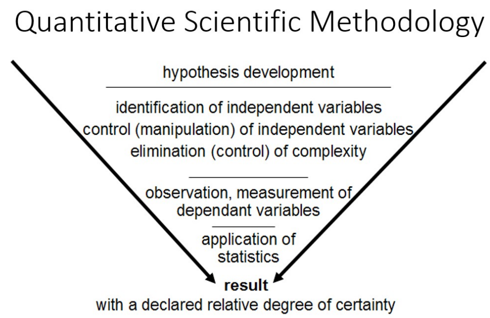

Figure 1. Simple outline of the scientific approach (see [3]).

Scientific Method Resources

Jardine, N., Ondov, B., Elmqvist, N., and Franconeri, S. (2019). The Perceptual Proxies of Visual Comparison. IEEE TVCG, 26(1).

Talbot, J., Setlur, V., and Anand, A. (2014). Four experiments on the perception of bar charts. IEEE TVCG, 20(12): 2152-2160.

A key objective of applying the scientific method to visualization research is to build a theoretical foundation for the field and ensure the theory and results are accessible and actionable. The VIS community is a blend from multiple disciplines, which have their own specific criteria, validation, and rules for research outputs. The scientific method offers the possibility of actionable theory, rigor, structure and verifiable results. However, because of the relative age of the visualization discipline with respect to other more foundational sciences, the theory is still forming and as a result can be difficult to apply.

Finally, it is important to understand the gravity of defining theory and best practices in the ways that they are applied. Theory is often created with relatively small studies, but applied in broad foundational ways. It is important to recognize the nuances and applicability when using the scientific method to report on and define visualization theory.

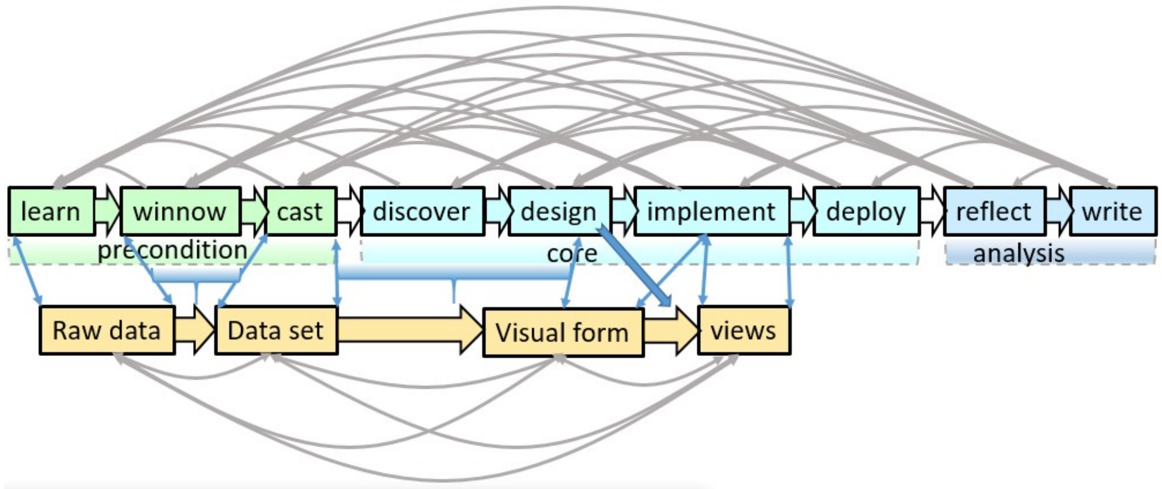

Figure 2. Overview of a typical design study process [13] in comparison with he data pipeline (see [3]).

> **Design Study Resources**
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> Meyer, M., Munzner, T. and Pfister, H. (2009). MizBee: a multiscale synteny browser. IEEE TVCG, 15(6): 897-904.
>
> Pandey, A., Shukla, H., Young, G.S., Qin, L., Zamani, A.A., Hsu, L., Huang, R., Dunne, C., and Borkin, M.A. (2019). CerebroVis: designing an abstract yet spatially contextualized cerebral arteries network visualization. IEEE TVCG, 26(1): 938-948.

