Cultivating Climate Action Through Multi-Institutional Collaboration: Innovative Data Visualization Educational Programs and Exhibits for Public Engagement

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Abstract

This paper details the development and implementation of a collaborative exhibit at Boston's Museum of Science showcasing interactive data visualizations designed to educate the public on global sustainability and urban environmental concerns. Supported by cross-institutional collaboration, the exhibit provided a rich real-world learning opportunity for students, resulting in a set of public-facing educational resources that informed visitors of global sustainability concerns through the lens of a local municipality. The realization of this project was made possible only by a close collaboration between a municipality, science museum and academic partners, all who committed their expertise and resources at both leadership and implementation team levels.This initiative highlights the value of cross-institutional collaboration to ignite the transformative potential of interactive visualizations in driving public engagement of local and global sustainability issues. Focusing on promoting sustainability and enhancing community well-being, this initiative highlights the potential of cross-institutional collaboration and locally-relevant interactive data visualizations to educate, inspire action, and foster community engagement in addressing climate change and urban sustainability.

Index Terms: Data visualization, interactive design, climate, sustainability, education, city government, museums, open data.

1 Introduction

In response to the pressing need for innovative approaches to climate education and action and with the support of municipal, museums, and academic experts, an educational program was developed in which university students created a series of interactive data visualizations that constituted a new exhibit on sustainability and community well-being. The collaboration between the Museum of Science, the city of Boston, the joint MA in Design Engineering (MADE) program at Brown University and the Rhode Island School of Design (RISD), and the Berkman Klein Center for Internet & Society at Harvard University (BKC), brought together a network of experts who supported the students to consider how open data can fuel visualizations that that inspire museum visitors to reflect upon their urban spaces in new, more agentic and sustainably-focused ways. This work extends the findings from the Viz4Climate 2022 workshop by demonstrating how interactive visualizations can enhance public understanding and engagement with climate data, integrate thoughtful consideration of ethical guidelines of technology, and use visualization as a tool to engage public audiences [41]. Specifically, the project aimed to inspire both the student exhibit designers and the museum audience to consider how city and other data can help us to understand, interpret, participate and effect change to benefit local urban environments, and to encourage them to embrace hope and agency regarding a sustainable future. The project demonstrates 1.) how building strong cross-sector partnerships can lead to impactful educational outcomes by bridging academic research with public education [15] and 2.) how providing students with real-world, cross-disciplinary, locally-grounded projects provides rich learning opportunities that foster innovation and creativity in visualization design [5].

Our project builds upon previous work in data visualization, public engagement with science, and sustainability education. Interactive visualizations have shown potential for engaging public audiences with complex data [23, 30, 40]. Science museums have pioneered innovative approaches to public engagement, with research emphasizing the importance of interactive, self-directed experiences [20]. The communication of climate and sustainability data has been explored through various visualization techniques [31] and strategies for non-expert audiences [6]. Our work applies these insights to urban sustainability in a museum context. Cross-institutional collaborations in higher education have been shown to foster interdisciplinary thinking and real-world problem-solving skills [10]. Our project extends this model to include academic institutions, a museum, and city government.

The remainder of this paper is composed of section 2 on the collaborative framework and methodology, section 3 on the educational program itself, section 4 on the exhibits presented at the museum, section 5 and section 6 the impact and lessons learned, and section 7 on challenges and future directions.

2 Collaborative Institutional Framework

Though trust in many groups and institutions [36], including educators and scientists [27], higher education [12], and government [33], has decreased in recent years, science museums have fared better than other contexts [2]. Science museums still serve as valued institutions where the public engages with scientific knowledge and innovation. By working with public-serving institutions such as museums, civil society, municipalities, academic institutions can bring collaborators' expertise and resources to benefit public understanding of complex scientific concerns that have societal and environmental impact. Based on this, institutions can encourage the public to take action including engaging with civil organizations and government.

The collaboration involved the Museum of Science, the City of Boston, MADE program at Brown University and RISD, and the Berkman Klein Center at Harvard University (BKC). The program was initially developed as a collaboration between academic leaders at MADE and BKC, building the effort across their formerly distinct programs [14, 9]. The independent programs have commonalities in their educational philosophy, expertise, and student backgrounds, The MADE program supported the first educational phase of the project via the first author's winter term course, and subsequently provided advising focused on creating compelling data-driven visual and interactive narratives. while BKC offered their existing Research Sprint program [9] for the second educational phase, as well as their expertise in ethical technology use, ensuring that the data visualizations were responsible and respectful of indi-

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vidual rights. The Museum of Science offered both their expertise in public science communication and their platform for public engagement on a topic that aligned with their 'Year of the Earthshot' [35]. The City of Boston provided access to and advice regarding their Analyze Boston open city data initiative [3].

3 The Educational Program

3.1 Introduction

Technological tools that use city-based data are encoded with the value systems of their designers. These value systems often prioritize efficiency, usability, productivity, and profit rather than including personalization and delightful experience of urban space. Based on a planning phase and subsequently across two phases of educational programming, students engaged in dialogue about the values-based design and ethical technology and to generate outputs that reflect playfulness, joy and sustainability in urban spaces.

In the planning phase, the co-authors explored how to bring their two distinct programs with differing program goals and team together, established a series of collaborations with partners, and built out the content of the program. Then the first educational programming phase was an intensive month-long design investigation month focused on data selection, cleaning, analysis, and developing the initial visualization concepts. The first educational phase was composed of a student cohort of design engineering graduate students from the MADE program while the second educational phase was composed of a subset of these students along with a new cohort of Harvard undergraduate and graduate students from a range of disciplines, schools, and programs. The second educational programming phase was an eight-week series of topical discussions and working sessions designed to support the creation of the visualizations and associated exhibit materials.

