Complexity in Facilitation of Public Computing

Hladik, Stephanie Kay


doctoral thesis

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Complexity in Facilitation of Public Computing

by

Stephanie Kay Hladik

A THESIS
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Abstract

Museums and other informal learning spaces have been found to be sites of playful and transformative engagement with computing, especially for learners who have been historically marginalized in the discipline. However, as educational researchers and designers create new programs and exhibits for computing in museum spaces, the roles, experiences, and labour of museum educators – those who facilitate the exhibit, answer questions, and scaffold learning – have often been ignored, with the focus instead falling mainly on the hardware and software used within the learning environment. In this manuscript-based dissertation, I bring to light the complexity of museum educators’ experiences and practices in the context of a computational science exhibit in a Canadian science centre. Firstly, I review the literature on museum educators in science museums, pointing out their high importance yet low status in their institutions, comparisons of their practice with school science teaching, a growing call for professionalization in the field, and their positioning and participation in educational research projects – often as sources of data rather than co-designers of educational innovations they are expected to enliven on a daily basis. Next, I investigate the *infrastructuring* done by museum facilitators as they work to support the success and sustainability of a computational science exhibit, highlighting the ways in which this hidden labour is intertwined with their personal, professional, and community practices. Finally, I zoom out to reflect on the chronological shifts in the research project as a whole, from one that is device-centered to a more praxis-centred approach through four phases: an early device-centered framing of “redesign,” recognizing infrastructuring and developing relationships with facilitators, understanding improvisational infrastructuring as hidden design work, and, finally, making space for facilitators as co-designers. Across these papers, this dissertation highlights the ways in which methodology, epistemology, and axiology
are intertwined in design-based research in informal settings. Shifting away from a device-centered approach led to listening carefully to museum facilitators, acknowledging and valuing their labour, and attending to power dynamics, which is essential for centering praxis in design-based research. I conclude with implications for future design-based research in computing education that are vital to equitable imagined futures.

*Keywords:* museum education, facilitation, design-based research, computing, infrastructuring, praxis
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I would like to gratefully acknowledge the support and mentorship of my supervisor, Pratim Sengupta, throughout my PhD journey – from when I was just considering applying for the program, through to his final questions and comments at my defence. You always knew when to give me space to think about a new concept or article and when to push me to think more deeply about theory or analysis, leading to me doing the very best work that I could do. I would also like to thank my committee members, Marie-Claire Shanahan and Beaumie Kim, for their thoughtful feedback and support throughout my program. You helped me to stay true to my feminist ideals and weave them into design and education in ways that I didn’t even know were possible. A big thank you to Miwa Takeuchi and Pallavi Banerjee for challenging me in their courses to think about equity and justice in new ways that went beyond my final papers and into my scholarship and academic practice. Completing a PhD is impossible without a community of friends, classmates, and colleagues. Thank you to Basak, Dylan, Marilu, Chris, Brit, Apoorve, Marc, Simren, Lisa, Peter, Maryam, Santanu, Megha, Emily, Robyn, Kat for giving me space, in and out of class, to explore my ideas and learn in community with you. To my family – parents, grandparents, siblings, and everyone else – thank you for letting me ramble about my work over family dinners and Zoom calls. Thank you to my best friend Melissa, a dedicated teacher and friend who continues to inspire and support me in this research every day. And finally, a huge thank you to my husband, Everett. You celebrated my successes, no matter how small, and supported me through the challenging times. Your unwavering support and love through this journey are so appreciated, and I can’t wait to see what we will do next, together.
Dedication

This dissertation is dedicated to the amazing facilitators and educators at Telus SPARK Science Centre in Calgary. I have been inspired and humbled by your daily labour and dedication to your professional practice. Thank you for allowing me to learn from and with you.
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## List of Symbols, Abbreviations and Nomenclature

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<thead>
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<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>DBR</td>
<td>Design-based research</td>
</tr>
<tr>
<td>HTML</td>
<td>Hypertext Markup Language</td>
</tr>
<tr>
<td>RGB</td>
<td>Red-Green-Blue</td>
</tr>
<tr>
<td>RPP</td>
<td>Research-practice partnership</td>
</tr>
<tr>
<td>STEM</td>
<td>Science, technology, engineering, and mathematics</td>
</tr>
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Chapter 1: Introduction

As digital technologies are invented, mature, and spread across the globe, the field of education has shown significant interest in computing and computer science. Computing is being included in both formal education curricula as well as in informal learning environments such as museums and after-school clubs. However, diversity within computing is lacking – despite computing’s roots as “women’s work,” the culture of computing is steeped in masculinity and whiteness (Abbiss, 2011; Carter, 1998; Ensmenger, 2015; Martinez & Cameron, 2018). This culture can be unwelcoming and even hostile to women and underrepresented minorities within computing, and unless it is explicitly challenged, can be reified in K-12 and postsecondary classrooms (Margolis & Fisher, 2003; Margolis et al., 2010). Fortunately, recent research has shown that museums can be particularly promising learning environments where learners who have been included from science in informal spaces have opportunities to experience and perform science in playful and transformative ways (Horn et al., 2012; Rahm et al., 2005; Rahm & Ash, 2008). Existing within informal spaces such as public walkways and museums, public computing environments (Sengupta & Shanahan, 2017) are “a new form of open-ended, public learning environments, in which visitors can directly access, modify and create complex and authentic scientific work through interacting with open source computing platforms” (p. 1124). Public computing exhibits are intentionally designed to promote playful and exploratory interactions with computing as visitors of all ages and experience levels engage in conversations with expert facilitators and work together to collaboratively modify and “hack” the scientific simulations (Sengupta & Shanahan, 2017).
Despite the careful design decisions made by educational researchers, guided by epistemology and pedagogy, installing a public computing exhibit in a science museum is much more complicated than simply designing it, building it, and placing it in a gallery. A science museum is an ecosystem comprised of visitors, facilitators, managers, exhibit designers, exhibits, galleries, signage, educational programs, and more. While much attention has been paid to family interactions (e.g., Dierking & Falk, 1994; Kisiel et al., 2012; Kopczak et al., 2015) and school programs (e.g., D. Anderson et al., 2000) in science museums, relatively little research has been carried out to deeply explore the experiences and practice of science museum facilitators (Pattison et al., 2018; Tran, 2007). Facilitators may find their work devalued in both their institutions and in educational research projects, as they are rarely given the opportunity to participate as co-researchers or co-designers and draw upon their wealth of experience. This is particularly problematic as museum facilitators are the ones who will be engaged in the day-to-day work of facilitating the exhibit with visitors, long after the original educational designers and researchers have collected data and left the research site. Furthermore, failing to engage with museum facilitators throughout the design process can create points of tension and incongruence between designer intentions and perceptions and practice of the museum facilitators. Thus, approaches to educational design in museums may require epistemological, methodological and axiological shifts in order to promote successful research-practice partnerships.

Engaging with these problems of research and practice, I present my research across three manuscripts, as per the University of Calgary guidelines for a manuscript-based thesis. The goal of this thesis is to investigate how the power, positioning, and labour of museum facilitators contribute to their participation in design-based research, and what implications this has for the
design of a computational science exhibit and the methodology of DBR overall. Specifically, the research questions addressed by this thesis are:

1. How are museum educators positioned within:
   a. Their institutions?
   b. Reported research projects?
   c. The field of educational research overall?

2. How is this positioning intertwined with conceptualizations of power?

3. How is museum educators’ labour conceptualized and made in(visible)?

4. How do museum facilitators negotiate their personal epistemological stances toward learning, institutional norm and constraints, and the roles that they play as participants in a research-practice partnership?

5. How are these factors intertwined with infrastructuring at the exhibit?

6. How are methodology, epistemology, and axiology intertwined in an informal STEM DBR project taking place in a research-practice partnership?

The first manuscript (Chapter 2) presents a critical systematic review of the literature pertaining to science museum educators. In particular, the critical aspect of the review focused on themes of positioning (Davis & Harré, 1990; van Langenhove & Harré, 1999), power (Philip & Gupta, 2020), and labour (Acker, 2006; Fletcher, 1999; Hochschild, 1983). The literature review revealed that museum educators are ascribed high importance in their roles that are critical to visitor experience and the institution’s educational agenda (Dragotto et al., 2006; Nyhof-Young, 1996; Pattison & Dierking, 2012), but are simultaneously asked to take on difficult work that may fall out of the purview of education (Bailey, 2006; Diamond et al., 1987;
Ji et al., 2016), all the while dealing with low pay and job precarity. Alongside feelings of powerlessness to request institutional resources to meet workload demands (Bailey 2006; Ji et al., 2016; Moore et al., 2020) and a general lack of agency and voice in their workplaces (Ash et al., 2012), these issues point to their positioning as low-status workers in the museum. Additionally, the review exposed tensions between science education in museums and science education in schools in terms of notions of expertise, pedagogy, goals, and institutional influences. While some authors positioned museum educators as experts in the unique learning affordances of museums (e.g., Tran, 2007), others critiqued them for a lack of scientific knowledge (e.g., Shaby et al., 2019) or pedagogical expertise (e.g., Bevan & Xanthoudaki, 2008). These critiques failed to take into account the ways in which institutional requirements impacted the desired qualification of museum educators or constrained the ways in which they could carry out their work with visitors.

Next, ongoing efforts to professionalize museum education have resulted in a large number of studies focused on professional development, but many of these studies unfortunately relied on a deficit perspective of museum educators, focusing on one-way transmission of knowledge from experts (i.e., educational researchers) to museum educators so that they can gain content knowledge, experience, or practice with a particular tool (Piqueras & Achiam, 2019; Tran et al., 2019). This deficit positioning is widespread in the educational research literature: museum educator experiences are under-researched (Ji et al., 2016; Pattison et al., 2016; Tran, 2007), and when they do participate in research projects, museum educators are rarely given roles as co-researchers or co-designers. In fact, many studies rely solely on observational data of museum educators, leaving their voices out of the research and contributing to incomplete
understandings of their labour and practice. I conclude by arguing that we must do more to explore the experience and labour of museum educators, co-develop more contextual theories for learning in science museums, and explicitly position science museum educators as co-designers and co-researchers so that we can incorporate their experience and labour into new theories and designs for informal learning spaces such as museums.

The second manuscript (Chapter 3) showcases the theory-building that is possible when we, as educational researchers, see to understand and make visible the complex day-to-day work of facilitating in science museums. In the context of a public computing (Sengupta & Shanahan, 2015) exhibit, we highlight the ways in which the complexity of museum facilitation practice is intertwined with physical and social structures in the museum community that support the success of this new exhibit. More precisely, we draw upon Star and Ruhleder’s (1996) notion of infrastructures, referring to these systems that are locally relevant, relational, and are in constant development. Infrastructuring is the process by which these infrastructures become visible upon their breakdown or innovation (Star & Ruhleder, 1996). The analysis in this manuscript highlights the complexity of museum facilitator practice as they navigate tensions between institutional norms and policies, personally-held epistemologies about museum education and STEM disciplines, and their expected duties as participants of a design-based research project.

Zooming in on the facilitation practices of two facilitators in particular, we show how infrastructuring and facilitation practices are co-constructed. Facilitators adapt their practice to fit with the infrastructure available to them in moments of uncertainty, drawing upon personal epistemologies to flexibly address infrastructure breakdowns within the bounds of institutional expectations. Additionally, their practices can inform new infrastructuring at the exhibit – from
new code comments, a reset button, or the content of a facilitation guide. We also discuss how this infrastructure emerged from within the facilitator community: they collaboratively carried out knowledge-sharing practices amongst themselves, without initiation from researchers managers. This work has implications for future research, including attending to power dynamics between participants and researchers or participants and their institutions. It also highlights the fact that educational design does not take place within a vacuum; users of these educational innovations, including museum educators, must adapt their practice such that it supports the new innovation, which has the potential to create local adaptations that may or may not align with designers’ views. Therefore, including facilitators as co-designers in such work can ensure that educational designs take into account institutional restrictions and the epistemologies which facilitators hold and manifest in their daily practice, leading to successful innovations and a deeper understanding of museum facilitators’ experiences, labour, and practice.

The third manuscript (Chapter 4) zooms out to provide a reflection on methodology, epistemology, and axiology in design-based research. Drawing from our experiences in a DBR project involving the (re)design of a computational exhibit in a science museum and utilizing a phenomenographic approach (Marton & Booth, 1996), we present a chronological account of the ways in which our project shifted from one that was centred around the technological device (i.e., the exhibit) to one that focused on praxis and sought to centre the voices and contributions of museum facilitators in the project. Our perspectives were strongly influenced by Gutiérrez and Vossoughi’s (2010) idea of mediated praxis, which “promotes expansive forms of learning in which individual and collective zones of proximal development coalesce, as individual participants ‘act a head taller than themselves’ in ways that lift the activity towards its future,
emerging form” (p. 111). Additionally, we drew upon scholars who have explored the ways in which design can make visible formerly invisible labour (e.g., Jurow et al., 2016), axiological innovations in design research (Bang & Vossoughi, 2016), and power dynamics in educational research projects (Carlone & Webb, 2006; Shanahan & Bechtel, 2020).