Design Studies Design studies are a popular approach in the VIS community to problem-driven research, as described by Sedlmair et al. [13]. Design studies apply existing or new visualization techniques to domain specific problems with domain expert collaboration, to (1) create visualization theory that can later be applied to other problems, and (2) validate efficacy of the techniques. Many different approaches to design studies have been offered starting with Munzner's nested model [11], which takes a waterfall approach to the design and validation of visualizations. The output of each phase (domain problem characterization, data abstraction, encoding and interaction techniques, and algorithm design) drives the next. As shown in Fig. 2, Sedlmair's [13] approach is a cycle, showing that researchers often cycle back to previous stages of design ('learn, winnow, cast, discover, design, implement, deploy, reflect, and write') based on the output and what is learned at each stage.

Visualization researchers and practitioners who regularly practice design studies often admit that the process is challenging and that much of the learning occurs in the journey towards an end product [13]. Every design study is unique, often not directly applicable to future research. Although several design study methodologies have been offered, the process is often unique to each study.

Tool Building Popularized by Fred Brooks's concept of "toolsmiths" [1], this approach focuses on building gadgets, software, tools, and techniques that solve specific problems. Tool building (see Fig. 3) can often leverage and incorporate findings and theory from previous research, but focuses directly on building tools to solve problems. The approach asks questions such as: "How can we create visualization tools and techniques that are easy for humans to read and use to solve problems?", and "How can we use automation and abstraction to enable designers so that they do not need a deep theoretical understanding before being able to create visualizations?". A few foci that play important roles in tool building include: (1) Understanding user needs, (2) Readability criteria and aesthetic principles, (3) Encoding criteria into algorithms, and (4) Validation.

Understanding user needs helps tool designers define requirements and map them to visualization tasks. Task abstraction centers on the idea that a designer can pull out com-

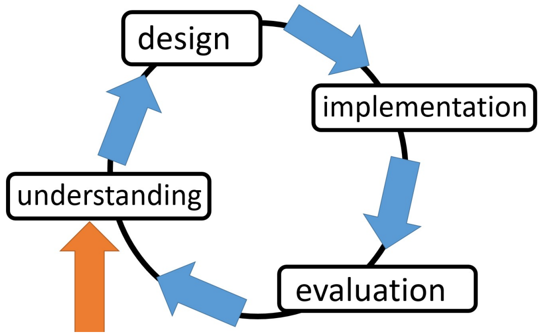

Figure 3. Basic steps in iterative tool building. The orange arrow indicates a recommended start point (see [3]).

monality in domain specific requirements and translate them into more well known tasks. But, getting the domain specifics correct can be challenging when visualization designers are not familiar with the domain. For example, in a design study on diabetes, Zhang *et al.* found that traditional visualization task abstraction methodologies were not sufficient to capture the complex relationships that exist between doctors, patients, log books, instruments, blood tests, backgrounds, and other sources [17]. They created a hierarchical task abstraction technique that allowed visualization experts to see and understand the relationships and interactions that exist between the tasks. *One of the interesting aspects that is often realized in this process is that there is no linear, repeatable, or predictable way to obtain and truly understand user needs and every visualization tool created captures this focus very differently.*

Readability criteria and aesthetic principles represent researchers' attempts to incorporate theoretical findings into their visualization designs. This is often a balance between scientifically derived visualization principles and hard-to-define design theories. This focus can utilize visualization design theory (e.g. [11]) and graph drawing aesthetics (e.g. [15]), but also input from psychology, cognitive science, art, and design. It is often noted that more work needs to be done in this area, particularly with trying to capture hard-to-understand design principles as they relate to connecting human interpretability, memorability, and usability with visualization techniques.

Tool Building Resources

Bostock, M., Ogievetsky, V., and Heer, J. (2011). D³ data-driven documents. IEEE TVCG, 17(12): 2301-2309.