3.2 Pedagogical Approach

The pedagogical approach integrated multiple learning theories and practices, primarily grounded in experiential learning theory [29], project-based learning [39], user-centered design and design thinking [13]. The program structure allowed students to engage in iterative cycles of experiential learning, aligning with Kolb's revised experiential learning theory [28]. Each cycle involved:

- Concrete Experience: Students worked with real urban datasets [1] and interacted with museum visitors;
- Reflective Observation: Weekly reflection sessions and design journals facilitated critical analysis of experiences [37];
- Abstract Conceptualization: Expert panels and working sessions fostered the development of new ideas and approaches;
- Active Experimentation: Students iteratively refined their visualizations based on feedback and observations; and
- Renewed Concrete Experience: The second museum presentation allowed for a new cycle of experience and learning.

This iterative approach aligns with design-based research methodologies [4], enabling continuous improvement of both the educational process and the resulting exhibits. The project also incorporated elements of problem-based learning [7], with students addressing real-world sustainability challenges posed by city experts. This approach fostered the development of critical thinking and problem-solving skills in authentic contexts [24]. Student reflective practice through design journals and weekly reflection sessions, promoted metacognition and self-regulated learning [42]. And iterative design based on expert feedback and visitor interactions, promoted principles of user-centered design [32].

For public learning, we drew on principles of informal science education [18] and public engagement with science [26]. The student-created exhibits served as boundary objects [38], facilitating knowledge transfer between experts (students) and novices (museum visitors). This approach leverages the concept of cognitive apprenticeship [17], where visitors learn through observation, coached practice, and participation in authentic scientific visualization practices. This multifaceted pedagogical approach aimed to create a rich learning ecosystem that benefited both students and museum visitors, fostering knowledge co-creation and public engagement with complex sustainability issues.

3.3 Planning Phase

Nine months before the launch of the first educational phase, the two co-authors worked together to determine how to design a set of educational programs, associated curricula, potential collaborators, and team roles. The co-authors identified the educational, organizational, and output goals, the resources that each program and team could bring to bear, and their existing engagement with museum, municipal and domain experts. All partners contributed their time to the project. The educational program was designed to span 14 weeks: Phase 1 consisted of a 4-week intensive phase (60 in-class hours and 60+ hours out of class) and Phase 2 involved a 10-week development phase (10-12 hours/week), aligning with best practices for immersive learning experiences [22] and allowing sufficient time for deep learning and skill development [19].

Given the complexity of the project and the number of partners, the Phase 2 collaboration was enabled by the capacity of BKC educational staff to facilitate by establishing program milestones and deadlines, organizing project meetings, managing relationships, and more. Similarly, the length of the planning phase was necessary in order to 1.) properly engage the partners on the project and establish methods of collaboration, 2.) engage speakers to speak at specific predetermined session times who may have constrained schedules, and 3.) complete the application process for the second phase of educational programming. The second phase of the educational program was built into an existing student application-based not-for-credit educational program at BKC, the Research Sprint program [8]. Programs such as this one require longer lead times due to the application announcement, intake, review, and acceptance process.

3.4 Program Phase 1: Exploring and Selecting Data and Conceptualizing Value-based Design Approaches

In the first educational phase, students were guided by city experts, designers, and data scientists as they learned the principles of data-driven storytelling and developed data, recommendations, and initial visualization concepts for use in Phase 2. They were presented with a project design brief that asked them to recommend topical areas and approaches to data visualization that addressed how data-driven systems for the city of Boston could be designed for a broader set of human values, including personal and social enjoyment. Students were prompted to foreground the agency and safety of residents, and to create projects that encouraged personal connection, well-being, and involvement in sustainability of the shared environment and promoted justice and inclusivity.

The cohort for the first phase was composed of twenty-two students from the MADE program. With support from experts from the city of Boston including its Chief Information Officer, the students examined multiple datasets from Analyze Boston to determine which were best suited to support the exploration of delightful, personal, and sustainable interactive data visualizations of the city. Having access to Boston's CIO team provided essential guidance on strengths, biases, and limitations of the data. For example, in a dataset on sidewalk maintenance requests, it initially appears as if there are more cracks appearing in one city area compared to others. After talking to the people who prepared that dataset, students learned that wealthier areas of the city are often more likely to report issues like sidewalk cracks. Since the city's open data is expansive and not all is of interest for the goals of the projects, students were encouraged to explore a specific subset of data. These data included transportation modes and usage, building energy usage, shade canopies locations, sidewalk accessibility, climate risk levels, farmers markets, crime, and bike-share trip histories. The students crafted comprehensive descriptions, evaluated the strengths and weaknesses of each dataset, aligned them with the design project brief and came up with suggestions for Phase 2 such as reimagining the concept of the CityScore [16] for sustainability and community engagement goals. The CityScore was originally designed to help inform the Mayor and city managers about the overall health of the city by aggregating key performance metrics into an easier to track number. This phase culminated in a set of deliverables that provided a foundation for subsequent work in Phase 2 by the BKC research sprint participants.

3.5 Program Phase 2: Expert Input and Exhibit Development

In Phase 2, a diverse cohort from Harvard University joined a subset of the MADE students. The students who were invited to apply from participating universities were selected to have complementary backgrounds in data visualization, data science, community engagement, and public policy, which not only created richer team experiences for the students but more meaningful and well-designed data visualizations. The MADE students were distributed across teams to ensure that knowledge from Phase 1 carried over to all teams in Phase 2.