We highlight the ways in which our project moved from early device-centred framings of “redesign” to developing relationships with facilitators and recognizing facilitator infrastructuring as both hidden design work and a key factor in the success of the project (see Chapter 3), and finally our methodological pivot to explicitly position museum facilitators as co-designers in the research. This methodological pivot was deeply intertwined with an epistemological shift from centring materiality of the exhibit and intentionality of designers to more deeply considering who (Philip et al., 2018) takes part in design, especially given that it is the labor of the facilitators that enlivens the exhibit. We argue that productively navigating tensions during the re-mediation of a learning environment is in itself labour, and that labour is necessary for researchers and participants to create a shared vision of what could be and what should be in educational research. By noticing, valuing, and inviting museum facilitators to participate more centrally in the project, we built trust and understanding that made it possible for us to explicitly position them as co-designers, and for them to feel empowered to take up that positioning. Thus, we bring to light and attempt to challenge these power differentials and institutional demands on labor, work that is necessary for researchers and practitioners within research-practice partnerships to begin to understand the complexities of praxis and work towards an imagined future, together.
Taken together, these three manuscripts address issues of museum facilitator power, positioning, and labour across different timescales. Understanding museum facilitators’ participation and positioning in previous educational research projects helps us to understand the historical and cultural factors leading to their original positioning in our DBR project: as informers and testers, but not necessarily partners. Explicitly highlighting the facilitators’ infrastructuring work showcases the moment where we began to more carefully attend to issues of power, positioning, and labour in our project, which led to deeper reflection on past work in the project, as well as reconsidering methodological decisions for the future, such as inviting facilitators as co-designers in design meetings. By exploring issues of methodology, epistemology, and axiology across the past, present, and future of this DBR research, we bring to light the complexity, nuance, and constant re-making of these ideas over the months and years – presenting DBR as something that is inherently messier than traditional innovation-centred notions of DBR. In particular, striving for equity and justice in this type of work can be difficult, despite the best intentions of researchers as they enter the project; relationships, both personal and professional, are continuously renegotiated in response to researcher and practitioner needs and ideas of potential futures. I hope that by following the project through time, zooming in to particular theoretical and methodological innovations, zooming out to consider how the often-invisible epistemological and axiological commitments impact methodological choices, and grounding all of this work in historical and cultural understandings of museum facilitator labour and power, I can highlight this complexity not as something to fear or try to mitigate, but instead something that must be embraced for deeper understanding and innovation to occur – new ideas for educational design work in museums, new theoretical understandings of informal STEM
education, and new approaches to DBR that acknowledge complexity and justice as central to the methodology.

**Researcher Reflection**

I think that if I could have a conversation with myself from four years ago, past me would be amazed at just how much I have changed. Working on a PhD has shifted my understandings of my discipline, the world, and my role within it. Even though I could point to dozens of points throughout my PhD in which I felt challenged intellectually, was faced with an alternate perspective, had to reconcile past and present beliefs, and pivoted in a slightly different direction, the combined effects of all of these moments led to a version of me that stands in stark contrast with the woman who sat down for her first lecture in “Historical and Philosophical Foundations in the Learning Sciences.” In this section, I reflect on how my epistemology and axiology as a researcher gradually shifted across the four years of my doctoral studies. Though computing and design were both familiar to me due to my undergraduate degree in electrical engineering, and I had dipped my toes into the world of computing education in my master’s research, my motivations, theoretical commitments, and research questions underwent their own iterative making and remaking in relation to course content, suggested readings, and conversations with my supervisory committee, colleagues, and friends.

**Familiar Domain, New Questions and Approaches**

When I started my PhD, I knew I wanted to use the skills I had gained during my undergraduate and master’s degrees in electrical engineering. Even though I had no programming experience before entering university, I quickly grew to love the problem-solving aspect of programming and its wide range of applications, from medical technology to electronic
artwork. In my master’s degree, I had investigated how participating in various computational thinking activities improved K-6 student and teacher perceptions of computing. I knew that my PhD supervisor and his colleagues were working on a computational science exhibit that would become part of the local science centre, and it felt like a perfect fit for my interests in design, computing, and education, and I was especially interested in how computing education could work in a museum setting as opposed to the classroom or workshop settings which were familiar to me. My initial idea was that I would use a qualitative approach to investigate learner perceptions of the exhibit and learning that took place there, though my definition for what counted as “learning” was vague and largely premised on the framework of computational thinking I had used to guide my master’s work (i.e., Brennan & Resnick, 2012).

Immersion in learning sciences coursework felt like jumping into the ocean into which I had barely dipped my toes in my master’s work. Suddenly, words like “epistemology” were thrown around in both academic and casual discussion, the notion of “objectivity” was widely debated, and “learning” became much more than simply demonstrating a skill. I can remember times when my supervisor and I would be in a discussion, and I would have to stop him and ask, “Sorry, can you say that all again but… slower?” Those first few months were incredibly difficult as I grappled with words that seemed to have different definitions depending on who you asked/cited and tried to locate my own understandings of epistemology and learning within a sea of historical and contemporary ideas. I found myself drawn to socio-cultural theories of learning which situated learning within historical and cultural settings, emergent in interactions with others, something that was at once deeply personal but also collective. It was during my reading of *Identity and Agency in Cultural Worlds* by Holland et al. (1998) that I stumbled upon
the idea of identity as it pertained to learning. As I followed that thread of inquiry, I found myself engaging deeply with notions of science identity, feminist technoscience, phenomenological approach to computing education, which influenced my epistemology and guided my research.

Science Identity. Exploring how culture and identity interact, Holland et al. (1998) proposed the idea of figured worlds: cultural realms in which “particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others” (p. 53). Individual’s identities are constructed by and within these figured worlds (Holland et al., 1998; Sengupta & Shanahan, 2017). Science identity itself emerged as an essential construct for understanding science learning in the 1990s as feminist science educators grappled with the implications of epistemological critiques of scientific culture and practice (e.g., Haraway, 1988; Harding, 1991). That line of identity-oriented research has since strongly illustrated that when students perform science identities that do not match what is celebrated in the classroom, they may feel that science is not for them, and quickly lose interest in the subject, despite being high performers (Archer et al., 2017; Brickhouse et al., 2000; Brickhouse & Potter, 2001; Carlone, 2004, 2017; Carlone et al., 2011; Carlone et al., 2014). Put another way, students may construct a figured world of science which, for example, values “getting the right answer” and using the scientific method while devaluing creative thinking. If this student also views themselves as being a creative person, they may not feel that they can be a recognized actor within the figured world of science (Shanahan & Nieswandt, 2011).

Science identity research also seeks to challenge cultural-historical biases and assumptions in science education by asking what science may look like from the perspectives of
those individuals who are marginalized in science due to race, class, gender, or other personal characteristics (Haraway, 1988; Harding, 1991, 2008). Though computer science identity specifically has been under researched (Dempsey et al., 2015; Rodriguez & Lehman, 2018), I felt that starting from science identity provided me with the tools to connect the culture of computing (its objects, actors, stories, and goals) with the ways in which people can identify with the discipline and feel welcome within it. It also aligned with my personal experience: even though I had taken multiple computing courses in various languages, written code for different projects, and held two degrees in electrical engineering, I still hesitated to call myself a “coder.” In order to dig deeper into my own computing identity crisis, I had to research computing culture, and not just its most familiar faces and narratives. Feminist technoscience literature provided me with the tools to make visible the cultural-historical biases and assumptions in computing that impact figure worlds and computing identity development.

**Feminist Technoscience.** Scholars in Science and Technology Studies (STS) have demonstrated the ways in which computing is far from an “objective” field. Its connections with abstract thinking, formal logic, mathematics, and the military led to its association with masculinity (Clegg, 2001; Ensmenger, 2015; Stepulevage & Plumeridge, 1998; Turkle & Papert, 1990). Efforts have been made to increase diversity in computing through outreach programs that aim to spark interest in folks who are underrepresented in computing (though this usually refers to women; Dunbar-Hester, 2020). However, feminist technoscience scholars such as Abbiss (2008) have pointed out that the dominant liberal equity discourse is one of deficit, positioning women and other minoritized folks as “missing something” (e.g., interest, access) that is necessary for their success in computing, and proposes solutions including curriculum
modifications to emphasize “feminine interests” or ensuring that every school has a room of computers. Wajcman (2007) has argued that we must move past this deficit view to instead consider cultural change, aligning with a more critical discourse which “locates the ‘problem’ more broadly with the social construction of IT as a masculine domain, with socially constructed notions of what ‘counts’ as computing and with power/knowledge relations” (Abbiss, 2008, p. 161). Scholars taking on this critical discourse challenge constructed binaries of masculine/feminine, technical skill/“soft” skills, and expert/novice; the association of technical mastery with technical dominance; and the assumption that the technical is not inherently political. The critical discourse can be linked with the idea of science identity and figured worlds – we cannot and should not expect learners to mold themselves or hide aspects of their identity such that they fit into the masculine, white, and heterosexual mythos of computing. Instead, we should challenge the culture of computing as it exists in our classrooms, computer labs, and informal learning spaces such that folks who are historically underrepresented in computing can socially construct a culture of computing that allows them to identify with computing in ways that are personally meaningful for them. As a researcher and designer, I drew upon this literature to think about how I might begin to reject these binaries and traditional ideas of what computing was supposed to be, instead creating space for my participants to voice their own narratives and values in computing and allowing their lived experiences and expertise to guide the design
process. Their figured worlds of computing and their identities as “coders” would be central to my work.

**The Evolution of my Educational Research**

This is not the dissertation I had planned to write back when I passed my candidacy exam in August 2019. Everyone who knows me well knows that I like to make a plan and then stick to it, and the past four years have forced me to grapple with the ways in which my plans frequently did not match what was actually happening in the field, in my paper drafts, and in the world more generally. One of my most important takeaways from this PhD journey has been the importance of flexibility; flexibility is what allows us to see something interesting happening in the field and decide to investigate it further, leading to the uncovering of hidden work and the creation of new educational theory. Additionally, flexibility is also required when unforeseen circumstances lead to the closure of research sites and 18 months of working exclusively from home. While I address particular epistemological and axiological shifts in my research in greater detail in Chapter 4, in this section I aim to provide an overview of how my research evolved throughout my doctoral journey, illuminating how remaining flexible in my work led me to rework my understandings of which research topics really mattered to me, to follow leads presented in data and informal conversations, and to accept the impact that the worldwide COVID-19 pandemic would have on this dissertation.

**The Plan**

In the first two years of my PhD program, my research interests underwent a gradual shift that reflected my broader epistemological and axiological shifts. I had settled on the domain (computing education) and setting (a public computing exhibit in a museum) of my research
fairly early on, wanting to extend my previous masters’ work and indulging my lifelong love of the local science centre. However, courses in foundations of Learning Sciences, educational theory, design, feminist theory, and research methodologies infused my research with new questions, approaches, and concerns. My interests in computing education, design, and museum education remained, but feminist technoscience and science identity literature spurred me to move beyond simply assessing the “what” and “how” of learning at a computational science exhibit and instead attend more deeply to the question of “who,” along multiple dimensions: who are we designing this exhibit for? Whose ways of knowing and being are prioritized, and whose are unintentionally marginalized in the current design? Who are we designing with, when we engage in the redesign of the exhibit? Thus, my PhD project expanded from simply evaluating learning at the exhibit to redesigning it with feminist principles in mind and exploring its impact on computing identity of diverse visitors and learners.

**Hacking Methodology.** With this new dual focus for my research (redesign + computing identity) came a new dilemma: what research methodology should I use? I had taken courses in design-based research and ethnography, but neither of them seemed to meet all of my needs. Design-based research was the obvious choice for iteratively creating new theory and redesigning the public computing exhibit, but its treatment of the designed intervention as central to the work (Barab & Squire, 2004; McKenney & Reeves, 2012; The Design-Based Research Collective, 2003) also seemed to push the voices and identities of the people involved in its design and the future users to the edges of the research. I struggled to find a way for DBR to explore and attend to computing identity in ways that did not reduce it to a data source, whether as an input to the exhibit’s design, or as a desired output of a successful design. On the other
hand, exploring the ways in which learners (re)defined themselves in relation to computer science, their disciplinary values and perspectives, and the ways in which culture influenced what would “count” as computer science at the exhibit meshed well with my understandings of critical ethnography (Madison, 2012) – after all, I wanted to study “computing culture” at the exhibit, evident through patterns of behaviour, voiced beliefs, and language (Creswell, 2015), in ways that sought to surface hegemonic masculinity and whiteness, and make connections between this culture and computing identity. But I also wanted to articulate feminist design principles for the exhibit that would be of interest to other educational researchers and designers, and this required careful mapping of design choices, conjectures, and visitor interactions. I did not just want to understand computing culture as it was, but as it could be, entangled with the materiality and intent, and I did not feel that traditional ethnography could paint the full picture of iterative design that was key to this work.

It was at that point that I realized I did not need to decide between the two methodologies. Instead, I could hack together a combined methodology that allowed me to focus on both aspects of my desired research, as long as I was being intentional about their combined strengths and limitations. I used DBR to determine the overall structure of my proposed research: four phases of evaluation and reflection, analysis and exploration, construction and implementation, and final evaluation and reflection (McKenney & Reeves, 2012) that would guide the redesign of the exhibit. Working through these phases would help me to analyze visitor interactions as they were influenced by the exhibit design, to review feminist technoscience literature and determine feminist design principles for computing exhibits, actually carry out the redesign work on the software and hardware, and to evaluate the final design, all in an iterative
manner. DBR also provided the flexibility to explore and probe different problems or aspects of the design (Kennedy-Clark, 2013) – something that gave me the freedom to explore aspects of the “design,” loosely defined, that I had not considered central to the exhibit when I first articulated the research plan. Within each phase, critical ethnography guided the data collection and analysis, especially as it pertained to computing identity development. It sought to link visitor and facilitator observations with fieldnotes and interviews with questions that probed their perceptions of themselves in relation to computing. Critical ethnography also “takes us beneath surface appearances, disrupts the status quo, and unsettles both neutrality and taken-for-granted assumptions by bringing to light underlying and obscure operations of power and control” (Madison, 2012, p. 5) – allowing me to take an activist position in my work, but also forcing me to disrupt my previous technocentric understandings of what counted as “doing computing” at the exhibit, something that required iterative reflection and reflexivity throughout data collection and analysis.