Satyanarayan, A., Moritz, D., Wongsuphasawat, K., and Heer, J. (2016). Vega-lite: A grammar of interactive graphics. IEEE TVCG, 23(1): 341-350.

Encoding these criteria into algorithms synthesizes the often messy output of design criteria into executable code. This can be challenging and often boils down to the designers' judgement of "Does it look right?" Designers may manually run data through heuristics multiple times in order to get the right look. Studies and tools that open up this option space a bit more modularly do exist. For example, di Bartolomeo *et al.'s* [4] work on networks allows designers to experiment with combinations of readability, crossings, bendiness and groupings to optimize aesthetics and layout. This focus often requires mathematics and an ability to bring together user needs, design criteria, psychology and code.

Validation typically encompasses: (1) quantitative validation of measurable attributes such as speed and computational efficiency, often making use of statistical analysis, and (2) some combination of study design, observational techniques, and qualitative analysis.

Participatory Research and Co-Design with Communities The goals of the first three approaches frequently center on producing a tangible product and evaluating how effective a tool or technique is rather than, for example, learning about how people understand and think about problems or examining how communities function with visualizations in practice.

Although design studies and tool building often look at the journey rather than the end product, *there is still a large opportunity to leverage insights and exploratory outputs from qualitative studies that do not necessarily focus on a deliverable, and to take part in observational and investigatory work rather than the need to be "better" or "right"* [5], [10].

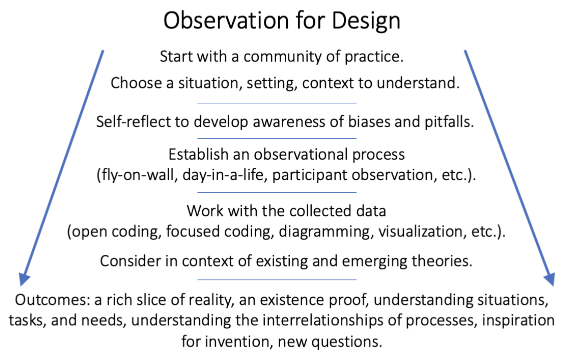

Figure 4. Observation for design is a possible approach when working with communities (see [3]).

Participatory research, instead, looks at how researchers work with specific communities of people, such as domain expert stakeholders or people who have relevant lived experiences (experience gained through first hand knowledge). These approaches prioritize human relationships, immersion, and deeply understanding how people want to use visualization in a particular context [7]. For example, in a health application, there are many communities who can have very different needs, such as the clinicians and the patients. Researchers collaborate with communities to better understand a problem and the rich complex contexts before addressing the problem itself. In this way, these studies aim to broaden our understanding of distinct communities and lived experiences, and focus less on building something that promises to be ideal or useful but gain rich insights into a specific reality, offering breadth and depth through the process [10]. Example steps for working with such communities are outlined in Fig. 4.

This approach embraces the idea that there is validity and power in the in-depth observation of just one case. Borrowing from the medical and education fields, individual patient or student cases may not fit a known model, but are nonetheless valid and important to understand. An interesting observation from researchers choosing this type of approach is that visualization in context can be completely different than the idealized or optimized visualizations published in the literature. This supports the need to create a place for research that captures unique observations.

We often value seemingly measurable concepts such as generalizability, scalability, and project impact. Yet, participatory research approaches show the importance of other research outcomes as well [10]. For example, qualitative studies and Research through Design (RtD) [16] are research processes that have to do with observation, trying something out, and reporting on what was learned through the process. These approaches may result in "one off" studies, but they are important research findings because they reveal how communities use and interact with visualizations in practice. There is tremendous potential for rich contributions using these research approaches and they should be more widely adopted in the VIS community.

Participatory Research and Co-Design with Communities Resources

Hall, K.W., Bradley, A.J., Hinrichs, U., Huron, S., Wood, J., Collins, C., and Carpendale, S. (2019). Design by immersion: A transdisciplinary approach to problem-driven visualizations. IEEE TVCG, 26(1): 109-118.

