Expanding and Focusing Infrastructuring Analysis for Informal STEM Education

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Abstract: In our efforts to build transformative informal STEM learning environments, we must consider how innovative educational practices and tools are adaptable, sustainable, and equitable. The lens of infrastructuring allows us to attend to the ways that people, practices, and objects already present in these environments can be leveraged and redesigned to support equitable learning outcomes. Through qualitative analysis of 16 facilitator interviews across three informal STEM organizations, we determined six types of infrastructure that support engagement with computational tinkering in informal learning environments: institutional routines and resources, social and facilitation practices, institutional and facilitator values, facilitator expertise, tools and materials, and physical space. We also point out some critical gaps or challenges within these categories that can serve as points for reflection and redesign. This work has implications for researchers, designers, and facilitators/managers who work in informal STEM settings and aim to engage learners with STEM in new ways.

Introduction and purpose

Informal learning environments, such as museums, libraries, and after-school clubs, can support expansive ways of engaging with STEM, especially for learners from communities marginalized in STEM education (Calabrese Barton et al., 2017; Rahm et al., 2022). While informal spaces operate outside of some constraints of the formal school system, such as a government-mandated curriculum and strict training and evaluation protocols, informal learning environments have their own structures, policies, and practices that can either support or constrain learning opportunities. Studying infrastructure allows us to attend to the invisibilized and relational work at play within these local systems, practices, and environments (Star, 1999), which has implications for how we can effectively design educational practices and tools that are adaptable, sustainable, and equitable.

In this paper, we offer a study of infrastructure across three informal STEM learning organizations. We aim to understand how existing infrastructures at these sites can support facilitator and learner engagement with what our project team has termed "computational tinkering," a novel approach to computing education that prioritizes relationships, joy, and creative explorations of physical and digital materials to create personally meaningful artifacts. We also looked for infrastructure gaps or challenges that hinder engagement with computational tinkering at each of the sites. Our work adds to the existing infrastructuring literature by focusing on informal learning environments as opposed to school classrooms. We also highlight how using a particular approach to computing (i.e., computational tinkering) as a lens for infrastructure analysis brings to light the ways that epistemologies are implicated in both the support systems and the infrastructure gaps.

Theoretical framework: Infrastructuring

Star and Ruhleder (1996) proposed the notion of infrastructure as a way to examine moments in which local practices and solutions intertwine with larger-scale structures and technologies. They argue that infrastructure is inherently relational due to its ties to people, practices, and things - an argument echoed by Bielaczyc (2013) in her social infrastructure framework. In this way, infrastructures are resources in a learning environment that should be designed around and with. Critically, infrastructures are not static, but can be redesigned and renegotiated by the people within a system - an action known as "infrastructuring" (Karasti & Syrjänen, 2004). In a formal education setting, Penuel (2019) uses infrastructuring to discuss efforts that are focused on creating the conditions of support for educators around educational innovations. Studying infrastructure means paying attention to how, where and when resources are taken up, and allows designers to understand how innovations can be implemented equitably across an educational system and be sustainable long term (Penuel, 2019).

Our work continues to build on these theoretical conceptions of infrastructure in design work and brings them into informal STEM environments. Informal learning environments can potentially engage youth and communities that have been systematically marginalized and excluded from traditional STEM learning spaces, particularly by creating a supportive environment that helps learners develop their interest and identities as people who are capable and motivated to pursue STEM fields (Bell et al., 2009; Bevan & Michalchik, 2013; Ito et al., 2009). Touted as spaces with great transformative potential outside of the constraints of formal education, it is important to recognize that these informal learning spaces also have their own deeply contextualized tensions, contradictions and gaps in infrastructure that designers engaged in design projects must recognize in order to design and implement sustainable and consequential learning innovations (Hladik et al., 2022). To that end our work proposes an initial framework of types of infrastructure that might be analyzed and reimagined in these environments, informed by the perspectives of facilitators within these spaces.

Research design

Context

This work stems from a multi-year collaboration between research institutions and informal STEM learning environments in the US, including a museum makerspace on the West Coast, library makerspaces in the Mountain Region, and community-based technology centers across the US. The purpose of the partnership is to collaboratively design, implement, and evaluate activities for "computational tinkering." To guide the co-design of our interventions, our project team articulated particular values as being central to the design of computational tinkering activities: engaging entry points, supporting multiple interests, allowing for deepening complexity within activities, the use of both digital and physical materials, experimental and playful practices, projects that are culturally and personally meaningful, positive affect in the learning experience, and a desire to create a sense of belonging in STEM for all participants. As part of this work, we wish to understand the relationship between this particular approach to computing and the infrastructures in these learning spaces.

Participants, data collection, and analysis

We aimed to examine infrastructures from facilitators' perspectives, as their professional practice requires daily interactions with these infrastructures. Based on nominations from institution leadership, we invited facilitators to participate in 90-minute interviews via the video conferencing software, Zoom. We interviewed 16 facilitators: 5 from the museum makerspace, 6 from the library makerspaces, and 5 from the community technology centers. Through a semi-structured interview, we asked them about their role, their organization's goals, their views on equity, and what they were excited to try in the future. We also asked them to bring an example of a computational activity, share how it was designed and facilitated, and detail the challenges that facilitators or learners faced during the activity. Interviews were recorded, downloaded, and transcribed.