Figure 1: Visitor interacting with 'Boston on the Move' data visualization presented in its final form

The BKC Research Sprint program employs an explicitly participatory model to approaching issues on the frontiers of rapidly changing fields, from sustainability to education innovation to democratic reform [8]. Student participants are put in active dialogue with experts and then create an output based on what they learn. In a series of eight two-hour educational sessions students learned about data visualization, exhibit design, and the ethical use of technology. In these sessions, over twenty global experts including academics, municipal governmental leaders, museum exhibit developers, artists, educators, and design practitioners spoke in an interactive panel format and joined students in small groups to provide feedback on their projects. The experts challenged students to 1.) think critically about balancing the benefits of data-driven tools for public education with the need to minimize associated risks and harms, 2.) consider when to design for convenience and when to design friction into an experience, and 3.) examine how data-driven visual and interactive design can play an essential role in public education [11]. After the formal program ended, the students had two additional weeks to polish their exhibit materials before they first presented it on the museum exhibit floor.

As students developed their projects, weekly critiques from organizers and expert guests emphasized clarity, relatability, and ethical considerations in visual design to enhance public understanding and encourage a sense of optimism and agency to inspire behavioral change [41]. The weekly time commitment for students was typically ten to twelve hours including two-hour weekly session, two to four hours of readings, audio and video, two-hours of assignments, and the remaining time on project work. Readings and assignments were front-loaded in the program and by the last three sessions having no additional assignments beyond the project work.

Community engagement was a core aspect of our project. Interactive elements allowed visitors to contribute their own data and feedback, which was then integrated into the visualizations. This participatory approach not only increased engagement but also provided valuable insights into public perceptions and concerns. The dynamic interactions between students and museum visitors and the educational impact of the exhibits were seen across the two occasions that the work was exhibited at the Museum of Science.

Real-time feedback from museum visitors, including diverse demographics, was crucial in refining the visualizations between the two exhibits. Students adapted their interactives based on this feedback, enhancing the exhibits' effectiveness and engagement. This iterative design process, based on real-time feedback, highlighted the importance of user-centered design in educational exhibits [34].

4 The Exhibit

The exhibit was presented at the museum twice, first as a soft launch during which students edited their work and second as a formal launch. During the planning phase, the team worked with the museum to select exhibition dates that would maximize engagement with the general public and improve the exhibits based on the public feedback (see Figure 1).

To meet this public feedback goal, both presentations of the exhibit occurred during two of the busiest times of the year at the museum: 1.) during the public school vacation week for all Boston and the vast majority of greater Boston- area schools and, 2.) two weeks later as part of a special event weekend, 'Rise Up Boston', which brought together many nonprofit museum partners who work on issues related to local and global sustainability.

The exhibit featured five interactive visualization projects, each created by a different student team composed of both MADE and Harvard students with a range of technical, design, policy, and social science backgrounds. The five interactive visualizations were:

1. Boston on the Move: Explored transportation themes through a gamified interface.
2. Boston Shorelines: Visualized past, present, and future coastlines.
3. Landmarks of Boston: Highlighted the city landmarks process, allowing visitor suggestions.
4. Roots of Boston: Revealed the impact of urban trees.
5. Why We Gather: Investigated public gathering spaces.

Figure 2: 'Boston on the Move' interactive visualization display

"Boston on the Move" (see Figure 2) was an interactive explored themes of transportation, congestion, and equality of commuting times through a gamified interface that invited visitors to estimate how long different modes of transportation take, with the results often being counterintuitive which provoked questions and conversations (Figure 1).

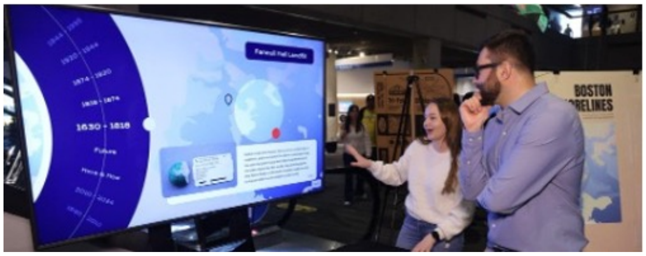

Figure 3: A student sharing the team project 'Boston Shorelines'

"Boston Shorelines" visualized the evolving contours of the city's coastline in response to climate change (see Figure 3). Visitors could explore sea levels and shorelines of the past, present, and future. This student group was surprised to learn how dramatically and frequently Boston's shorelines have changed and how much of this change has been shaped by humans. The exhibit also helped visitors to imagine how they could play an active role in the future of the shoreline. This part of the interactive shows the history of the shoreline over centuries.