Hinrichs, U., El-Assady, M., Bradley, A.J., Collins, C., and Forlini, S. (2017). Risk the drift! Stretching disciplinary boundaries through critical collaborations between the humanities and visualization. Proc. Workshop on Visualization for the Digital Humanities.

Data Storytelling Storytelling, visual journalism, and data narratives focus on different research outputs. These approaches recognize the intrinsic value in narratives and voices that can be drawn out from the data itself, and, also importantly, from individuals. The core of storytelling centers two perspectives [9] (Fig. 5): (1) The story itself, building a narrative and shaping the way the narrative is presented, and (2) telling the story, the idea that there is an intended audience with whom the story will be shared. Who we tell the stories to, and who gets to tell stories in the first place, make a difference.

Participatory citizen journalism prioritizes the lived experiences of marginalized communities and provides an opportunity for people to tell their own stories rather than having an outside "expert" journalist retell their stories for them. Based on mutual respect, citizen

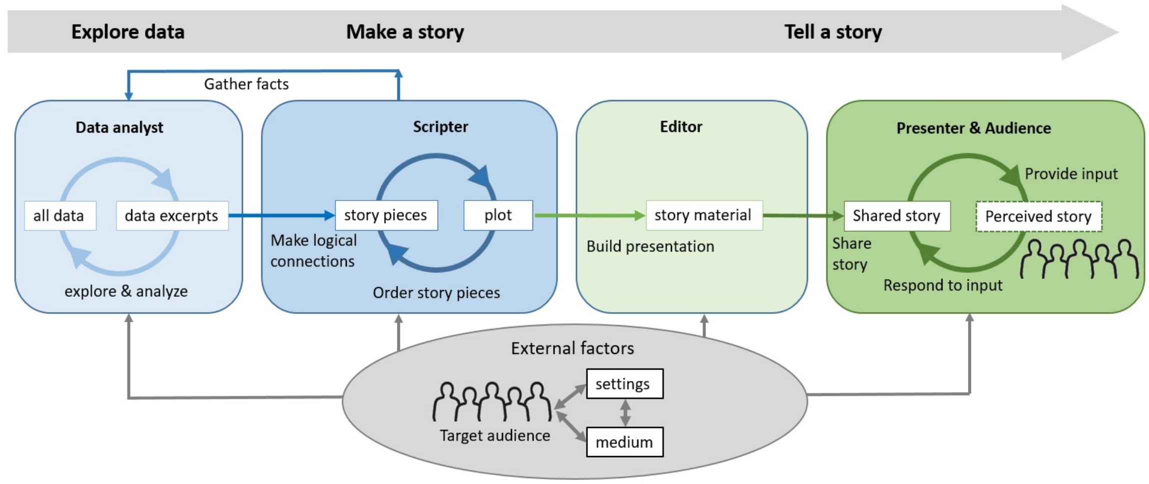

Figure 5. Data-Driven story telling. Diagram adapted from [9], (see [3]).

journalism honors the different ways people consume data based on their distinct contexts and needs by showcasing communities that are often excluded. These approaches aim to provide a platform for individuals to tell their own story through writing, spoken word, or photography and include their input throughout the research process. In this way, the role of the storyteller fundamentally changes the role of the researcher — from researcher acting as a conduit or interpreter of people's needs and lived experiences to a facilitator and a co-designer. The first-hand stories reveal new knowledge to the researcher and the co-designers' ongoing participation provides iterative design feedback wherein new knowledge is cyclically sought and found. For instance, through an online platform designed with members of the disabilities community (https://disabilityjusticeproject.org/), people with disabilities can share their stories by using a website with accessible visualization design choices. Participatory research approaches inform the visualization community with contextual knowledge for more equitable research and design. These are not "one-off" cases — they are examples of what researchers learn by working with marginalized communities to better understand distinct community contexts, experiences, problems and needs.