**Opening Up What “Counted” as Computing.** Informed by my readings in feminist technoscience, I was well-aware of historical and contemporary ways in which “computing” had been constrained such that it aligned with masculine, white, western perspectives on and pursuits in technology. Unfortunately, my own personal experiences with computing in my undergraduate degree in electrical engineering as well as the frameworks I had used in my master’s work had failed to show me what alternate imaginings of computing could be; at that point, for me, a large part of computing involved writing computer code (though not necessarily on a computer) and engaging with computational thinking concepts (Brennan & Resnick, 2012) such as sequences, loops, and conditional logic. Therefore, when I settled in to collect video
recordings of facilitators and visitors interacting with the workshop, I had to make a conscious effort not to pass judgement on which interactions counted as engaging with computing, and which were extraneous – something that proved to be difficult for me at first. Sure, changing the colour of the flocking shapes 15 times counts as computing, since it involved some understanding of RGB notation and that changing numbers on the screen created a change in the code. But is a young child carefully typing numbers dictated from a staff member computing, if they are not clearly connecting the typed numbers with the changes on the screen? What about a child who is perfectly content to move the mouse between the two screens as fast as possible, turning it into a game?

I had to eschew my previous technocentric (Papert, 1987) ideas about computing and instead embrace a phenomenological approach to computing (Sengupta et al., 2018), and once I experienced this shift in mindset, it opened up entire new ways to understand the exhibit and the interactions it promoted. A phenomenological approach to computing focuses on the sense experience (Merleau-Ponty, 1962) of computing, something that prioritizes multi-modal experiences in computing in context. Therefore, a learner’s engagement with computing is not limited to their production of computational abstractions, but is something that includes social, embodied, and affective experiences. The power of this framework quickly became clear to us: it provided a lens through which we could analyze visitor interactions to seek out the ways in which facilitators, parents, and children co-constructed experiences of computing beyond reading and typing code, such as parents making code changes specifically to entertain their toddler (I thank Basak for her keen eye in picking out this interesting interaction, which led to powerful analysis later on). Clinging to a technocentric approach to computing would likely have led to
design changes focused on the exhibit’s software and hardware. Instead, a phenomenological approach widened the design space to include the surrounding infrastructure ranging from the number of stools at the exhibit to facilitation practices. Additionally, identity and agency are relevant to a phenomenological approach to computing education – the experience of an individual at the exhibit is grounded in the context of their professional and personal identities, and encompasses much more than the code they write (Sengupta et al., 2019). Agency, in particular, is important when considering how particular experiences of computing may arise educators and learners, as they construct “computer models and simulations, embodied and material representations… to make code meaningful” (Sengupta et al., 2021, p. 26). As will be made clear in Chapter 3, agency also played a key role in how infrastructuring was carried out at the exhibit as well: facilitators needed to feel as if they had the expertise (and, sometimes, permission) to create new infrastructures such as physical blocks or particular strategies for facilitating the exhibit in order to make their experiences facilitation the computational exhibit a success. In other words, agency is very much at play in this research, though it will be made visible through the lens of infrastructuring. Early on in this research though, my understandings of the infrastructure at the exhibit were still limited. Time spent at the exhibit with facilitators would later make visible aspects of infrastructure and infrastructuring (Star & Ruhleder, 1996) that would eventually lead to a pivot in my research questions and methodology.

The Pivot

My pivot from design-based research centred on the redesign of the Hack the Flock exhibit to an in-depth look at the invisible infrastructuring work that museum facilitators were carrying out on a daily basis is explored in more detail in Chapters 3 and 4. Originally, the video
observations of visitor and facilitator interactions at the exhibit were going to be the main data sources for the project, and the facilitator interviews were intended to supplement that interaction data with facilitator impressions – meant to give me insight into why they facilitated the exhibit in a particular way, and how those reasons may be tied to the design of the exhibit. Specifically, I was looking for instances where some aspect of the exhibit’s design – the physical hardware, the code organization, the code comments, even the presence (or absence) of two stools at the exhibit – led to challenges in facilitator practice, which I then aimed to solve through a redesign of the relevant exhibit components.

However, as my fellow PhD student and I spent hours and days at the science centre, recording interactions, conducting interviews, and just generally spending time with the museum facilitators, we found more than what we were looking for. Unsurprisingly, some aspects of the exhibit (such as the non-intuitive interface and lackluster code comments) were leading to some challenges in their facilitation of the exhibit. But more importantly, facilitators were not simply giving up when faced with these challenges; they were improvising on the spot, using their technical and educational expertise and creativity to meet visitor needs in unexpected ways – skipping over a line of code that they felt would not be interesting to a five-year-old, modeling practices of experimentation and curiosity when faced with an unknown code change, and using social media to connect with other facilitators to share knowledge and their own creative “hacks” of the exhibit. Their ideas of the exhibit were not centred on what it was, but what it could be; they offered suggestions for facilitation guides, additional resources to provide to visitors, and small tweaks to computer code and facilitator practice that would make the exhibit more inviting and engaging to all visitors, regardless of their computing experience, age, or gender. We
eventually termed this facilitator practice as *infrastructuring*. Even more intriguing was their deep interest in the research taking place around the exhibit. Facilitators were interested in our research questions, data collection and analysis methods, and future work – a scope that went far beyond their original recruited role to facilitate the exhibit in front of a camera and answer some questions. This expertise challenged traditional deficit positionings of museum facilitators as in need of content or pedagogical training (Tran et al., 2019), or as data sources (rather than collaborators) in educational research projects (for exception, see, Piqueras & Achiam, 2019). While I had intended to bring in museum facilitators as co-designers of the exhibit and related educational programming later in the project as part of the community design meetings, my time spent with facilitators in the summer of 2019 made clear the importance of including them earlier and more centrally in the project than I had originally conceptualized.

The pivot to investigate facilitator infrastructuring at the exhibit led to increasing efforts to include the facilitators in every part of the project – not just as voices to inform design, but as co-designers and colleagues in the research process. It also drew me to new literature on DBR methodology and implementation including participatory design research (Bang & Vossoughi, 2016; Booker & Goldman, 2016; Fine & Torre, 2019) mediated praxis (Gutiérrez & Vossoughi, 2010), axiological innovations in design research (Bang et al., 2016), and the difficulties in overcoming power hierarchies in research-practice collaborations (Carlone & Webb, 2006). Alongside the future community design meetings, I wanted to hold separate design meetings for museum facilitators in which they would be empowered to voice issues and brainstorm solutions related to the exhibit. Unfortunately, only two of these design meetings were held before a global pandemic locked down the science museum, the research team, and the potential participants.
The Pandemic

The worldwide COVID-19 pandemic began with the discovery of SARS-CoV-2 in China in December 2019, and in mid-March 2020 it had reached Calgary, resulting in business and school closures, travel advisories, grocery store shortages, and fear. I will clearly admit that I have had immense privilege in this pandemic: I have a comfortable home office in which I can work, access to the technologies that I need, the ability to still write my dissertation (even if it is not the one that I had planned), and I have not been impacted financially. I recognize that my position is considerably better than many folks in Canada and around the world. And yet, at the same time, I felt a sense of loss. The interviews, the initial design meetings, the video-recordings of visitors’ interactions with the exhibit – all of these efforts were supposed to lead to powerful co-design sessions, wherein researchers, museum staff, and visitors could all work together to reimagine what a computational exhibit or educational programming for computing could look like in a science museum. Then, only a couple weeks after the ethics application was approved and I was just about to recruit participants, my research site closed, museum staff workers were temporarily laid off, and folks in my city and around the world were undoubtably more concerned with staying alive than designing the future of computing education, and rightfully so.

As the pandemic stretched from weeks into months, I reflected on the ethics of attempting to push ahead with the design meetings. The type of design meetings I had envisioned, which included sharing of materials, lengthy discussions, and close contact with many individuals were clearly not possible. I also considered holding online design meetings with museum facilitators, using video calling and digital tools to facilitate brainstorming. However, the museum facilitators were employees that were some of the hardest hit by the
pandemic, as their worksite went through a period of being closed entirely from March-July 2020, a gradual reopening that kept many hands-on galleries closed (reducing the need for facilitators in the building, as well as limiting access to the exhibit under study), and then additional closures in December 2020. The museum facilitators were in incredibly precarious work situations, and the last thing I wanted to do was to add more to their plates at that time.

Though I held out hope that I might be able to pull together some design meetings later in 2021, with the support of my committee I began to reconceptualize a dissertation without the community-based design that I had dreamed of. This provided me more space to focus on the science museum facilitators, their practice, their invisible labour, and the ways in which they contributed to shifts in my research methodology and axiology – themes which are carried across all three manuscripts in this dissertation. While I could not complete the entire macro cycle of design that I had set out to do post-candidacy, that does not mean that my other findings are any less valuable to the fields of learning sciences, computing education, or museum education. Additionally, it serves as a reminder that while doctoral research feels like one of the biggest, most important projects of all time while you’re neck-deep in it, it is really just a starting point for future discovery, inquiry, and innovation – and I look forward to building on the work I have done in the future.

**Statement of Contribution**

Chapter 2 is a sole-authored paper written entirely by me.

For Chapter 3, I came up with the original paper idea, collected data, analyzed the data, and wrote the majority of the manuscript. My co-authors, Pratim Sengupta and Marie-Claire Shanahan provided guidance with respect to the theoretical framework, contributed to the writing
of the introduction, helped to edit the findings section for clarity, and provided written and oral feedback on earlier drafts of the manuscript.

For Chapter 4, all authors took part in conversations to formulate the original idea. I collected data, analyzed the data, and wrote the majority of the manuscript. My co-authors, Pratim Sengupta and Marie-Claire Shanahan provided guidance related to additional sources to draw upon for the theoretical framework and provided written and oral feedback on earlier drafts of the manuscript.
For the past 13 minutes, Janelle has been facilitating a computational science exhibit with a family in a science museum. The father holds a toddler on his lap while his son, roughly 3 or 4 years old, sits on a stool and makes changes to the code with Janelle’s help. A video camera placed behind them records their gestures, their talk, the small screen with the computer code, and the larger screen that displays the running simulation. The boy has just finished adding images of monkeys and bees to the larger screen and has made the bees very big, but he signals his desire to make the bees even bigger to Janelle by waving his arms and exclaiming, “I want big and big and big!” From her previous work at the exhibit, Janelle knows that she can make the images bigger by making a particular number smaller, so she explains she’s going to try using a decimal number to make the bees even bigger. Everyone – father, boy, toddler, myself (the researcher), and facilitator – waits with anticipation as Janelle makes the change in the code and invites the boy to press the button that will run their new code.

The bees disappear and they are left with the blank screen - evidence of an error in the code. The dad remarks, “Oh, I think it’s broken,” and Janelle realizes the decimal didn’t work. Janelle and I engage in a quick problem-solving session in an attempt to realize the boy’s dream to make the bees even bigger: would multiplying by a number work? How do you indicate multiplication in the code? We try a few different strategies, knowing that we don’t have long before the boy’s attention will be attracted by the other sights and sounds in the gallery. Unfortunately, we cannot make the bees any bigger than before, so
we resign ourselves to returning the code to its last working state with big (but not big enough) bees. The boy looks at Janelle, gesturing with his arms and again saying, “So big and big and big!” Janelle replies that that’s as big as the computer can make them, and the dad echoes her phrasing. However, Janelle responds quickly with an idea of something else they could do: “We could maybe make the monkeys bigger?” The child agrees, and with that they are back to their playful exploration of the code that lasts another 5 minutes before the family moves on, thanking Janelle for her assistance at the exhibit. (Video-recording at a Canadian science centre, July 23, 2019)

The field of educational research has shown increasing interest in the teaching and learning that takes place in informal settings, including science museums. These institutions may host school groups, families, adults, and children, providing valuable learning opportunities that allow learners, especially those who may be excluded from science in formal learning spaces, to have opportunities to experience and perform science in playful and transformative ways (Horn et al., 2012; Rahm et al., 2005; Rahm & Ash, 2008). Some examples of previous research in science museums includes investigations of family interactions (Dierking & Falk, 1994; Zimmerman et al., 2010), scientific claim-making (Kisiel et al., 2012), new exhibits and interfaces (Horn, 2018) and students’ changing scientific conceptions (D. Anderson et al., 2000).

While science museums are certainly learning environments full of possibilities, they are also workplaces. Some of the most visible science museum employees are museum educators (also known as docents, explainers, or facilitators). Science museum educators play a critical role in visitor sense-making (Afonso et al., 2019; Hayward & Hart, 2015) and are often considered to
be the public face of their institutions (Dragotto et al., 2006). Despite their critical role, literature on the roles and experiences of science museum educators is scarce (Pattison et al., 2018; Tran, 2007). As we can see in the opening vignette, the labour of museum facilitators such as Janelle is crucial in engaging visitors with new scientific ideas and tools. There are also dual expectations on her labour: she has particular tasks and work to do as part of her institutional role as a museum facilitator (namely, engage with visitors and work with them at exhibits), but as a participant in an educational research project, she has additional demands on her labour: spend time facilitating a new exhibit with visitors, participate in interviews, and think about the ways in which the design of the exhibit can be improved. These dual forms of labour – as employees in an institution, and as participants in a research project – must be taken into consideration by educational researchers. Additionally, education scholars are calling for researchers to attend to issues of power in their research practices (Philip et al., 2018) – something that is increasingly important as researchers attempt to form partnerships with science museums and carry out projects with implications for research and practice.