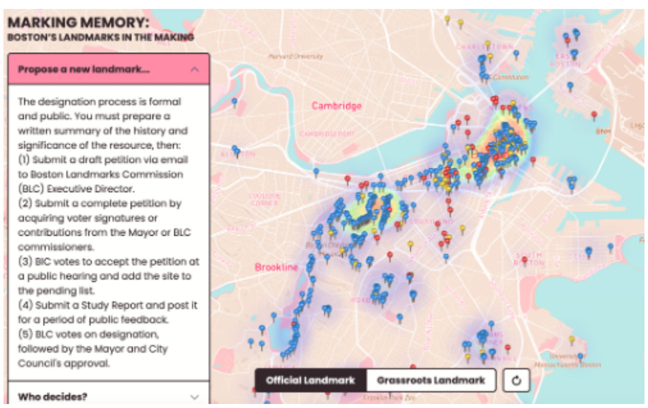

Figure 4: 'Landmarks of Boston' interactive data visualization of the interactive shows the history of the shoreline over centuries

"Landmarks of Boston" used geospatial data to highlight historical and cultural landmarks (see Figure 4) by presenting the city's history of landmark creation, location, and meaning. While some landmarks inspire broad agreement, this exhibit highlighted how the city landmarks process can feel arbitrary or opaque. Landmarks are meant to represent a shared understanding of what and who is worth memorializing and why. The students's clever and fun interface allowed visitors not only to engage with the past, but also to participate in the future by suggesting their own landmarks. Visitors responded by proposing places that fit more traditional ideas of landmarks in addition to places with more personal memories, such as the ice cream truck they remember from childhood or the restaurant with the best ramen.

"Roots of Boston" revealed the secret lives of the city's trees and their impact on the urban ecosystem (see Figure 5). Starting with the city's shade canopy data, this team developed a broad understanding of the histories and futures that city trees bear witness to. Trees from different parts of the city welcomed visitors to learn about the city from the trees' perspective. Visitors who explored the exhibit in depth would come upon hidden gems, strange tree

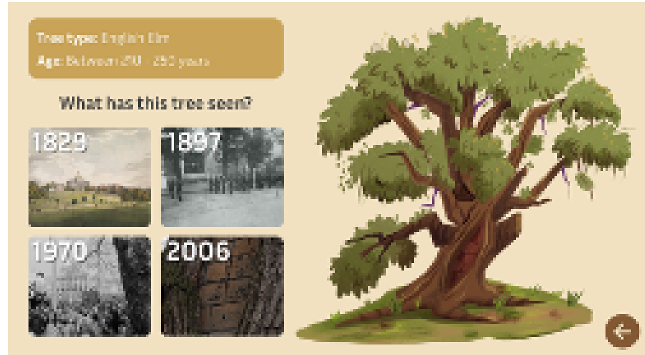

Figure 5: Screen in storytelling sequence of a tree in 'Roots of Boston'. The team combined hand-drawn trees with historical photos

stories that visitors could learn about if they queried 'after dark' tree stories.

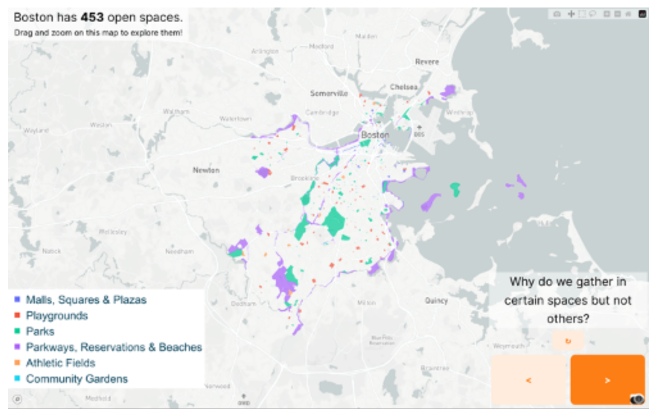

Figure 6: 'Why We Gather' interactive data visualization

"Why We Gather" investigated the availability, distribution, and social dynamics of public gathering spaces and their significance to community life (see Figure 6). Visitors could select categories of gathering spaces that they enjoy, such as food and beverage areas, parks, and active areas. They discovered in their data exploration a composite measure, called an 'activity score' that incorporated several types of activities that a gathering space activated, and brought this to life for museum visitors.

To encourage easy relatability, visitors could do this simply for the purpose of discovering a new (to them) gathering space related to their interests, as they might on a website, but in this team's design, visitors would soon encounter friction that also exposed them to broader gathering space themes that this team wanted to inspire dialogue around. Radial bar graphs and combined multiple datasets told a complex data story in an accessible and streamlined presentation (Figure 7).

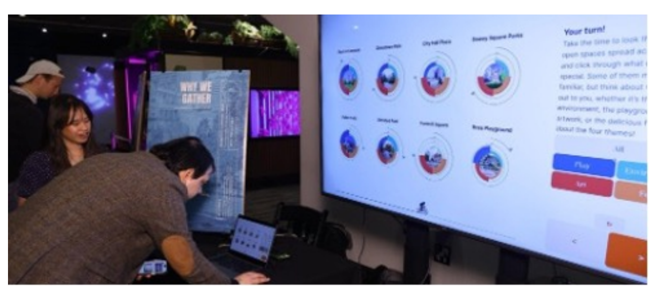

Figure 7: A student observes a visitor interacting with radial bar graphs from the 'Why We Gather' interactive

5 IMPACT AND LESSONS LEARNED

5.1 Openness to Learning

While trust in educators, higher education, scientists, and government has declined in recent years, science museums have maintained higher levels of public trust compared to these other institutions, and this provides an opportunity. Museum visitors may come to museums to be inspired and to learn. Thus, the museum context provides an opportunity to engage both local and global visitors to build awareness of climate and sustainability issues, and to call for action to a potentially responsive audience.

We observed deep engagement in climate and sustainability issues not only through the student exhibit but also with other community partners in the museum's Rise Up Boston weekend. Bringing together multiple partners with different but complementary approaches and calls-to-action is one potentially powerful approach towards environmental change and sustainability.