Another approach within storytelling is visualizing data in ways that intrinsically express a narrative. Here, researchers strive to

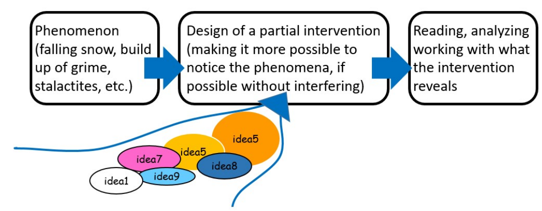

Figure 6. This diagram merely emphasizes that the design thinking process is concentrated in making the phenomena noticeable, (see [3]). For autographic design process diagrams see [12].

show linear narratives through a combination of viewing time, space and position, so that viewers can see a story through a data set's trajectories over time. This type of work makes an attempt to capture ideologies in politics through visualizing text from speeches or debates, for example, or belief systems, sentiments and theories.

Participatory citizen journalism approaches increasingly straddle disciplines ranging from natural sciences to mathematics, statistics, psychology, political science and journalism, disciplines that differ in their acceptance criteria and measures of rigor. *In these unfortunate cases, by focusing on the methods or techniques to visualize data, the VIS community may be discarding valuable insights, inferences, and narratives that are produced from the data.*

Data Storytelling and Autographic Design Resources

Riche, N.H., Hurter, C., Diakopoulos, N., and Carpendale, S., eds. (2018) Data-driven storytelling. CRC Press.

Hanrahan, P. (2004). Self-illustrating phenomena. Proc. IEEE Visualization.

Haroz, S., and Ma, D. K.-L. (2006). Natural visualizations. Proc. Eurographics, 43–50.

Autographic Design Autographic Design [12], which is the act of self-writing or self-inscription, offers a different way of thinking about the problem of representing data. This approach seeks to expose and present physical traces of phenomena to show evidence or reveal something interesting. With Autographic Design, researchers focus on the idea of expressing data through natural units and structures of the world, rather than on mapping or representing data artificially (see Fig. 6). The natural world captures reality and offers this in ways that are experience-able. The ways that these experiences occur differ in such areas as climate change, health, air pollution, and ozone pollution. For example, air pollution leaves deposits on the buildings but may need interventions (e.g. a patterned stencil that is removed after a prolonged period) to enable humans to recognize the build up over time.

The directness of this approach stands in contrast to what we traditionally consider visualization, where there is a mapping between an abstract representation and the underlying natural phenomenon it represents. People can use physical traces much like the intentionally designed visualizations and increasingly in place of them altogether. They act as mechanisms for understanding often complex systems in simple and exploratory ways. The importance of this approach is that traces are not representations at all and do not stand for something else. In fact, they stand for themselves and act as a first-hand account of the effects of a system. People make sense of these glimpses of natural data in interesting ways that can, in fact, inform and add to the discourse within the visualization community. However, because visualization is often so focused on data mapping and data representation, this type of approach is often overlooked.

Discussion

Approaches to visualization are rarely exclusive or independent. There are countless variations of approaches with commonalities in their challenges and contributions; the differences can be nuanced rather than stark. For example, tool building may involve a form of a design study but a design study may not always produce a tool. Understanding these overlaps and differences can strengthen visualization studies and help the community break away from the idea of rigidly evaluating studies based solely on the perceived paper or study type.

For each of us, understanding approaches used in other disciplines opened our eyes to new possibilities. Approaches that we had never before considered struck us as interesting and informative. Yet many of these approaches are uncommon at mainstream visualization conferences. Should these and other approaches be welcomed in VIS? We think so.

Therefore, we envision bringing more voices and expertise to the VIS community. We imagine leaving the office environment to learn and collaborate with the general public who are experts in local knowledge and context. We call on the VIS community to involve a broader set of reviewers and practitioners to represent the multitudes of approaches in VIS and to offer suitable guidance for approaches from different domains. The full scope of what is valued as visualization in the world at large inherently values the differences in approaches. However, only a subset of research approaches are commonly represented at VIS conferences such as IEEE VIS and EuroVis. We suggest showcasing more research approaches and outputs to expand and strengthen cross-disciplinary diversity at the conference and to enable connections for new ideas and collaborations.