But when we partner with science museums, who exactly are we partnering with? Educational researchers may work closely with directors, managers, and exhibit designers to design innovative exhibits and programs. However, it is the museum educators whose on-the-floor job duties may require them to take part in new professional development, work with visitors in a specific way, or facilitate a newly-designed exhibit – not the managers or designers. In light of the critical role that science museum educators play in much of the research that is carried out in science museums, in this paper I present results of a critical systematic review of the literature focused on science museum educators. My critical theoretical lens draws upon key
themes in feminist literature and analyses: power, positioning, and labour. I investigate how these themes are intertwined, that is, how the positioning of museum educators has implications for the power they hold both in their institutions and in educational research projects. Additionally, I seek to make visible the labour that museum educators carry out on a daily basis, labour that also feeds back into their positionings by visitors and self-positionings, and reflects the level of power and agency given to them.

I begin by reviewing the research questions that guided my critical systematic literature review. I next define the three themes that inform my critical feminist lens: positioning, power, and labour. After explaining the methods and selection criteria for my systematic literature review, I discuss four main themes that emerged from the analysis: (1) the high importance yet low status of museum educators in their institutions, (2) comparisons of museum education and school science teaching contexts, (3) the professionalization of museum educators, and (4) the roles that museum educators are given within educational research projects and research-practice partnerships. Finally, I discuss the connections between these themes and offer recommendations for future educational research involving science museum educators.

**Research Questions**

The following research questions guided a critical systematic review of the museum educator literature:

- How are museum educators positioned within (a) their institutions, (b) reported research projects, and (c) the field of educational research overall?
- How is this positioning intertwined with conceptualizations of power?
- How is museum educators’ labour conceptualized and made (in)visible?
Theoretical Perspectives: Positioning, Power, and Labour

Positioning

Positioning refers to “the assignment of fluid ‘parts’ or ‘roles’ to speakers in the discursive construction of personal stories that make a person’s actions intelligible and relatively determinate as social acts” (van Langenhove & Harré, 1999, p. 17). These storylines unfold in collaboration with others, and are dependent on existing social structures and recognizable roles within them (Davis & Harré, 1990) – including cultural institutions such as science museums. Leander (2004) argues that this positioning is not only local, but depends upon a “social/individual matrix” which “links locally situated action to ideological and seemingly recognizable ways to be” (p. 210). This positioning can be interactive, in which one person is positioned by another, or reflexive, in which someone positions themself (Davis & Harré, 1990). Within this literature review, attention is paid to both kinds of positioning; authors may position museum facilitators, as research participants, in particular ways through their writing, and museum facilitators may also position themselves in their interviews.

Existing literature on positioning in science education spaces has focused mainly on the positioning of the learners. For example, Rahm (2008) investigated the hybrid positionings of youth within school science, comparing their positionings within typical school science activities and their positionings in projects involving partnerships with scientists and museums. Engaging in hands-on science projects in archeology and robotics, youth were able to position themselves positively towards science and school, something that contrasted with previous negative self-positionings in school science. Rahm (2007; 2008) also noted that after-school settings, such as a girls’ science club or youth gardening space, provided space for youth to challenge hegemonic
notions of scientists (often as white men) and science and instead position themselves as insiders in science, building on their own understandings and desires within the discipline. Engaging with science in these new ways, guided by facilitators and scientists, provides space for youth to be empowered and self-author their own understandings of and positionings within the discipline of science (Rahm & Gonsalves, 2012).

However, the positioning of the educators in informal science spaces has received less attention. These spaces are simultaneously spaces for disciplinary engagement with science and also workplaces with specific goals and constraints. Rahm and Gonsalves (2012) briefly mentioned how youth’s construction of science may come into conflict with that of the instructors – such as when a group of students wanted to study the paranormal as part of a science newsletter initiative, and idea that was shot down by other instructors as being unscientific. Avraamidou’s (2020) case study of a young Muslim woman working as an academic in the field of physics utilizes an intersectional case-study and life-history approach. She found that Amina’s identity as a scientist intersected with her gender, racial, religious, and socio-economic identities. Though Amina discussed her professional work, her teaching duties were not mentioned in the article, and therefore it is not possible to make connections between her positionings in science and academia and her work as an educator. This gap is critical in our understandings of science education, as our sense of what science is, and how it should be taught, is based on our positionings within the discipline. In this way, understanding the positionings of museum educators as they relate to both science and their professional practice has implications for the field of science education, as it may impact their own professional and
disciplinary identities as well as the view of science that they share and construct with learners in their institutions.

Museums are not just places that facilitate positionings within science; they are also places where employees are positioned as workers. The positioning of museum educators has direct implications for their power and labour within their institutions. Beyond the job duties set out in their employment agreements, being positioned in a particular way also “conveys the rights, duties, and responsibilities presumed to be associated with such positions relative to shared cultural repertoires” (K. T. Anderson, 2009, p. 292). In this way, how museum educators are positioned has an impact on the work that they can do and the work that is expected of them in ways that may not be explicit within traditional employment documentation. Additionally, according to Holland et al. (1998), positional identities impact power, deference, entitlement, and social affiliation as they are manifested in day-to-day interactions - including interactions that occur within workplaces. However, it is important to note that positioning, and especially reflexive positioning, can be used as a tool to challenge existing positions. Davis and Harré (1990) note that the discursive practice of positioning can be used to negotiate new positions, and van Langenhove and Harré (1999) point out that self-positioning can be used by an individual to express their professional identity. How an individual positions themself can be a call for others to look at them and relate to them in particular ways (Vanassche & Kelchtermans, 2014). For that reason, it is imperative that we investigate the ways in which museum facilitators’ self-positionings are similar or different to how they are positioned by researchers and authors within the literature, as it may showcase ongoing efforts of museum facilitators to challenge their
existing positionings, opening up new ways of researchers and museum facilitators to interact and conduct research within research practice partnerships.

**Power**

Philip and Gupta (2020) defined power as “the ability to alter or maintain the physical, social, structural, cultural, and political conditions, resources, and/or opportunities of individuals and collectives” (p. 197). For museum facilitators, having power may refer to being able to voice concerns about or change institutional practices or environments, something that, for them, is rarely the case (Ash et al., 2012). Power is interconnected with positioning, as museum facilitators may be positioned discursively (within research and day-to-day interactions) and institutionally (through employment details) as employees with or without power within their institutions. For example, as typically low-paid, entry-level employees, museum facilitators are positioned at the bottom of their institution and as being in need of additional training, and are not given opportunities to make their voices heard in museum administration or design decisions that have considerable impacts on their day-to-day work. However, when facilitators guide visitor interactions with exhibits in a science museum, they may draw upon their scientific knowledge and positioning as an educator to claim, whether intentionally or not, the powerful role of “expert” within the interaction.

Looking at power from a different angle, researchers within the Learning Sciences have begun to pay more attention to power and positioning within their research – specifically, the fact that educational researchers generally hold the power to determine research questions, methods, analyses, and dissemination, while participants are not part of those decisions (Bang & Vossoughi, 2016; Esmonde & Booker, 2017; Philip et al., 2018). In summary, this review aims
to investigate the power that museum facilitators may hold, or not hold, both within their institutions and within research projects in which they are asked to take part.

Labour

Feminist scholars have studied labour in different ways, from Marxist analyses to root out exploitation and social relations of work, to investigations of the types of work that women do in the public (i.e., workplace) and private (i.e., home) spheres. As I will explore later in this paper, the work that museum facilitators do is largely under-studied and underrecognized (Tran et al., 2019). This work is not just tied to the daily tasks and necessary skills (some of which may be invisible to outsider observation; Rose, 2004), but also the conditions of that labour: part- or full-time, volunteer, with or without benefits, stable or precarious. Science museums, just like any organizations, can become a site of inequality. Acker (2006) defined organizational inequality as “systematic disparities between participants in power and control over goals, resources, and outcomes; workplace decisions such as how to organize work; opportunities for promotion and interesting work; security in employment and benefits; pay and other monetary rewards; respect; and pleasures in work and work relations” (p. 443). Institutions such as science museums may invite, or, conversely, limit and deny specific labour and performances through the ways in which their workers are defined (Rose, 2004). Additionally, various organizational controls can serve to ensure that workers accept this system of inequality (and therefore, their positioning within it) even as they protect the power of management (Acker, 2006). Museum facilitators’ positioning within this system of inequality can result in a lack of voice within their institution, a lack of access to organizational resources and claims (Ash et al., 2012; Avent-Holt &
Tomaskovic-Devey, 2019), and a potential lack of meaningfulness in their work (Rose, 2004), all of which have implications for their daily labour.

We must also consider labour beyond cognitive and physical tasks; feminist studies of organizations have also pointed out work that employees do that goes above and beyond their stated job requirements, and yet is expected by managers and colleagues. For example, Fletcher (1999) found that women engineering designers were implicitly expected to complete “women’s work” such as mentoring coworkers and interfacing between teams. However, this work was not recognized as part of their performance reviews, which centred on technical performance, and the men employees were not expected to perform that work – therefore, this labour became invisible. Additionally, Hochschild (1983) coined the term “emotional labour” to describe the work that employees must do to manage and control their emotions while at work, such as when they interact with customers, colleagues, and managers. Employees may be expected to “perform” specific emotions, even if they do not actually experience them. Munro (2014) found that museum employees carry out emotional labour when they deal with community members’ emotions in discussions around community engagement. Museum facilitators may need to perform emotions of excitement and interest when interacting with visitors at an exhibit. While this labour can be exhausting, some scholars have argued that emotional labour can produce feelings of well-being, satisfaction, and a sense of connectedness (Hardt, 1999). Thus, the labour that museum facilitators perform on a daily basis goes beyond their stated job requirements and physical/cognitive tasks to include the hidden and emotional aspects of their work.

STEM disciplines have a history of promoting technical and scientific knowledge without acknowledging the subjectivity and labour that make these innovations possible (Galison &
Daston, 1992; Keller, 1996). In particular, labour that is not directly related to technical output, such as team management, mentoring, and emotional labour is devalued or even made invisible (Fletcher, 1999). Instead, the data is assumed to “speak for themselves,” ignoring the way that science is created “out of a complex dynamic of interwoven cognitive, emotional, and social forces” (Keller, 1996, p. 4). Thus, to be disciplinary in science is to erase labour, and this viewpoint has the potential to spill over to our formal and informal education spaces. The labour that educators in such spaces carry out on a daily basis may be pushed to the background in favour of analyses of scientific content knowledge. Therefore, it is necessary for us to take a deeper look at the labour of science museum educators, not only within their professional practice but within educational research projects intended to study or improve science education in these informal spaces.

**Literature Selection, Methods, and Analysis**

**Databases, Search Terms, and Initial Filters**

In mid-June 2020, I conducted a database search using EBSCO. In order to widely survey the existing educational research, three databases were included in the search: ERIC, ERC, and ASC. A default (unqualified) search was conducted, which looks for keywords within the subject, title, abstract, author, and keywords. Keywords and Boolean operators used for this search were: “science” AND “museum” AND (facilitator* OR explainer* OR floor staff OR educator* OR docent* OR interpreter*). The first two keywords were selected to narrow down the articles to those that take place within museums, and within the discipline of science. The diversity of words used to describe the museum staff members was necessary as different informal science institutions use different words for the same position – that is, a staff member
who operates mainly on the floor and interacts with visitors in different ways, such as providing explanations, conducting mini experiments, and giving presentations, among others. These positions may be paid or volunteer, full-time or part-time. For ease of reading this paper, the term “facilitator” will be used to encompass the above terms. Additionally, the wildcard (*) operator allows the search to match both “facilitator” and “facilitators”.

Two additional filters were used on these search results. Results were limited to those within academic journals and written in English. Specific journals were not selected for this literature review; I decided that limiting the search to top journals within the domains of educational research or museums may filter out first-person accounts given by facilitators within smaller or less prestigious journals. With these search terms and filters, once exact duplicates were filtered out, the database search yielded 448 raw results.

**Inclusion Criteria**

In order to narrow down the search results, two inclusion criteria were set. I read the abstract of each article to determine whether or not it met these inclusion criteria, with the rationale that the criteria outlined below needed to be salient enough to the article to be mentioned specifically within the abstract. If an article did not have an abstract, it was automatically excluded from the review.

**Science Museum Setting.** Despite the inclusion of “science” and “museum” as keywords, the raw hits varied widely in subject and setting. Some results focused on scientific articles unrelated to education. Many results included educational settings that were not science museums. Therefore, only articles that focused on the setting of science museums were included. In this case, a science museum was defined as a setting that includes a variety of hands-on
exhibits and other educational activities specifically for learning about science content, including subjects of chemistry, physics, biology, natural history, etc. To further explain this criterion:

- Museum settings without an explicit commitment to science education (such as art galleries or history museums) were excluded.

- Settings which focused solely on animals and the environment (e.g., aquariums, zoos, natural parks) were excluded due to their typical lack of hands-on exhibits.

- Planetariums were excluded because although they focus on sky science, the articles surveyed were focused on dome shows (portable or permanent) rather than hands-on exhibits.

- Articles which included a variety of settings (for example, formal classrooms and science museums and an after-school club) were excluded as results did not typically delineate between the settings, and as such it was impossible to determine which aspects of the study were specifically related to the museum facilitators.

**Focus on Facilitators.** The other criterion for inclusion was that the articles had to focus specifically on museum facilitators. A “focus on facilitators” was considered broadly to include investigations of pedagogies, experiences, impact, and training programs. Articles which included participants from many levels of the science museum (for example, directors, managers, and floor staff) which did not clearly differentiate between these levels in the analysis were excluded, as the focus of this literature review is specifically on floor staff. The term “educator” in particular required close attention to determine if the educator was involved in delivering educational content and interacting with visitors on the museum floor, or if they were simply designing educational programming in an office setting (which would then be carried out by
others). Additionally, museum facilitators had to be the main focus of the article – articles which, for example, detailed the experiences of children in science museum school visits and included a short paragraph in results about the impact of facilitators were excluded.

After I read through each of the 448 article abstracts and applied the above inclusion criteria, 26 articles were selected for further analysis.