5.2 Iterative and Participatory Design

User feedback and iterative design are critical to realize effective, accessible and impactful data visualizations. Perhaps the students' biggest takeaway was how much they learned by taking an interactive and participatory design approach and how much these learnings impacted and improved their creations (see Figure 8).

Figure 8: A student observes a visitor interacting with the 'Boston on the Move' data visualization installation

In order for the interdisciplinary teams of students who had varying experience in interactive design and audience feedback to gain all necessary skills for the project, we assigned readings and resources that provided foundations of usability, exhibit content development, and ethical considerations in data visualization. The materials included a usability testing checklist, which the students were assigned to use and self evaluate. The exhibit content development materials highlighted the need for clear, engaging, and inclusive content development in educational visualizations. A diagnostic report created by the city of Boston about its surveillance landscape, aligning with session discussions on ethical data sourcing, use and transparency. Materials on engaging museum visitors compared different strategies for engaging museum visitors with scientific data, supporting the idea of diverse approaches to enhance engagement. Inclusive design frameworks provided guidelines for creating welcoming and accessible exhibits, reinforcing inclusive design practices.

Throughout the development process, the students received feedback about their specific projects. The project requirements included three milestones and after the students completed each milestone, they received feedback both from the instructors and sprint speakers who included experts in children's media, data visualization, museum exhibit design, museum education, municipal open data, and science communication. Additionally, they were offered additional feedback sessions with experts, which most teams requested.

After the first day of soft launch of the exhibit, students revised both their interactives and their presentation of the interactives based on their experiences on the museum floor with visitors. Though the students received feedback from experts throughout the process, nothing was more informative for the students than seeing people, young and old, interacting (or not interacting) with their creations. The details of these experiences are discussed in detail in the following section.

The expert and end-user feedback is complementary. Experts are able to not only share what they know but also help the students to learn how to interpret the rich but often complicated and self-conflicting feedback they receive from users. In particular, students who have limited experience with end-user feedback benefit from the context and wisdom of expert practitioners.

5.3 Real-World Experience

Engaging with real audiences provided students with a deeper understanding of how to communicate complex climate data effectively, fostering a stronger connection between education and public engagement. Though the students took in and believed what they heard experts tell them, particularly the museum and other educational and data designers, they applied and deepened their learning through interacting with museum visitors.

Many different kinds of people come to museums with different goals and interests. Understanding and engaging diverse audiences is crucial. Students learned to tailor their presentations to different age groups and backgrounds, making complex data accessible and engaging.

One critical lesson that students reported learning serves as an example. Throughout the program sessions, students were told that museum visitors typically spend only seconds on a given exhibit and that exhibit designers advise a limit of one or very few learning goals per exhibit. The students kept this in mind throughout their design process but rapidly pivoted the first day with a museum audience. Some changed the start screens of their creations, others eliminated text on screens and all dramatically decreased their verbal introductions to the project (see Figure 6).

At the same time, since museum visitors were primed to be inspired and to learn, the interaction between visitors and students sometimes led to a virtuous cycle in which the eagerness of the students deepened the interaction with the visitors. Many of our students not only reported that this was the first time in their education that they had a real-world experience but also how different it was to build something that was designed to learn and inspire, rather than a more conventional industrial application that might have envisioned creating in the future.

5.4 Career Pathways

Students are well aware of the typical industry pathways available to them after graduation and are eager, or sometimes nervous, to find a job that provides financial sustainability. These students may wish to make a positive impact on sustainability and the environment but are unaware that these pathways exist or whether they are financially realistic. Highlighting diverse professional pathways that combine design, data science, technology, and sustainability is both essential for attracting talent to work on important multidisciplinary problems and for helping students learn about careers that relate to their varied interests.

This project connected students with experts outside of the paths the students imagined for themselves, providing models of professional pathways with cities, museums, nonprofits, education, design, policy, and independent work. They saw that organizations need people who have the very skills the students were developing:

data design, data visualization, and data science. And they experienced the excitement of working with audiences, such as museum visitors who seek to be inspired. These glimpses into the impact they can have may inspire them to pursue career or side projects that contribute to climate action and sustainability.

5.5 Reflections on What We Would Do Next Time

Reflecting back upon the experience of developing this project, we would build upon what we learned, continuing and repeating some aspects while modifying others.

In our debriefing sessions, all participating leaders felt that this partnership with museums and municipalities was valuable, and worth repeating as evidenced by joining the start of a new planning cycle iterating on this framework for a new project. The team agreed that next time we would expand the students' experiences with both museums and municipalities. We would engage with the audience earlier and more frequently, which would not only provide a rich learning experience for the students but also result in better work. Although the first version contained participatory design opportunities, in subsequent programming, we would add at least one more participatory cycle, and provide more time between cycles to allow students to take in the feedback and refine accordingly. Additionally, the museum has greater capacity to teach and mentor students than was deployed in this first project. If we were to do this again, we would integrate this capacity more throughout the program.

Similarly and as discussed in section 5.3, providing students with real-world experience was invaluable and should be expanded. Feedback from students and faculty and staff observations confirmed that engaging with a live audience provides a diversity of surprising insights that can't be replicated in a controlled environment. When we first launched this program, we wanted to include an early observation session during a period of peak museum attendance but were unable to fit it into our short program. In a future, expanded iteration, we would include this early observation session and potentially also a second session in which students could interview museum visitors about design ideas in the earliest stages of their design process.