While these interviews did not specifically ask facilitators about infrastructures for computational tinkering, we were able to gain some insight into infrastructures by looking for things that support their work, or challenges they are facing, across their responses. We drew upon grounded theory and constant comparative methods (Glaser, 1965) for this analysis. First, authors 1 and 2 engaged in open coding of three transcripts, looking at the data through the lens of infrastructure that supported facilitators' work in computational tinkering. We organized these codes into broader categories of infrastructures for an initial codebook. We then coded two additional transcripts separately and met to refine the codebook. We then coded the remaining nine transcripts individually, resolving any questions through discussion.

Findings

Our analysis revealed six types of infrastructure that support design and implementation of computational tinkering activities in informal STEM environments:

1. *Institutional routines and resources*: Institutional practices or rules that impact activities and how facilitators engage; resources that can be accessed by the wider institution
2. *Social and facilitation practices:* Learner and facilitator interactions that support engagement
3. *Institutional and facilitator values:* Values that align with ideas of computational tinkering
4. *Facilitator expertise:* Knowledge and attitudes of facilitators that impact activity design and implementation
5. *Tools and materials:* Procurement and use of computational tinkering materials; specific material properties that support engagement
6. *Physical space:* Arrangement of resources within the physical environment

Our framework is applicable to any STEM learning approach when its materials and values are made explicit. To illustrate our findings, we next highlight examples from two different categories of infrastructure: (3) institutional and facilitator values and (5) tools and materials.

Institutional and facilitator values

Drawing on Bielaczyc's (2013) notion of cultural beliefs as a form of social infrastructure, we suggest that institutional and facilitator values around computational tinkering can either support or hinder the design and implementation of these activities in their organizations. More specifically, alignment between the values that made up the core of computational tinkering (as described in the context section) and established values of the space was an important factor in implementation and continued engagement.

For example, as computational tinkering is premised on the idea of both physical and digital materials being meaningfully integrated into a final project, spaces that already valued this diversity in materials were also more easily able to support CT in their spaces. However, this valuing of physical and digital materials was not always balanced; Primo (note, all facilitator names are pseudonyms) pointed out that families and youth within the CTC loved to have something to take home with them, making solely digital projects less exciting for their participants and possibly excluding some CT activities that do not lead to a final physical product. Another value that both supported CT and at times constrained that work was the desire for positive affect. Facilitators wanted youth to have joyful experiences working with computing, and at times, they perceived their learners' frustration in an activity as a barrier that hampered their engagement, such as an activity where a girl was not able to "immediately figure out" the "complicated vision for what she wanted the [Scratch] sprite to do" (Amy). Trying to determine the fine line between "true frustration" voiced by Amy and a productive struggle as part of learning something new (Warshauer, 2015) can be challenging, possibly leading to moments where facilitators step in to solve a problem or pivot to a different activity, leading to decreased engagement with computational tinkering.

Finally, a value that both supported facilitators in CT and also constrained their work at times was the desire not to mirror formal education settings. Facilitators spoke about wanting to encourage learning without strict outcomes or grades, instead aiming to get youth deeply involved in the iterative process of learning in a safe way. (Diego, Daniel, Eric). This aligns well with computational tinkering, where process is valued over a final product. However, the spread of popular computational tools into formal education settings where they may be introduced in more instructivist ways led some facilitators to avoid these tools in their spaces. As Diego said, "I just struggle when there are a lot of activities that are already offered in most of the school systems, so a lot of kids, they don't see it as something new, they see it as part of like, "Oh this is schoolwork." Several facilitators (Diego, Leonardo) mentioned that they rarely designed activities which used the creative block-based programming language, Scratch, because children associated it with their school settings - even though many youth already had some knowledge of Scratch and it is known to be a tool with the potential to promote creative, personally-meaningful learning experiences, especially for youth and families from marginalized communities (Roque, 2016).

Tools and materials

Perhaps unsurprisingly, having access to computational tools and materials was a significant part of the infrastructure to support computational tinkering activities at these organizations. Our analysis showed however, that *availability* was not the same as *accessibility*; Amy pointed out that "some of it is in very deliberately setting up a space in a way that materials and equipment, it's just open, it's just available and just out [in the space]," accompanied by explicit facilitator explanations and invitations to try it out, such as relating a Raspberry Pi microcontroller to a regular computer (Amy). Tensions also emerged between giving participants the opportunity to use computational tools and materials that they would not typically have access to, such as a laser cutter, versus ensuring that the tools and materials could also be used at home, such as looking for free software (Diego). However, even if the software was free, many facilitators spoke about how some of their visitors did not have access to computers or high-speed at home, revealing another infrastructure gap in how they could extend their impact beyond their organization's walls. Facilitators also mentioned that having different tools or software packages that could be used across different projects, such as using a digital illustrator software that could be used on its own or to create designs for a vinyl cutter (Eric), helped learners to be more comfortable with a variety of tools and take on new projects.