Analysis

I began the critical analysis by first reading and summarizing each article. After reading each article once, I went back and reread each of them, noting two aspects that I felt were beginning to emerge as salient to my analysis: the roles held by museum facilitators in the article/study (e.g., interviewed, observed, acted as co-researchers), and whether or not training/professional development was mentioned as a motivating factor for the study and/or as a possible implication for the study. Next, I proceeded with a thematic analysis (Miles & Huberman, 1994) of each of the articles. This thematic analysis was informed by my critical feminist theoretical lens, in which I was concerned with issues of positioning, power, and labour within the articles. However, the codes were not pre-determined by this lens. The first level of coding was conducted in vivo, using the exact words or phrases within the article. I then used constant comparison (Glaser & Strauss, 1967) to group the codes into emergent clusters and themes. Four overall themes emerged from my critical analysis: (1) the high importance yet low status of museum educators in their institutions, (2) comparisons of museum education and school science teaching contexts, (3) the professionalization of museum educators, and (4) the roles that museum educators are given within educational research projects and research-practice partnerships. I elaborate on each of these themes in the sections below.
Findings

**High Importance Yet Low Status of Museum Educators Within Their Institutions**

**Facilitating Engagement and Meaning-making: Museum Educators as the Public Face of the Institution.** Museum educators were acknowledged to be an essential part of the museum experience (Dragotto et al. 2006; Nyhof-Young, 1996; Pattison & Dierking, 2012). In his larger study involving docents in a natural history museum, Allen and Crowley (2014) pointed out that docents may be “the only point of human contact for visitors to museums” (p. 85), lending credibility to Dragotto et al.’s (2006) assertion that museum educators act as the “public face” of the museum. Museum educators were also seen to play a critical role in advancing the museum’s missions (Dragotto et al., 2006), especially the institution’s educational agenda (Shaby et al., 2019; Tran, 2007). The acknowledgement of this role has occurred as both science museums and educational researchers began to recognize the powerful ways in which front-line museum educators can support learning in such informal spaces (Pattison & Dierking, 2012) and lead efforts to engage new audiences (Bevan & Xanthoudaki, 2008). The language used by authors to describe museum educators points to their (verbal) positioning as essential employees in their institutions.

Even though the work of museum educators is not well-characterized (Pattison & Dierking, 2012), existing descriptions of the impact that they have on the visitor experience aligns with their positioning as employees essential to the educational mandate of the institution. Across the reviewed literature, museum educators were understood to mediate meaning-making of visitors to science museums (Afonso et al., 2019; Hayward & Hart, 2015). Their approaches to this mediation varied, including engaging visitors in conversation (Hayward & Hart, 2015),
asking questions and scaffolding understanding (Allen & Crowley, 2014), engaging visitors with items from museum collections (Hecht et al., 2020), interacting with and assisting visitors at hands-on exhibits (Shaby et al., 2019), communicating new scientific concepts (Afonso et al., 2019), and working with teachers to develop lessons for school groups (Tran, 2007). This focus on visitor engagement and meaning-making has significant impacts for visitors. Pattison et al. (2018) noted that “facilitators enrich family learning not only by increasing engagement time, but also by increasing the quality of that engagement’’ (p. 22). In this way, we can see that the positive impact of museum educators on the visitor experience is due to their labour, creating opportunities for understanding and engagement. While the work of asking questions and providing explanations, for example, may seem simple, the daily work of museum educators is complex and heterogeneous.

**Complexity and Heterogeneity in Museum Educator Work.** Acknowledgment of the complexity of facilitation beyond their day-to-day tasks is something that is beginning to emerge within the museum educator literature. Pattison et al. (2018) wrote that museum facilitation is, in itself, a complex social situation involving role negotiation between family members and museum staff. Museum facilitation is not an established routine (Pattison et al., 2017), but instead “may necessitate both an artistic and scientific touch” (Johnson et al., 2019, p. 325) when balancing wonder with content, responding to alternate scientific conceptions, and striking an appropriate balance between transmission and inquiry modes of learning for visitors (Hecht et al., 2020). When visitors walk through the doors of a science museum, whether they are families or school groups, adults of children, museum facilitators flexibly respond to their unique learning needs and goals (Pattison et al., 2017; Tran, 2007), sometimes even adapting on-the-fly to late
school busses and unexpected questions. Additionally, museum facilitators have to carefully balance tensions between “hosting” and lecturing, and educating or entertaining visitors (Nyhof-Young, 1996). It becomes clear that museum facilitation is not something that can be carried out by following a checklist or lesson plan; the on-the-floor educators must respond quickly and appropriately to each complex learning situation in which they find themselves.

Researchers who interviewed museum educators pulled back the curtain to reveal an essential heterogeneity in their work (Piqueras & Achiam, 2019). Of course, museum educators performed a variety of educational tasks at the museum, including running programs, giving tours and demonstrations, explaining exhibitions, and developing and evaluating educational content. On top of their educational duties, museum educators also carried out other tasks including administrative work, training volunteers, fixing exhibits, finding lost children, security, visitor wayfinding, and even housekeeping (Bailey, 2006; Diamond et al., 1987; Ji et al., 2016). While some museum educators specifically mentioned enjoying the variety of their work (e.g., Bailey, 2006), it is important to note how museum educators routinely carry out tasks that conceivably fall outside the purview of “education.” Specifically, the addition of traditionally low-status tasks such as housekeeping, repair, and administrative work may have implications for how museum educators are viewed by visitors, or how they position themselves (Rose, 2004). Only 44% of visitors surveyed in Diamond et al.’s (1987) study understood the museum’s “explainers” as active agents to help visitors with their understanding; 39% felt that explainers were passive who gave information (if asked) and looked after exhibits, and 17% thought that the explainer’s role was related to maintenance. Additionally, Shaby et al. (2019) noted in their study that when museum educators mainly interacted with visitors to ensure they knew how to
use the exhibits properly, they fell into the role of “technicians” and engaged in few deeper conversations about the scientific phenomena. Thus, we can see how labour and positioning are intertwined for museum educators.

**Difficult Work and Variable Employment Status.** The labour of museum facilitators is not just complex – it is difficult. Participants in only one article stated that museum education work was easy and undemanding (Ji et al., 2016). Across the other articles, the work was characterized as difficult and challenging (Diamond et al., 1987; Harlow & Skinner, 2019; Nyhof-Young, 1996; Pyatt et al., 2009). Diamond et al. (1987) stated that the floor staff in the Exploratorium were given “the most difficult task in the museum” (p. 643), referring to their work with the public, which Pyatt et al. (2009) described as a job requiring a person to wear many hats at once - an educator, a public speaker, and a leader. The labour that museum facilitators put into their work on a daily basis was even described as “surviving on the floor” (Diamond et al., 1987), a metaphor that highlights the extreme workload, its complexity, and its perceived importance to the museum. Some museum educators felt overwhelmed by their multiple responsibilities and projects, compounded by unpredictability in their work and a lack of institutional resources to meet those demands (Bailey, 2006; Ji et al., 2016; Moore et al., 2020).

This lack of access to resources speaks to a lack of power of museum educators within their institutions. As a result, museum educators were often “spread thin” (Dragotto et al., 2006) across their heterogeneous workload. Apart from their workload, museum educators also had to deal with institutional issues such as a lack of communication routines that resulted in feelings of distrust and nervousness during managerial observations (Tran et al., 2019), or restrictions in
how they were expected to explain scientific content to visitors (Afonso et al., 2019), again pointing to managers wielding power over the daily work and evaluation of museum educators.

Finally, museum educators had to carry out emotional labour on a daily basis: it was expected that they would maintain a positive, professional attitude with visitors (Ji et al., 2016; Nyhof-Young, 1996; Johnson et al., 2019), even as they dealt with potentially controversial topics with visitors (Allen & Crowley, 2014). Complex role negotiation meant that museum educators had to deal with their attempts to direct learning goals and engage with visitors rebuffed or ignored by the adults in family groups, situations which can be uncomfortable (Pattison & Dierking, 2012; 2013). Currently, very few researchers have considered the demand that is placed upon museum educators in terms of their skills, attitudes, and labour as they carry out their difficult work on a daily basis (Tran, 2007).

We would hope that with the acknowledgement of the difficult, crucial work that museum educators do within their institutions, they would be rewarded within their employment contracts. However, the pay and scheduling of museum facilitators varied across institutions. I found a huge disparity between museum education being positioned as a tenured, full-time position with benefits (Ji et al., 2016) versus a minimum-wage, entry-level position (Librero, 2005). In some cases, museum work offered stable, full-time employment with a good salary and benefits (Ji et al., 2016; Nyhof-Young, 1996). In other institutions, museum educators were hired as part-time, contract employees (Librero, 2005; Pattison et al., 2018; Shaby et al., 2019). While part-time work was viewed as a benefit in terms of flexibility (Nyhof-Young, 1996), their part-time employment caused some museum educators to feel the stress of low wages, the need to work evenings and weekends, job insecurity, and high turnover (Allen & Crowley, 2014; Bailey,
Additionally, museum education researchers cannot ignore the huge burden of labour placed upon unpaid volunteers who may work as docents, facilitators, and educators; in some museums, volunteers may outnumber paid museum staff by three to one (Glaser & Zenetou, 1996).

The monetary value placed on the labour of museum educators varies considerably, and these employment factors may play a role in their positioning within their institutions – as valuable, respected full-time employees? Or easily-replaceable, part-time, low-cost workers? The details of their employment have implications for their positioning by both themselves and others within their institutions. For example, there museum education may be viewed as a “fallback career” (Ji et al., 2016) and educators are perceived (and may position themselves) as not being “real teachers” (Ji et al., 2016; Tran et al., 2013), showcasing a low status in relation to school teachers. Additionally, labour journalist John P. Hoerr (1988) has noted that wage workers have been perceived since industrialization “to lack the competence to handle complex issues and problems requiring abstract knowledge and analytical ability” (p. 273). While not all museum educators are wage workers, those working for low, hourly wages may be positioned as workers who are in need of direct instruction and oversight. Importantly, this positioning can impact their power and agency within their institutions.

**Agency and Voice.** This positioning also has implications for the power and agency museum educators hold within their institutions. I have already noted that museum educators did not have the power to access or request institutional resources to meet the demands of their heavy workload (Bailey, 2006; Ji et al., 2016; Moore et al., 2020). Ash et al. (2012) had previously found that museum educators did not think of themselves as having power and voice
in museum operations or administration, facets of their institutions, while not necessarily an explicit part of their job duties, still have a significant impact on their daily work. This self-positioning was echoed by Ji et al., (2016), who argued that the “central plan” culture in Chinese museums ignores the voices of frontline museum staff. However, some articles in this review pointed to the positive impact that taking part in research projects can have on museum educators in terms of their perceived agency.

Pattison and Dierking (2012) concluded with a call that educational researchers should advocate for front-line educators in museums, both “on their behalf and in partnership with them” (p. 78). Tran et al. (2013) found that after taking part in their Reflection on Practice program, museum educators “were more emboldened to speak up, be critical, and make changes” (p. 342) within their institutions. As they created a sense of community, they felt empowered to make changes that would impact their daily work, such as questioning existing institutional learning goals and practices. These results are heartening, and point to researchers attending to issues of museum educator agency and voice within their research. However, it is clear that we still have a long way to go – outside of these examples, museum educator voice and agency were not mentioned in the articles I reviewed. This is concerning, showcasing a preoccupation with the pedagogical practices of museum educators (and the training to improve them) rather than noting issues of power and positioning that, while invisible, certainly play a role in their professional practice.

**Science Museum Education in Relation to School Science Teaching**

The relationships between science education in museums and science education in schools varied across the analysed articles. This variance served to expose tensions between the
two in terms of notions of expertise, pedagogy, goals, and institutional influences. In this section, I aim to explore these tensions as they impact the positioning, labour, and power of museum educators in science museums.

**Science Museum Affordances and Educator Expertise.** Science museums have been said to have unique affordances for science education that set them apart from traditional school science classrooms (Bell et al., 2009; Falk & Shepard, 2006). Additionally, some educational researchers have argued that museums may provide space for different ways of being and knowing in science, outside of formal trajectories, which can have particularly significant impacts on learners with identities which have been historically marginalized in school science learning (Allen & Crowley, 2014; Dawson, 2019; Horn et al., 2012; Rahm et al., 2005; Rahm & Ash, 2008). Science museum educators interviewed by Bailey (2006) noted that the learning in museums is more individualized and learner-directed, takes place in a natural and relaxed atmosphere, and generally involves a positive museum audience. Additionally, the diversity of their visitors in terms of age, interest, and previous science understandings require museum educators to think of their practice as expansive, as compared to school science which often involves students sorted by age, discipline, and sometimes “ability” (Bevan & Xanthoudaki, 2008).

Some authors described museum educators as “experts” in the educational affordances of their institutions, including the programs and resources available (Tran, 2007). Museum educators were positioned as experts in terms of content and pedagogy (Bevan & Xanthoudaki, 2008; Johnson et al., 2019; Uzelmeier, 2006) and utilized a unique set of skills in their work (Dragotto et al., 2006). They drew upon prior knowledge and interests (Hayward & Hart, 2015),
intuitive understandings of exhibits gained through experience (Diamond et al., 1987), in-depth training and continual professional learning (Allen & Crowley, 2014; Nyhof-Young, 1996), and their colleagues (Librero, 2005) to engage with visitors and perform their duties. In these descriptions, museum educators are positioned as having expertise and carrying out complex work on a day-to-day basis. However, as evidenced by the low number of articles related to museum facilitator practices and expertise in this review, the body of literature related to science education in museums is relatively small when compared to theories relating to school science – something that has led multiple authors to ground their museum work in school science literature instead, which I argue can lead to inaccurate conflations between the two.