Across science museums, visitors spend limited time on a given exhibit, and visitors to the Museum of Science spend only seven seconds on average with an exhibit [21]. As a result, our museum colleagues emphasized the importance of prioritizing one to three key messages for the vast majority of visitors. Yet students were excited to provide rich and deep experiences with topics that fascinated them. As soon as the students observed museum visitors with their data visualizations, their minds were immediately changed and they revised their work accordingly. If we introduce participatory design methods earlier, students will simplify the exhibit messaging from the onset, and provide more layered learning designs, instead of having to redesign. We would also create a new project milestone solely focused on learning goals, rather than having the learning goals as part of a larger exhibit design milestone. We would ask students to return to their defined learning goals throughout the design and development process. Based on many of the reflections detailed here, we will likely fully integrate this framework into a for-credit, semester-long course rather than the original mix of short winter intensive course and extracurricular research sprint. Given the value we experienced from a partnership-based approach, this could eventually become a course that brings together students from several institutions, each focused on their unique local sustainability issues, to create delightful, inspiring, and agentic public engagement projects.

6 Lessons for Other Institutions

The "Visualizing Boston's Urban Spaces" project provides valuable insights and practical lessons for other institutions looking to leverage data visualization for climate action and sustainability education. By reflecting on the challenges and opportunities highlighted in the IEEE paper "Challenges and Opportunities in Data Visualization Education: A Call to Action," we can distill several key takeaways that are broadly applicable [5].

6.1 Embracing Diversity and Inclusion

One of the central themes in data visualization education is the importance of embracing diversity and inclusion. This project demonstrated the effectiveness of involving a diverse group of students from multiple institutions, including the MADE program at Brown University and RISD, and the Berkman Klein Center at Harvard University, in collaboration with experts from museums and municipalities. The student diversity, characterized by personal identity, nationality, home locality, discipline, professional experience, and personal experiences, enriched the project by bringing together varied perspectives and skill sets, fostering innovation and creativity in the visualization designs. Museums and municipalities bring specialized expertise and practice that both improve the student experience and the outputs. Museums' resources include expertise in science and other public communication, informal education, museum exhibit design and development, knowledge of the diverse members of the public who come to the museum, how they interact, and what they value, and substantial practice of providing experiences for the public. Municipalities understand the needs, priorities, identities and values of their constituents, the resources, policies and priorities of the governments, and the methods by which the public can engage with cities.

Recommendation: Institutions could actively seek to include participants from diverse backgrounds and disciplines in data visualization projects [5], ensuring that teams include a range of complementary skills and backgrounds. Working with museums and municipalities can have synergistic effects for all partners, the students, and, therefore, improve outputs. This approach not only enhances the quality of the outputs but also promotes a learning environment that prepares students to address real-world challenges and for the reality of many professional workplaces.

6.2 Building Communities and Collaborative Frameworks

The collaboration between academic institutions, the city of Boston, and the Museum of Science exemplifies how building strong partnerships can lead to impactful educational outcomes. Successfully working across organizations requires effort, clear communication and trust in both the individuals and organizations involved. It is not easy to do; people, particularly those in nonprofits and government, are often tasked with many socially important initiatives that vie for their time. However the scaling, impact, and organizational learning benefits are profound.The participatory model employed in the MADE program studio course and BKC Research Sprint facilitated active dialogue and co-creation between students, academics, and practitioners, resulting in practical and actionable outputs.

Recommendation: Institutions should form partnerships with museums, municipalities, and civil society to leverage their resources for greater locally-focused public engagement and benefit. Eventually, these institutions might partner across locations both for the benefit of their educational participants and broader understanding of regionally relevant sustainability planning. Other institutions could consider adopting a collaborative framework that involves partnerships with external organizations, such as museums, governmental agencies, and nonprofits. These collaborations can provide students with real-world contexts and resources that enhance their learning experiences and the relevance of their work.

6.3 Leveraging New Technologies and Interactive Tools

The project underscored the importance of utilizing new technologies and interactive tools to create engaging and informative visualizations. The use of touchscreens, interactive maps, and dynamic visualizations allowed visitors to explore complex data in an accessible and engaging manner. When investing in these tools in partnership with other organizations, consideration for the other organizations' constraints and preferences must be co-examined. For instance, currently some museum partners may be more prepared to host screen- or projection-based experiences at scale more than XR visors.

Recommendation: Institutions should invest in and encourage the use of advanced visualization technologies and interactive tools that make engaging with real data more accessible [25]. These tools can make data more comprehensible and engaging for diverse audiences, fostering deeper understanding and engagement with the issues at hand, as long as they work for all partners involved.

6.4 Engaging in Iterative and Participatory Design

The real-time interactions between students and museum visitors provided invaluable insights that helped refine the visualizations, making them more effective and impactful while also enriching the student learning experience.

Recommendation: Institutions could prioritize interactive, participatory design practices that provide feedback at project milestone points and beyond and actively involve end-users [34], as well as experts. Gathering and incorporating feedback from target audiences can significantly improve the relevance and effectiveness of educational visualizations.

6.5 Addressing Ethical Considerations

The project tackled the ethical considerations of data use, particularly in the context of surveillance and privacy. By engaging students in discussions about the ethical implications of their work, the students were primed and guided to create visualizations that not only informed but also respected the rights and privacy of individuals. This practice should be part of any educational experience in which students build technology, experiences with technology, and technology policy today.

Recommendation: Ethical considerations should be an integral part of data visualization education [11]. Institutions should encourage students to understand and critically examine the ethical implications of their work and to create visualizations that respect privacy and rights.