One of the most significant infrastructures related to tools and materials were the supporting resources, such as guides, videos, instructions, and example projects. In many cases, existing supports were not meeting the needs of their learners, due to a lack of detail or relevance to their particular project, or not including instructions in learners' home languages. Facilitators frequently filled these infrastructure gaps themselves, highlighting their agency in creating their own infrastructures. For example, Amy discussed how learners were having trouble understanding what a breadboard is and how the various rows are connected, so he decided to break one apart, "open it up and show the guts" so that learners could see, touch, and understand how to connect electronic components. Facilitators also created activity cards and visuals to spark project ideas (Eric), cards to explain basic coding principles (Jenna), sample projects (Emilia), practice sheets (Emilia), and instructional videos (Daniel, Eric, Katie). These resources were especially helpful when facilitators did not have the time to sit down and walk a learner through an activity 1-on-1 for an extended period of time, something that was very common across the library makerspaces and CTCs. In this way, facilitators designed their own infrastructures to deal with day-to-day operational challenges that occur in busy, drop-in, and under-staffed settings.

Discussion and conclusion

This work aims to expand our capacity to build equitable informal STEM learning environments by better understanding how infrastructure can be considered and leveraged in the design and implementation of educational innovations. We specifically highlighted two categories, facilitator and institutional values, and tools and materials, to show the complexity of systems and practices that may support or constrain uptake in the case of computational tinkering activities.

Our findings also show the impact of considering the role of epistemologies of STEM in an analysis of infrastructure. By using our specific lens of computational tinkering, we can make the epistemologies of STEM — that is, what STEM *is* or *should be* — visible. Values are built into approaches to STEM learning within the activities, pedagogies, materials and goals. We must be especially mindful when we are trying to promote or create space for new approaches to computing, because it may or may not be supported by the organization. Our work builds on previous scholarship about infrastructures in formal learning environments (e.g, Penuel, 2019) to highlight that informal learning spaces have their own affordances and constraints with respect to infrastructure that must be considered by researchers, designers, and practitioners in these spaces. We also highlight the important perspectives of facilitators in this work, further making visible the complexity of informal facilitator practices (Hladik et al., 2022).

We also want to make clear that this framework was built from data across distinct informal learning spaces. Our goal is not to collapse these organizations into a monolith, but rather to offer a framework to help designers use infrastructure as a lens to see the nuances of the spaces they are working with. In our future work we plan to more deeply investigate the agency of facilitators with respect to infrastructures: what infrastructures do facilitators have the power to redesign, and what more constraints remain. We will also continue to validate this framework through in-person observations of infrastructure as well as infrastructure-specific interviews with facilitators.

References

Bell, P., Lewenstein, B., Shouse, A. W., & Feder, M. A. (2009). *Learning science in informal environments: People, places, and pursuits* (Vol. 140). National Academies Press Washington, DC.

Bevan, B., & Michalchik, V. (2013). Where It Gets Interesting: Competing Models of STEM Learning after School. *Afterschool Matters*, *17*, 1–8.

Bielaczyc, K. (2013). Informing design research: Learning from teachers' designs of social infrastructure. *Journal of the Learning Sciences*, *22*(2), 258–311.

Calabrese Barton, A., Tan, E., & Greenberg, D. (2017). The makerspace movement: Sites of possibilities for equitable opportunities to engage underrepresented youth in STEM. *Teachers College Record*, *119*(6), 1–44.

Glaser, B. G. (1965). The constant comparative method of qualitative analysis. *Social Problems*, *12*(4), 436–445.

Hladik, S., Sengupta, P., & Shanahan, M. C. (2022). Museum facilitator practice as infrastructure design work for public computing. *Cognition and Instruction*, 1-42. DOI: 10.1080/07370008.2022.2129639

Ito, M., Horst, H. A., Bittanti, M., Herr Stephenson, B., Lange, P. G., Pascoe, C. J., & Robinson, L. (2009). *Living and learning with new media: Summary of findings from the digital youth project*. The MIT Press.

Karasti, H., & Syrjänen, A.-L. (2004). Artful infrastructuring in two cases of community PD. *Proceedings of the Eighth Conference on Participatory Design: Artful Integration: Interweaving Media, Materials and Practices-Volume 1*, 20–30.

Penuel, W. R. (2019). Infrastructuring as a practice of design-based research for supporting and studying equitable implementation and sustainability of innovations. *Journal of the Learning Sciences*, *28*(4–5), 659–677.

Rahm, J., Gonsalves, A. J., & Lachaîne, A. (2022). Young women of color figuring science and identity within and beyond an afterschool science program. *Journal of the Learning Sciences*, *31*(2), 199–236.

Roque, R. (2016). Family creative learning. In *Makeology* (pp. 47–63). Routledge.

Star, S. L. (1999). The ethnography of infrastructure. *American Behavioral Scientist*, *43*(3), 377–391.

Star, S. L., & Ruhleder, K. (1996). Information Spaces. *Information Systems Research*, *7*(1), 111.

Warshauer, H. K. (2015). Productive struggle in middle school mathematics classrooms. *Journal of Mathematics Teacher Education*, *18*(4), 375–400.