**Where School Science Literature Falls Short: The Erasure of Institutional Influences.** Certainly, school science and museum science are not entirely dissimilar – there are some strong similarities between the two (Tran, 2007). The disciplinary content is the same, especially as both museum educators and school teachers attempt to expand notions of what “counts” as science in their learning environments (Bevan & Xanthoudaki, 2008; Nyhof-Young, 1996). Ideas mentioned in articles analyzed for this review included the fact that both teachers and museum educators should consider their use of language, metaphor, and analogy while providing explanations of scientific phenomena (Afonso et al., 2019); they may face the same problems in terms of a push towards inquiry-based, participatory strategies for learning (Allen & Crowley, 2014); and both may benefit from appropriating culturally-recognized strategies for
teaching, such as standing in front of a group visitors or students, to perform the role of a knowledgeable and authoritative expert (Pattison & Dierking, 2013).

However, as we have seen in the previous section, museum education has some unique affordances and constraints that set it somewhat apart from school science. In particular, institutional factors have a considerable impact on the labour that museum workers do to meet their museum’s goals. In order to dive deeper into these institutional influences, I explore two common critiques of museum educators that emerged in this review: museum educators as lacking scientific content knowledge, and museum educators as lacking pedagogical expertise and relying on instructivist approaches with visitors. These critiques reflect a deficit view of museum educators that do not necessarily take into account their job requirements and institutional practices that impact their work as it is observed by educational researchers, limiting the applicability of school science research (often cited in the background sections of these articles) on their practice.

*An Ill-defined Emphasis on STEM “Content Knowledge”*. Evaluations of museum educators’ content knowledge in STEM subjects vary, and yet, across the studies, a remarkable characteristic is the lack of epistemological depth in defining what counts as “content knowledge” and/or expertise in science or STEM fields that is expected from facilitators. As I have previously mentioned, some authors positioned museum educators as content experts (Bevan & Xanthoudaki, 2008; Johnson et al., 2019; Uzelmeier, 2006). However, others argued that while educators may be interested in STEM, they may lack full understandings of the content behind the exhibits that they are expected to facilitate (Harlow & Skinner, 2019; Shaby et al., 2019). Nyhof-Young (1996) spoke to one host (museum facilitator) who was worried
about not having the “right answer,” as they “did not want to mislead or misinform the public” (p. 73), voicing a fear that their content knowledge may not be adequate. Unsurprisingly, articles which positioned museum facilitators in this way often followed up with suggestions for future training. Bizarrely, none of the reviewed studies in which researchers observed museum educators as they worked revealed situations in which their content knowledge was insufficient – the presumed lack of content knowledge was included in the introduction of many articles, but was not necessarily supported in the data.

This calls for a deeper, epistemological examination: What do authors mean by “content knowledge” or the “facts” of science? In Nyhof-Young’s (1996) article, one museum facilitator thoughtfully pointed out that her institution tended to make “Western science seem all powerful and the only way of knowing and doing” (p. 73). As educational researchers and practitioners have argued for decolonial, anti-racist, Indigenous, and other cultural ways of knowing in science (Kimmerer, 2013; Sammel, 2009; Snivley & Corsiglia, 2001), it would be inappropriate to judge museum educators’ knowledge of science based solely on their ability to articulate the Western scientific facts that largely dominate formal schooling. Museum educators themselves have engaged in lively discussions to what “counts” as STEM, “with positions ranging from science as facts and science as practice” (Bevan & Xanthoudaki, 2008, p. 116). Within the science as practice perspective, it may be more appropriate to consider within their “content knowledge” their practices of modeling, questioning, discussing, and even acknowledging when they do not know an answer (Pickering, 1992) – portraying science as more than a simple collection of facts to be memorized and recalled, and possibly easing the burden for facilitators who are worried that they may not know the answer to a question.
Lehrer (2009) noted that “although the generation, test, and revision of models are fundamental to the professional practice of science, they are rarely emphasized in school science” (p. 758). Thus, promoting a view of science as practice requires a definition of “content knowledge” that is epistemologically rooted in this view, rather than assuming that content knowledge is a collection of scientific facts. As an illustrative example, consider a facilitator who expertly guides family members through a process of asking questions about the animals they see in an aquarium touch tank, making hypotheses, and testing them based on observed behaviour (Rowe & Kisiel, 2012). These actions can be viewed simultaneously as pedagogical strategies as well as scientific content knowledge, alongside the more traditional knowledge about the behaviours of those animals. In another context, a parent and two children working at a public computing exhibit (Sengupta & Shanahan, 2017) noted that their hacks in the code had created a “prison” for the flocking shapes (i.e., a “vortex” that the flocking shapes could not escape due to the strong cohesive forces). The mother used this opportunity to discuss jail cells and prison overcrowding with the children, remarking to the facilitator that she often tried to connect everyday experiences with lessons on social justice – an instance of boundary play, working to redefine the borders of what is considered scientific in this context. Knowledge of prison overcrowding would not traditionally be considered to be “scientific content knowledge,” especially in the context of computational science. However, it became relevant to their scientific exploration of the flocking model and ongoing discussion. Thus, in considerations of boundary play and science-as-practice, the notion of “content knowledge” falls flat; definitions of “content knowledge” must be epistemologically rooted in the perspective of science that museums are aiming to share with visitors, which often go far beyond simply presenting scientific “facts.”
Additionally, we cannot ignore the ways in which the museum educators’ labour practices and/or organization may require (or not require) particular levels of STEM knowledge. As I have argued in the previous section, museum educators often serve to welcome visitors to the museum, explain how exhibits work, and stimulate scientific conversation and understanding. Not every interaction between a museum educator and visitors requires in-depth scientific understanding – in fact, Pattison and Dierking (2012, 2013) noted that at times when facilitators attempted to direct scientific learning at exhibits, some parents rejected the new learning goal and simply stated that their child just wanted to play. In addition, the wide variety of labour that museum educators are expected to perform on a daily basis includes many tasks that do not necessarily require scientific knowledge – helping visitors navigate the museum, finding lost children, performing maintenance/housekeeping, drafting budgets, etc. Museum educators’ on-the-job knowledge is necessarily broader than just scientific content knowledge. Finally, there are ways in which labour organization in science museums can contribute to a perceived lack of content knowledge. While some museums may prefer hiring museum educators with distinct science qualifications, that is not the case everywhere. Diamond et al. (1987) specifically noted that their explainers were “not all science ‘whizzes’” (p. 646), and instead had varied interests including people, literature, art, science, politics, and sports. Hiring museum educators with strict expectations for university-level science credentials may impact the diversity of the museum’s staff given the continued lack of diversity in post-secondary STEM programs (National Science Foundation, 2017). This may also work against a museum’s educational mandate to broaden participation more widely; if the goal is to portray science as a
discipline that is connected to everyday life and multiple interests that visitors may hold, it may be beneficial to hire museum educators with a variety of disciplinary experience.

Some museum educators may even work with subject matter experts, including scientists, to develop educational programming and facilitation strategies to make the particular exhibit or topic more approachable to visitors (Dragotto et al., 2006). In this type of organizational structure, the museum educators may not have to be experts in all of the scientific content, as the hired subject matter experts may fill that role. However, we must be wary of the power dynamic this can create. Dragotto et al. (2006) wrote that as museum educators “[they were] privileged to work with content experts, who, more often than not, [respected their] abilities and [deferred to them] to design appropriate methods of conveying astronomy content to the public.” (p. 219, emphasis added). The language used here conveys the possibility of interactions in which content experts did not value or respect the work of museum educators, pointing to a power dynamic in which subject matter expertise was perhaps privileged above and beyond the museum educators’ expertise in their practice, mirroring a similar power dynamic between scientists and classroom science teachers (Shanahan & Bechtel, 2020).

**Institutional Constraints on Pedagogy.** Authors also had mixed perceptions on the pedagogical expertise of museum educators. In contrast to the authors who praised the pedagogical knowledge of museum educators above, others argued that museum educators lacked pedagogical expertise or experience (Bevan & Xanthoudaki, 2008; Ji et al., 2016). It is again important to note that while teaching credentials may be desirable for some science museums, they were not necessarily required to be hired into the role (Diamond et al., 1987; Dragotto et al., 2006). If enthusiasm for science is prioritised over, for example, formal
certification as a science teacher, it is not surprising that some museum educators may begin with limited pedagogical strategies. This lack of experience may be compounded by a lack of professional development opportunities (Bevan & Xanthoudaki, 2008). We can therefore see that there are institutional aspects in the hiring and training process that may not be taken into account.

There are also institutional restrictions on the labour of museum educators that may limit the pedagogical approaches available to museum educators. We cannot forget that museum educators are hired to do a job, with specific tasks included as part of that contract. For example, a museum educator may be hired to run school group tours, which involve stopping at particular galleries and exhibits and providing specific information to students, potentially coordinated with the school’s curriculum (Allen & Crowley, 2014). A critique of instructivist pedagogy and transmission approaches may not consider the fact that museum educators may not have the power to change the work tasks they are expected to perform – read from a script, present an artifact, ask a particular question, demonstrate a particular experiment. Even as Allen and Crowley (2014) showed that museum educators were able to shift away from acquisition metaphors of learning while taking part in a design study to recreate the school group experience, they do not mention that, had the research not taken place, the museum educators may not have had the agency within their institution to design and try out new school group approaches.

The conflation of school science literature and museum education literature has also led to critiques of museum educators as failing to adapt pedagogical approaches for different learners (Hecht et al., 2020; Pattison & Dierking, 2013). These critiques may fail to take into account the completely different learning contexts of science classrooms vs. a science museum.
As mentioned previously, the lack of power of museum educators in their institutions may mean that they are expected to follow a communal lesson plan or script, to be performed in a particular length of time. Even if museum educators can make some changes to the flow and depth of content knowledge in the lesson, as observed by Tran (2007), they do not have the same relationships with visitors and opportunities to assess their prior knowledge that classroom teachers may have with their students. Their “limited strategies for affectively engaging school-trip students” (Allen & Crowley, 2014, p. 85) may be due to a multitude of reasons beyond a lack of pedagogical knowledge; in her observation of school visits, Tran (2007) notes a multitude of issues including students not being prepared before the trip, time constraints (compounded by late busses), a lack of behaviour management by teachers and chaperones, and a lack of follow up after the visit. Power dynamics exist in these interactions, wherein the teacher acts as a gatekeeper for the timing of museum programs, students do not listen (as the museum educator is not their “teacher”), and museum educators are expected to perform on-the-spot regardless of the state of the class (Tran, 2007).

However, rather than focusing on the instructivist-constructivist binary divide in facilitators’ pedagogical approaches, this body of work really orients our attention to the importance of the contexts of these interactions. This, for example, is made clear in Hecht et al.’s (2020) study, in which they co-designed a facilitation tool to teach deep time with museum educators and observed its use in two different contexts: a summer camp, and in a “spotlight” session on the museum floor. While some educators in the spotlight sessions were able to incorporate more inquiry-based learning into their interactions with visitors, the educators occasionally used more transmission methods of explaining the tool and content to visitors in
short interactions (average of 6 minutes). In contrast, the museum educator responsible for the summer camp was able to create an inquiry activity lasting an hour and in-depth discussion and understanding of the campers. The authors acknowledged that a range of approaches between direct instruction (which they referred to as “transmission”) and inquiry can reach visitors in different contexts. For example, shorter, on-the-spot interactions of the spotlight sessions may be less conducive to deep, hands-on inquiry, as compared to the summer camp where interactions could stretch over multiple days. This article also illustrates the need for more literature related to the work practices and institutional requirements of museum educators.

Overall, the literature reviewed here suggests that we must learn to see facilitators’ pedagogical practices in relationship to their institutional expectations, contexts, and power. As my own empirical work shows, this is also essential for finding new ways in which researchers and educators can work together to improve practice and create new pedagogies specific to informal learning settings (Hladik et al., 2021).

**School and Museum Science as Distinct, Yet Reciprocal.** It becomes clear that direct comparisons between school science teaching and science museum education are inaccurate, ignoring factors such as institutional regulations and differences in performed labour. Simply critiquing museum educators for not doing all of the things that classroom science teachers do, without seeking contextual factors that inform their daily practice, can lead to positionings (and self-positionings) of museum educators as “not real teachers” (Ji et al., 2016; Tran et al., 2013). Instead, we must carefully tease apart the differences in each learning environment, attending to them within our observations, interviews, and other aspects of our studies. Only then can we begin to understand how the fidelity and implementation of what we have learned in the formal
science education literature may be directly impacted by labour, power, and positioning of museum educators.

There is a reciprocal relationship between formal science education and science museum education. Pedagogies and teaching strategies in formal science classrooms may well be applicable to science museums, finding ways to bring educational theory, developed in classrooms, into the practice and professional development of museum educators (Afonso et al., 2019). But museum education has something to give to formal science instruction as well: working as museum educators can help individuals, if they wish, to become strong teachers (Nyhof-Young, 1996); pedagogical practices grounded in free-choice, everyday understandings of learning can be of value to teachers wishing to disrupt historical methods of schooling in their classrooms (Nyhof-Young, 1996); and future research into learning theories specific to informal science learning environments may lead to new approaches both in and out of classrooms. Rather than pitted against one another, we must look for ways in which informal and formal science education can inform each other. Tran (2007) noted that the strong similarities between school science and science museum education may be the result of “transplantation” of pedagogies and people from schools to museums. She argued that while these similarities can be sites for improved practice, museum educators should also create their own professional language, practice, and identity as distinct from school science teaching (Tran, 2007).