6.6 Enhancing Visualization and Data Literacy

The project reinforced the need to develop visualization and data literacy among students and the broader public. By involving students in the creation of visualizations and providing them with the necessary skills and knowledge, the project contributed to a broader understanding of data visualization principles and practices. Additionally, incorporating iterative design and user feedback mechanisms can significantly enhance the effectiveness of educational visualizations.

Recommendation: Institutions should focus on enhancing visualization literacy through targeted educational programs and iterative workshops. Providing students with hands-on experiences and opportunities to create and critique visualizations can help build a solid foundation in this critical skill area.

7 Conclusion

The "Visualizing Boston's Urban Spaces" project offers a framework for how institutions can effectively integrate data visualization into their educational programs to address pressing issues like climate action and sustainability. By embracing diversity, building collaborative frameworks, leveraging new technologies, fostering engagement, addressing ethical considerations, and enhancing visualization literacy, institutions can create impactful educational experiences that prepare students to make meaningful contributions to society. This initiative demonstrates the value of experiential learning and public engagement in data visualization education. By connecting students with real-world challenges and diverse audiences, the program fostered a deeper understanding of sustainability issues and enhanced professional development. The insights gained from this project align with the broader challenges and opportunities identified in data visualization education, providing a practical example of how to address these in a dynamic and impactful way.

Figure 9: Project team, student participants, and co-authors at Museum of Science.

Future work. This cross-institutional educational framework could be built upon, whether by or with us or through unrelated initiatives. A set of the current interactives has been shared openly [8] and could be built upon by others. We plan to continue our existing collaboration and expand to additional locations, museums, and partners in the coming years with the potential of developing traveling exhibitions . Educators with similar goals could explore the use of virtual reality or projection-based exhibits to enhance engagement with climate data or develop mobile applications that allow for even broader public interaction with the visualizations.

Acknowledgments

We wish to thank and appreciate our collaborators at the nonprofit, Edgelands Institute which works with cities to address digital security (Beatriz Botero Arcila, Laura Garcia, and Santiago Uribe) the Museum of Science (Meg Rosenburg, Rachel Fyler, Sara Winslow and Tim Ritchie) and the city of Boston (Jeff Lambert and Santiago Garces), the expert speakers (Sara Arango, Federica Fragapane, Lina Giraldo, Tony Guidotti, Dorian Juncewicz, Anna Keune, Becki Kipling, Michelle Lee, Aditi Mehndiratta, Sarah Newman, Hugo Powel, Bill Schribman, Martin Waehlisch, Martin Wattenberg, Ben Wilson, and our collaborating partners, the project team from BKC and MADE (Ellen Willemin, Madeline McGee, Chelsea McGovern, and Griffin van Horne; see Figure 7) and the student participants who created the exhibit and inspired us (Krithika Balaraman, Felix Chen, Kevin Hu, David James, Max Kwass-Mason, Esther Krupp, Gemma Li, Katie Lynch, Celine Lee, Conan Lu, Saddat Nazir, Charlie Pozniak, Eva Richter, Samyuktha Sam, Sunny Satpathy, Jocelyn Shek, Justin Wei, Henry Wu, Chase Van Amburg, Amy Vu, and Pluto Zhang; see Figure 9).

References

[1] E. Adar and E. Lee-Robbins. Roboviz: A game-centered project for information visualization education. *IEEE TVCG*, 29(1):268–277, 2023. 2

[2] American Alliance of Museums and Wilkening Consulting. Museums and trust - spring 2021. 2021. https://www.aam-us.org/2021/09/30/museums-and-trust-2021/. Accessed: 2024-08-23. 1

[3] Analyze Boston. City of boston data hub. https://data.boston.gov/, 2024. Accessed: 2024-08-23. 2

[4] T. Anderson and J. Shattuck. Design-based research: A decade of progress in education research? *Educational Researcher*, 41(1):16–25, 2012. 2

[5] B. Bach et al. Challenges and opportunities in data visualization education: A call to action. *IEEE Trans. Vis. Comput. Graphics*, 30(1):649–665, 2023. doi: 10.1109/TVCG.2023.3254058 1, 6

[6] R. Ballantyne, J. Packer, and L. A. Sutherland. Visitors' memories of wildlife tourism: Implications for the design of powerful interpretive experiences. *Tourism management*, 32(4):770–779, 2011. 1

[7] H. S. Barrows. Problem-based learning in medicine and beyond: A brief overview. *New Directions for Teaching and Learning*, 1996(68):3–12, 1996. 2

[8] Berkman Klein Center for Internet & Society. Exploring urban sustainability through open city data. Available: https://cyber.harvard.edu/projects/exploring-urban-sustainability-open-city-data. Accessed: 2024-08-23. 2, 3, 7

[9] Berkman Klein Center for Internet & Society. Research sprints, 2024. https://cyber.harvard.edu/programs/research-sprints. Accessed: 2024-08-23. 1

[10] M. Borrego and L. K. Newswander. Characteristics of successful cross-disciplinary engineering education collaborations. *Journal of Engineering Education*, 97(2):123–134, 2008. 1

[11] J. Boy et al. A principled way of assessing visualization literacy. *IEEE Trans. Vis. Comput. Graphics*, 20(12):1963–1972, 2014. doi: 10.1109/TVCG.2014.2346983 3, 7

[12] M. Brenan. Americans' confidence in higher education down sharply. *Gallup, July*, 2023. https://news.gallup.com/poll/508352/americans-confidencehigher-education-down-sharply.aspx. Accessed: 2024-08-23. 1