If we look introspectively at the paper review process, are there road blocks or practices that prevent disciplinary diversity? How can we review, categorize and critique research in meaningful and constructive ways while avoiding conformity and allowing new ideas and approaches? How can we accept and understand these new approaches, leverage the diversity that exists in our community, and, at the same time, maintain research rigor? We offer the following recommendations to future reviewers and researchers:

Focus less on paper types. Paper types, which are used in the call for papers (CFP) and in the review process at IEEE VIS and EuroVis, may restrict and structure research in unintended ways that may discourage contributions that have not been previously been considered. Reviewing based on a paper's type may overly focus a reviewer on the wrong outputs of a research contribution that does not cleanly fit into one canonical type. Paper types may have value as training mechanisms for new visualization researchers to understand different ways papers can be structured. One idea that may at first seem like a practical way to rapidly induce change would be to simply add an "other" category. Though easy to implement, this would not achieve the goal as it potentially would treat these authors as intrinsically different from authors submitting defined paper types. In short, people could feel "othered", violating principles of inclusion. Instead, changing language in CFPs and review instructions towards treating paper types as examples in a broader space of possible contributions, rather than stringent review structures, may be a step towards encouraging new and unexpected papers.

Encourage qualitative studies. We see gaps in the visualization literature with understanding intangible aspects of how individuals interpret, understand, and use visualizations, yet the difficulty of getting qualitative studies published is perpetuating this. Qualitative studies add rich context to the community. In many qualitative studies, rigor, objectivity, and validity may emerge through the acknowledgement of researcher bias during the study, and research claims can be validated by researchers who share their qualitative findings with study participants to confirm the researcher's accuracy [5]. Scalability is not usually a goal in qualitative studies.

Allow reporting of research failures as well as successes. Because of the interdisciplinary nature and young age of the visualization community, we encourage papers that include lessons learned and research failures as well as successes. Much can be learned from research failures; such papers can drive debate and inspire new questions.

Consider more research contribution types. Expanding contribution types has been recommended previously [8]. A combination of different visualization problems, approaches, and research outputs can drive many different contributions. For example, qualitative studies may not map to a stringent type of output. Furthermore, we should recognize the potential for new contribution types that have not yet been considered.

Embrace unfamiliar and unusual methodologies. We encourage reviewers and researchers to understand that every piece of research is unique and may require an equally unique approach. If we truly want diversity of thought in the visualization community and if we understand that visualization borrows from so many disciplines, then we must encourage diverse, creative, and novel approaches.

Include reviewers from different disciplines. IEEE VIS, for example, is heavily weighted towards people with a background in computer science. While creating a culture shift in visualization will take time, we suggest additional support and resources for reviewers who may not have an in-depth understanding of research methodologies outside of computer sciences. For example, many VIS reviewers validate research studies based on measurable factors such as sample size, which is important for statistical significance in certain kinds of quantitative analyses. However, in other domains, even one participant may be sufficient to study human phenomena. Evidence of rigor may take many forms, such as in-depth interview methods, thoughtful research through design processes, or co-creation methods that address distinct research questions and values. Reviewers from other disciplines are needed to help validate research methods in the context that they are written within rather than through a specific research lens.

Actively welcome diverse perspectives. The world is increasingly focused on embracing social diversity. Towards this end, we advocate for including as many perspectives as possible, such as people with disabilities, the LGBTQIA2S+, BIPOC communities, feminist perspectives [5], emerging challenges to research methodologies [14] as well as careful consideration in the use of data through the CARE [2] and FAIR [6] principles.

Conclusion

Visualization research has many challenges, approaches, outputs and contributions. We highlighted disciplinary diversity, showing that there is more than one way to look at visualization research. Embracing this diversity has the potential to strengthen and broaden the VIS community and its capacity to generate knowledge. More perspectives in problem-solving will contribute to more ideas and a richer research context. We invite you, the reader, to join us in encouraging and welcoming research approaches from any discipline to contribute to the exciting field of visualization. Our voices alone are not enough.

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