**Professionalization of Museum Educators**

17 out of the 26 articles reviewed referred to museum educators or their work as “professional” at least once, excluding those that solely referred to “professional development.” However, it is unclear what exactly the authors mean when they convey
professional status upon museum educators; the word may refer to a particular skill set, formalized credentials, or training opportunities. Or, it could simply be used as a title intended to convey respect and status. In this section, I aim to dig deeper into museum education’s treatment as a profession, and what that means for the power, positioning, and labour of museum educators.

**Professional Status, Skills, and Credentials.** Over 60 years ago, Greenwood (1957) argued that professions have the following attributes (p. 45): systematic theory, authority, community sanction, ethical codes, and a culture. Today, these attributes can be clearly seen in professions such as medicine and law. However, Burbules and Densmore (1991) argue that these attributes are not enough in themselves – the attainment of professional status is “the successful outcome of a political struggle to legitimate various privileges and economic rewards” (p. 49) that serve to differentiate between supposed “elite groups” and others. Professionals had control of their occupational prerogatives, sought to restrict access to the profession (including through law), and aimed to distinguish “true” professionals from others (Burbules & Densmore, 1991). Arguing against trait-based determinations of a profession, Runté (1995) also pointed out that while professionals have historically been considered to have authority through the development and use of specialized knowledge, some of that authority is being lost as computers, para-professionals, and bureaucracies are breaking into the monopoly over that knowledge. In short, the criteria for determining what “counts” as a profession is not necessarily agreed upon, and efforts to find “official” lists of occupations considered to be professions are unfruitful. Instead
of looking for explicit professional status of museum educators, we can consider what about their work may lead it to be termed as a type of professional practice.

In chapter 3 of the book *Museums: A Place to Work*, Macdonald wrote the following about what it means to be a professional in a museum setting (1996, p. 35):

> To be a professional requires more than the command of a body of knowledge and skills. Professionalism compels you to apply that expertise in the context of the traditional values of the profession you have chosen. It is important in considering museum work as a career to understand that professionalism means more than competence in a particular area of museum work. In addition to mastering the specific discipline, museum professionals need to master the ethical traditions that will guide their work.

Though multiple authors mention museum educators as having professional competencies, it is unclear what makes their competencies – in, for example, communication, organization, and educational development – “professional,” other than they are clearly related to the work they carry out on a regular basis. A professional attitude was variably mentioned as being one that was “positive” (Ji et al., 2016) or one in which docents were expected to focus on exhibit content rather than their personal beliefs (Pyatt et al., 2009). In Macdonald’s chapter (1996), acting as a museum professional was more related to ethical attainment of collections and not accepting bribes. This lack of consensus around what is considered to be part of the professional practice of museum educators has led some museum educators in China to position museum education as a “substitute job without strict professional standards and skill sets” (Ji et al., 2016, p. 34).

Bevan and Xanthoudaki (2008) felt that the professionalization of museum education was hindered by a lack of formal professional development programs. They pointed out that
certificates and professional preparation programs may lead to the creation of new professional norms. However, if institutions such as universities lead such efforts, it could lead to a lack of diversity in museum educators (Bevan & Xanthoudaki, 2008), a concern echoed by Burbules and Densmore (1991) in their discussion of teaching as a profession: “raising standards, more extensive educational requirements, and stricter examinations will lower the already underrepresentative proportion of minority teachers” (p. 53). For all of these reasons, the conferral of explicit professional status on museum educators, whether through formalized professional training or attempts at labeling skill sets as professional, may not be possible or desirable.

**Professionals, or expert service workers?** If the notion of “professional” work remains nebulous, what other descriptions of museum educators may be possible that describe their labour, power, and positioning? In their article detailing the difficulties that museum facilitators had in negotiating their roles and relationships with visitors, Pattison and Dierking (2013) drew upon the notion of “expert service work” (George, 2008). According to George (2008), expert service workers apply their relational skills and expertise in one-on-one interactions with clients. Describing expert service work more specifically, George (2008) wrote (p. 111):

> Expert service work involves the performance of knowledgeable, customized, interactive labour. In contrast to frontline service work, most interactions are unpredictable, the service is partly intangible, and workers are largely self-supervised, making routinization of the consumer exchange or workers’ behaviors impossible. And unlike professional work, where the content of the service and role relations of the participants are more clearly defined and regulated, expert service work often takes place in unstandardized...
industries marked with ambiguous interactional roles. These facets require expert service workers to navigate an occupational middle ground and balance contradictory demands; they are service workers expected to cater to the needs of their clients as well as semiprofessional workers attempting to draw their authority from their specialized training.

Though George’s (2008) work was conducted in relation to personal fitness trainers, it is clear that her comments on the type of labour and positioning carried out by “semiprofessional” workers are applicable to the work of museum educators. The labour that museum educators carry out on a daily basis is certainly knowledgeable (drawing on experiential and academic expertise), customized to each museum visitor, and interactive – including taking part in demonstrations, asking guiding questions, providing content knowledge, and assisting visitors with exhibits. While museum educators may be subject to various institutional requirements and constraints, their work on the museum floor is often carried out without direct supervision. Additionally, the heterogeneity of museum educators’ work, coupled with a lack of formal certification options, makes it clear that their work is lacking the clear definition and regulation that George (2008) associated with professional work. Therefore, they act as semiprofessionals, balancing their authority in pedagogy and content knowledge with the needs of museum visitors – something that Pattison and Dierking (2012, 2013) noted can be difficult, requiring museum educators to negotiate their roles as experts and/or facilitators with family visitors, stepping into assist when required but also encountering situations in which their attempts to guide visitor learning are ignored or rebuffed by adults in the group. The labour and expertise required to successfully navigate these interactions is complex – facilitators’ moment-to-moment decisions
are based on many things including the visitor’s goals, their previous knowledge, their interests, and parental support (Helvaci Ozacar et al., 2020). When they are instead positioned as labourers, as noted in the previous section discussing their job duties and perceptions of visitors, their complex professional and intellectual work is devalued (Rose, 2004). To add insult to injury, even when they are treated as labourers, that labour is rarely valued or even seen by visitors or managers. Thus, it is important to note that these difficult interactions with visitors become places in which museum educators demonstrate their qualifications and professionalism, especially when they lack formal institutional support or credentials (George, 2008).

George (2008) wrote specifically that expert service workers draw their authority from “specialized training.” While it’s true that formal museum education programs at post-secondary institutions may be scarce, the sheer volume of literature devoted to the training or professional development of museum educators provides a source for some of the museum educators’ expertise and practices.

**Professional Development and Training.** Professional development or training for museum educators was included as a motivation, context, or implication in 16 out of the 26 analysed articles. It is important to note here that the terms “training” and “professional development” were generally used interchangeably, with the exception of Tran and colleague’s work (Tran et al., 2013, 2019) who specifically referred to professionalization of the field. The majority of articles described the creation of professional development programs aimed to fill a gap in training opportunities for museum educators, which were described as ways to inform or “recommit” to their professional practice (Bevan & Xanthoudaki, 2008), extend their professional competencies (Piqueras & Achiam, 2019), and generally support their ability to
facilitate learning with visitors (Pattison & Dierking, 2013). The training programs included in the surveyed literature focused on a variety of topics, including scientific content knowledge, pedagogical content knowledge, general research on learning, and the importance of reflective practice.

Unfortunately, despite the potential for research on professional learning for museum educators to “provide a better foundation for expanding our knowledge and understanding of this group of professionals who play a decisive role in the educational experiences in museums” (Piqueras & Achiam, 2019, p. 414), the majority of professional development programs for museum educators rely on deficit perspectives of the participants (Piqueras & Achiam, 2019; Tran et al., 2019) – something that is mirrored more widely in the educational research literature, as will be shown later in this article. Museum educators are positioned as lacking something, whether it’s content knowledge, experience, or a tool, and are expected to learn through the transmission of information from experts (who are mainly researchers or managers), and then smoothly integrate what they have learned into their daily practice. Additionally, the museum educators are rarely given positions of power in their training, acting as the learners rather than facilitators or leaders in the sessions (e.g., Moore et al., 2020).

Despite some of the issues with existing professional development programs, museum educators lament when the opportunities are not available to them, hindering their ability to continue learning and growing professionally in their field (Harlow & Skinner, 2019; Piqueras & Achiam, 2019; Tran et al., 2013). These programs can also mitigate issues of “brain drain” in the non-profit sector, when young professionals gain experience before moving to new sectors in order to grow (Tran et al., 2013). Unfortunately, science museums may disregard professional
development for museum educators (Bevan & Xanthoudaki, 2008). This may be an issue of scarcity of capital in non-profit institutions; science museums may consider professional development to be a “burdensome expense,” weighing the cost of bringing in trainers and hours spent away from their typical work duties, and determining whether that money might be better spent on exhibits instead (Tran et al., 2019). As Tran et al. (2019) pointed out, this viewpoint is in direct contradiction with the high quality of work that institutions expect their employees to carry out to support visitors’ experiences in the museums. This contradiction mirrors that of the seemingly high importance museum educators have in their institutions and their typically low pay and status, as I have previously explained. Ascribed low status within their museums, museum educators’ work is not necessarily seen as important enough to support and improve with capital, losing out to the digital and mechanical exhibits. Additionally, some articles discuss the possibility of formalized professional development programs such as certificates and preparatory programs, leaving the establishment of professional norms to institutions such as universities, and compounding the lack of voice and power that museum educators have in their own professional development.

Breaking away from traditional approaches towards training and professional development that are frequently standalone experiences and embody deficit views towards museum educators, Tran et al. (2019) described their Reflecting on Practice program as a professional learning program – a program that was collaborative, self-paced, and ongoing over time. This program involved 14 interactive sessions in which museum educators engaged in activities and discussions about educational research and their practice, watched and discussed video recordings of their visitor interactions with colleagues, and engaged in journaling and
online discussions (Tran et al., 2013, 2019). Through the Reflecting on Practice program, museum educators gained a common language with which they could describe their practice. This is significant, as in an earlier article, Tran (2007) argued that the creation of a professional language and identity for museum educators, as distinct from school science, should be an urgent priority. A distinct professional identity and language would “[acknowledge] and [highlight] the value and contributions of education in museums” (Tran, 2007, p. 293). A need for a professional vocabulary and pedagogy was echoed by Allen and Crowley (2014), as they felt it would “[capitalize] on the unique affordances of learning in informal settings” (p. 101), such as science museums. However, this professional language and identities for museum educators cannot be fostered through professional development programs which rely on borrowing from school science (Piqueras & Achiam, 2019; Tran, 2007). It is therefore imperative that museum educators are included more centrally in the design and implementation of their professional development programs. Unfortunately, as I explain next, their participation as co-designers of their own training programs has been scarce in educational research.

**Museum Educators Within Educational Research and Research-Practice Partnerships**

**Dearth of Research on Museum Educator Experience.** Despite institutional and researcher claims that museum educators are critical to the institution’s educational mission, the practices and experiences of museum educators have received little attention in educational research. Research that deeply examines the work, actions, explanatory practices, or experiences of museum educators is noted as being scarce in the introductions of many articles (Afonso et al., 2019; Ji et al., 2016; Pattison et al., 2018; Piqueras & Achiam, 2019; Tran, 2007). Librero (2005) reported that, specifically, “there are many personal and professional experiences that go
unnoticed or undocumented” (p. 129) for young people working as museum facilitators. Additionally, framing their study on the perceptions, experiences, and perspectives of Chinese museum educators, Ji et al. (2016) argued that research on museum education in non-Western cultural contexts is absent from the literature. Further evidence to the lack of literature specifically related to science museum educators is the number of articles found for this critical review – only 26 articles were found to focus on science museum educators, while many more articles examined the learning of school children, school teachers, and families in such spaces. It is clear that while a great deal of educational research is carried out in science museums, the focus is on understanding school field trips or family interactions, neglecting the role that museum educators may play in such scenarios.

**Deficit Views, Unidirectional Flow of Knowledge, and a Need for Training.** A deficit viewpoint of museum educators is clear in the reviewed literature. As noted previously, 16 out of the 26 articles mentioned training or professional development as the motivation for the study, or as a possible implication of its results. Unfortunately, Tran et al. (2019) have pointed out that many training opportunities made available to museum educators embody a deficit perspective – they are expected to gain new information or skills (which they presumably lack) in order to be better at their jobs. Researchers were seen as individuals who can “provide evidence and insight to guide the roles of educators in [out-of-school learning] spaces” (Pattison et al., 2018, p. 24). Specifically, it was seen as important that researchers leverage their learning sciences theory to act as resources and support change and training within science museums (Allen & Crowley, 2014; Bevan & Xanthoudaki, 2008), especially as it was thought that museum experts were only
just starting to reflect on learning theory as something that could impact their institutional practices (Bevan & Xanthoudaki, 2008).

These results point to a few issues. Firstly, while considerable attention has been paid to how to train museum educators, relatively little has focused on *deeply understanding their experiences*. Researchers are just beginning to scratch the surface of the complexity and heterogeneity of museum educators’ daily practice, and a lack of investigation into this work leads some researchers to fall back on stereotypes of museum educators as practicing transmission approaches to learning (something that, while occasionally present, does not highlight their flexible approaches as noted by Hecht et al., 2020). Additionally, museum education is more than the particular pedagogical techniques that are used on a daily basis; it involves labour, including emotional labour, and complex interactions between professional identities, personal identities, and disciplinary identities (Ash et al., 2012; Hladik et al., 2020). In their study, Moore et al. (2020) found that their designed reflective practice tool had real impacts on not only the daily practice of facilitators, but also on their well-being. Articles which seek only to train museum educators on new theories of learning and methods of interacting with visitors constrain our understanding of museum educators’ work.