[13] T. Brown. Design thinking. *Harvard Business Review*, 86(6):84–92, 2008. 2

[14] Brown University. The made experience. https://design.engineering.brown.edu/made-experience, 2023. Accessed: 2024-08-23. 1

[15] M. Böttinger, H.-N. Kostis, M. Velez-Rojas, P. Rheingans, and A. Ynnerman. Reflections on visualization for broad audiences. *Foundations of Data Visualization*, pp. 297–305, 2020. doi: 10.1007/978-3-030-34444-3_16 1

[16] City of Boston. Cityscore metric definitions & targets, 2016. https://www.boston.gov/sites/default/files/file/document_files/2019/04/cityscore_metric_definitions_targets_for_website.pdf. Accessed 2024-08-23. 3

[17] A. Collins, J. S. Brown, and S. E. Newman. Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In L. B. Resnick, ed., *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser*, pp. 453–494. Lawrence Erlbaum Associates, 1989. 2

[18] L. D. Dierking and J. H. Falk. Redefining learning in museum settings: An alternative perspective. *ILVS Review*, 2(1):4–5, 1991. 2

[19] K. A. Ericsson, R. T. Krampe, and C. Tesch-Römer. The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, 100(3):363–406, 1993. 2

[20] J. H. Falk and L. D. Dierking. *Learning from Museums: Visitor Experiences and the Making of Meaning*. Altamira Press, 2000. 1

[21] R. Fyler. Research sprint session 4 presentation, 2024. 6

[22] J. A. Hatcher and R. G. Bringle. Reflection: Bridging the gap between service and learning. *College Teaching*, 45(4):153–158, 1997. 2

[23] J. Heer, F. B. Viégas, and M. Wattenberg. Voyagers and voyeurs: Supporting asynchronous collaborative information visualization. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 1029–1038. ACM, 2007. 1

[24] S. Hmelo-Silver. Problem-based learning: What and how do students learn? *Educational Psychology Review*, 16(3):235–266, 2004. 2

[25] S. Huron et al. Constructive visualization. In *Proc. of the 2014 Conf. on Designing Interactive Systems*, 2014. doi: 10.1145/2598510.2598596 7

[26] A. Irwin. Risk, science and public communication: Third-order thinking about scientific culture. In *Handbook of Public Communication of Science and Technology*, pp. 160–172. Routledge, 2014. 2

[27] B. Kennedy, A. Tyson, and C. Funk. Americans' trust in scientists, other groups declines. *Pew Research Center*, 2022. https://www.pewresearch.org/wpcontent/uploads/sites/20/2022/02/PS_2022.02.15_trustdeclines_REPORT.pdf. Accessed: 2024-08-23. 1

[28] A. Y. Kolb and D. A. Kolb. The learning way: Meta-cognitive aspects of experiential learning. *Simulation & Gaming*, 40(3):297–327, 2009. 2

[29] D. A. Kolb. *Experiential Learning: Experience as the Source of Learning and Development*. Prentice-Hall, 1984. 2

[30] T. Nagel and M. Dörk. Visualizing urban data through public installations. In *Urban Informatics*, pp. 299–316. Springer, 2021. 1

[31] T. Nocke, S. Buschmann, J. F. Donges, N. Marwan, H. J. Schulz, and C. Tominski. Review: visual analytics of climate networks. *Nonlinear Processes in Geophysics*, 22(5):545–570, 2015. 1

[32] D. A. Norman and S. W. Draper. *User Centered System Design: New Perspectives on Human-computer Interaction*. Lawrence Erlbaum Associates, 1986. 2

[33] L. Rainie, S. Keeter, and A. Perrin. Trust and distrust in America. 2019. https://www.pewresearch.org/politics/wp-content/uploads/sites/4/2019/07/PEW-RESEARCH-CENTER_TRUST-DISTRUST-IN-AMERICA-REPORT_2019-07-22-1.pdf. Accessed: 2024-08-23. 1

[34] N. H. Riche et al. *Data-driven storytelling*. CRC Press, 2018. 3, 7

[35] T. Ritchie. Year of the earthshot, 2024. https://www.mos.org/earthshot. Accessed: 2024-08-23. 2

[36] L. Saad. Historically low faith in us institutions continues. *Gallup, July*, 6, 2023. https://news.gallup.com/poll/508169/historically-low-faith-institutions-continues.aspx.. Accessed: 2024-08.23. 1

[37] D. A. Schön. *The Reflective Practitioner: How Professionals Think in Action*. Basic Books, 1983. 2

[38] S. L. Star and J. R. Griesemer. Institutional ecology, 'translations' and boundary objects: Amateurs and professionals in berkeley's museum of vertebrate zoology, 1907-39. *Social Studies of Science*, 19(3):387–420, 1989. 2

[39] J. W. Thomas. A review of research on project-based learning, 2000. 2

[40] F. B. Viegas, M. Wattenberg, F. van Ham, J. Kriss, and M. McKeon. Manyeyes: a site for visualization at internet scale. *IEEE Transactions on Visualization and Computer Graphics*, 13(6):1121–1128, 2007. 1

[41] F. Windhager, G. Schreder, and E. Mayr. On inconvenient images: Exploring the design space of engaging climate change visualizations for public audiences. *Proc. of the Workshop on Visualization in Environmental Sciences (EnvirVis)*, pp. 1–8, 2019. doi: 10.2312/envirvis.20191098 1, 3

[42] B. J. Zimmerman. Becoming a self-regulated learner: An overview. *Theory Into Practice*, 41(2):64–70, 2002. 2