Next, I agree with Piqueras & Achiam (2019) that we must overcome “the dichotomy between ‘formal knowledge’ provided by researchers and ‘craft-knowledge’ from practitioners” (p. 412). While it is certainly important to consider how learning sciences theory can inform educational practices in informal spaces, such as the work carried out by science museum educators, we need to push back on this unidirectional model of knowledge transmission. Instead, researchers should ask themselves: what educational theory might careful attention to
museum educators’ practices, identities, and labour create? Piqueras and Achiam (2019) wrote that their museum educator participants presented some of their own research work at international conferences, and thereby had “contributed to the development of the research yield of informal learning in a real sense” (p. 393). This is especially important if we are to overcome the conflation of informal and formal learning contexts and practices, as mentioned previously.

**Participation in Research Projects.**

![Bar chart](Image)  

*Figure 2.1. Roles of museum educators within reviewed literature*

**Participation Roles.** Figure 2.1 above showcases the various roles that museum educators played in the reviewed literature. Please note that as some studies cast facilitators in multiple roles (e.g., they were co-designers, but were also observed and interviewed) the total is greater than the number of articles reviewer (26). To determine the museum educator participation in each article, I reviewed the methods section (if available) for information about participants and data collection. I also looked for evidence of data within the analysis (e.g., discussing a video
analysis) and specific naming of museum educators (e.g., referring to them as co-designers or co-researchers). It is, however, important to note that just because museum educators were named as “co-designers” or “co-researchers,” that does not necessarily mean the same thing to participants and researchers within and across studies. It is possible for a facilitator to be named a co-author and have very little input into the writing of the paper, or to be named a “part of the design team” without having any decision-making power. Alternatively, museum educators who are interviewed can have powerful opportunities to share their experiences and be given voice via analysis and dissemination choices by the researchers. Therefore, I determined categories for this chart in the following way: if the museum educators were specifically named as having a particular role (i.e., designer, interviewee, researcher), I used that name, regardless of whether I agreed exactly with that labeling or not. In instances where museum educators were not explicitly given a particular role, I used evidence in the methodology and analysis sections to match their level of participation with the tasks they were asked to carry out. In some papers, facilitators were part of the study (i.e., they were facilitating an exhibit), but no data was collected from them – instead, the study reported on surveys or interviews from museum visitors. Those articles were categorized as only “mentioning” museum educators. Articles which reported on the structure of training sessions for museum educators without including any data detailing the educators’ perspectives or opinions also fell into that category.

It is clear from this chart that if our goal is to create meaningful research-practice partnerships (RPPs) between museum educators and educational researchers, we still have a long way to go. Out of 26 articles, there were only six cases in which museum educators participated in the design, research, or writing processes as co-contributors. These are roles in which they can
participate actively in determining educational interventions (such as training programs) and conducting research in their work settings, drawing on their expertise. While museum educators are still able to vocalize their opinions and perspectives when they participate in interviews or answer surveys, these data collection methods do not in themselves mean that museum educators will have an impact on, for example, a proposed intervention such as a new exhibit or training program. Soliciting someone’s opinion is not the same as acting on it. However, interviews are an excellent complement to observational data, as museum educators can explain the *why* behind their pedagogical techniques. It may be naïve, for example, to assume that museum educators do not *value* a specific type of scientific explanation, based solely on the fact that they did not use them in conversations with school students (e.g., Afonso et al., 2019). Values and identities cannot be determined from observational data alone, and therefore it may strengthen researchers’ understandings of the complex work of museum educators if they consider interviewing them on top of observations or surveys – therefore allowing museum educators space and voice within studies of learning in science museums. We must be aware of the key difference between conducting research *on* museum educators, as opposed to conducting research *with* them (Philip et al. 2018).

This review does showcase ways in which researchers and practitioners can come together as co-researchers. In their study, the only one in the review in which the participation of museum educators was categorized as “co-researchers,” Piqueras and Achiam (2019) explained that there exists a kind of negotiation between educators and researchers. They reached common understandings about how theoretical frameworks can inform their practice, before museum educators (with the support of researchers) decided which exhibits to study, presented potential
research questions, created observation protocols, and analysed their data. One educator even used what he had learned from participation in this study to design a new investigation on his own. In this case, “the interests and needs of the museum educators were not only a central concern but also decisive for the development of the project” (p. 410). This type of participatory research, though gaining popularity in educational research literature (e.g., Bang & Vossoughi, 2016; Bang et al., 2016; Bevan, 2017; Booker & Goldman, 2016; Jurow et al., 2016; Penuel et al., 2015), is still rare in studies centred on museum educators.

Who Gets to Participate. This review uncovered potentially inequitable ways in determining which museum educators get to take part in educational research projects. Some projects specifically ensured that junior-level staff members would get a chance to participate in (and benefit from) the research-led professional development programs (e.g., Tran et al., 2013). However, in other studies, museum educators were selected based on perceived expertise (from their managers), full-time employment status, and/or whether they held science and teaching qualifications (e.g., Pattison et al., 2018; Tran, 2007). Given what we have learned about the invisible labour and expertise of museum educators, their varied employment contracts, and variation in the professional qualifications that they hold, selecting for participants based on these criteria means that many creative new or part-time/volunteer museum educators may struggle to have their voices heard in educational research projects. The criteria for selecting museum educators in such a way must be made clear, and must be relevant to the context. For example, in Pattison et al.’s (2017) study, only expert facilitators gave input and practiced with the new facilitation model. Does this mean that the institution is only intending on providing this facilitation model to experienced facilitators, as part of a professional development trajectory?
Or, instead, does it obscure data relating to how inexperienced facilitators may make sense of and enact this framework? While working with full-time expert museum educators can make it easier to schedule meetings and data collection, and provide expert practitioner insight, we must not ignore that only including such participants paints an incomplete picture of the educational intervention or pedagogical practice under investigation.

**When Researchers Leave: A Lack of Sustainability.** The lack of agency or co-production/co-design roles typically given to museum educators when they are recruited into research projects has implications for the sustainability of educational interventions in science museums. These implications are discussed by Moore et al. (2020) in their design and implementation of a reflective practice tool for facilitators who worked in a makerspace in a science museum. They acknowledged that a culture of reflection was not initially present in the makerspace, and while their tool was well-received by museum facilitators, this culture presented a challenge once the study formally concluded. Within the project, the reflective debriefings were led by the researchers, and once the researchers were gone, the facilitators did not continue the reflective practice as they had “received no training in going from simply participating, to leading the reflection themselves” (Moore et al., 2020, p. 102). This has been raised as a critique of design-based research projects, wherein the researchers lead data collection, facilitation, or pedagogical practices to test an innovation, but do not consider what training or cultural shifts are necessary for the intervention to persist sustainability after they are gone (Bevan, 2017; Fishman et al. 2004). The authors also noted that the institution, on top of valuing reflection as part of their work, would have to pay museum staff for their time participating in reflection – a type of labour that the museum may not consider to be critical to the museum facilitators’ tasks
and responsibilities. By giving more museum facilitators agency and voice within educational research projects, they may be more likely to be invested in the success of an educational intervention long after the researchers have moved on. However, this can only happen if a more equitable partnership between researchers and museum educators exists from the beginning of the project, necessitating participatory research methods and explicit positioning of museum educators as co-designers and co-researchers.

**Discussion**

It is clear, even simply from the relatively low number of papers that were included in this review, that our understandings of science museum education thus far are missing a key perspective: that of the museum educators. While existing work on the learning of school groups, families, and children are certainly important, the role that museum educators play in these interactions is often relegated to the background and mentioned only briefly, or is not mentioned at all. When educational researchers do focus on science museum educators, they frequently critique their content knowledge and pedagogy and offer new training programs. This narrow focus means that the complexity of science museum educators’ practice, their experience, and their intertwined disciplinary, personal, and professional identities is invisible, both to researchers and others in their institutions. George (2008) wrote that the occupational identities of semiprofessionals, such as museum educators, rely on roles that are “continuously forged and reforged through interaction” (p. 124), and therefore we must attend to these social and political interactions as they unfold in science museums. Additionally, there has been little work done to uncover and analyse the real physical, cognitive, and emotional labour that science museum educators are required to carry out on a daily basis, or how that labour is impacted by
institutional power structures and constraints. Finally, the deficit positioning of science museum educators in such professional development studies is rarely interrogated – and this has impacts on the agency of these critical employees within their work. Davies and Harré (1990) noted that:

Once having taken up a particular position as one’s own, a person inevitably sees the world from the vantage point of that position and in terms of the particular images, metaphors, story lines, and concepts which are made relevant within the particular discursive practice in which they are positioned. (p. 46)

A deficit positioning of science museum educators, both within their institutions and in educational research projects, has real consequences for the way they view themselves and their labour. If they position themselves as powerless, subject to the constraints of their institutions, they may not seek out ways to improve their employment status or feel as if they have the agency to make impactful contributions to informal science education. The same is true in educational research: if science museum educators are positioned as data sources for observational or interview data and not given the power to speak up and make decisions in the research or design processes, they will not have the opportunity to contribute to new theories of informal science education and museum facilitation, or to work collaboratively with educational researchers on problems of praxis that can have significant impacts on their work. We must attend to the ways in which science museum educators, and their labour, is positioned within power structures that stifle agency and innovation in both research and practice.

In light of the presented findings, I provide the following recommendations for educational research in science museums:

- Explore the experience and labour of science museum educators
It is clear that the experiences and labour of science museum educators is under-researched, especially when compared to the plethora of studies that examine the learning of school groups or families in science museums. Despite their critical role in their institutions, the labour of museum educators is largely invisible in the educational research literature. There is a need for more research that directly centres the experience and work of museum educators as the focus of study. That is, the labour of science museum educators as they take part in educational research projects should be considered as part of both the study design and its results. Future research should more deeply explore the experience of science museum educators, including their motivations, identities, daily practice, aspirations, and challenges. In particular, understanding their professional identities as museum educators, distinct from school science teachers, will provide insight into how the field of museum education is developing and what it means for their positioning both within and external to their institutions. Additionally, careful examinations of the daily labour of science museum educators can make visible issues of power in museum educators’ relationships with their employers, their colleagues, and the museum visitors. Once we have better understandings of how museum educators’ labour and power are intertwined, it will be possible to advocate for more equitable working conditions as well as new interaction patterns and pedagogies with visitors.

- Co-develop more contextual theories for teaching and learning in science museums

The educational theories for teaching and learning in science classrooms may not be directly applicable to science museums and their educators – especially when these theories are applied without consideration of the unique affordances and constraints of teaching, learning, and
working in a science museum. Science museum educators and educational researchers should work together to develop new theories for learning and professional practice that are grounded in the science museum context. Such theories may include those related to exhibit facilitation by museum educators (as opposed to parents or teachers), tensions faced by museum educators as they balance visitor expectations and their job requirements, and new theories of what “counts” as science education in these spaces. These new theories can lead to innovations in pedagogy, exhibit design, educational program design, and professional development in science museums.

- Explicitly position science museum educators as co-designers and co-researchers

I have shown that while observational studies of museum educators can provide some insight into their practice, such research does not give museum educators a voice, and tends to simplify or erase altogether the institutional factors that inform their complex practice. Additionally, professional development programs designed and implemented solely by researchers or managers may fail to engage museum educators due to their lack of agency in the process. As participatory research practices continue to gain visibility in educational research, we must consider the ways participatory methods may challenge existing power structures both in research projects and in science museums themselves. Explicitly positioning science museum educators as co-designers and co-researchers challenges previous deficit positionings by recognizing the wealth of knowledge and experience that they bring to their practice. Science museum educators can contribute positively to the field of educational research by determining problems of practice, designing studies that capture the complexity of their work contexts, analysing data from their unique viewpoints, and disseminating findings in both local and international communities of research and practice. This form of power-sharing will help to build
stronger collaborations, as well as provide new ways for science museum educators to increase the voice and agency they have in their institutions.

In conclusion, critical examinations of power, positioning, and labour in science museums can lead to new ways of understanding the identities, actions, and practice of science museum educators. Attending to these issues can help to tackle the “identity crisis” in museum education that results in “undervalued, ill-positioned and marginalized museum educators without a voice within their institutions” (Kristinsdottir, 2017, p. 428). Our future work must not only serve to empower museum educators within their institutions, but also within educational research as a whole; we must explicitly acknowledge the expertise and experience of museum educators within our research, and look for ways to challenge deficit positionings and researcher-participant power hierarchies at every stage, from the conceptualization of research questions to the dissemination of results.

Limitations

The results in this manuscript are limited firstly by the results of the keyword searches in the databases. Research that is not indexed within the ERIC, ERC, and ASC databases may provide additional discussions of museum educator labour, power, and positioning, but would not have been included in the raw results of my literature search. Additionally, as the search was limited to peer-reviewed academic journal articles, other types of publications, such as book chapters, would not be included. This is especially important as practitioner-focused publications may provide greater insight into the work and perspectives of museum educators through their own eyes and with their own voices, rather than relying on those of academic researchers. Limiting the search results to those in English was necessary due to my own language abilities,
and I acknowledge that limiting results in this way certainly impacted the countries, geographic locations, and communities whose perspectives were included. Finally, the results of this review focused on educators in science museums, but variation exists between institutions, within educational research projects, and across time. Results may not be generalizable to other informal science education settings such as zoos, aquariums, natural parks, after-school clubs; even if there is considerable overlap between the duties of educators in these spaces with science museum educators, as my results show, institutional factors such as hiring processes, physical setting, roles/restrictions, and governance structure have a strong impact on the labour, positioning, and power of educators in all settings.
Reviewed Literature


Other References for Chapter 2


Chapter 3: Museum Facilitator Infrastructuring for Public Computing

Located in informal spaces such as walkways or museums, *public computing* environments (Sengupta & Shanahan, 2017) typically consist of visually appealing simulations of complex systems alongside various interfaces that allow visitors to interact directly with the simulations and with the open-source code behind them. These learning environments offer direct access to scientific simulations of complex behavior, as well as the underlying text-based computer code, to visitors who may not typically have access to this authentic scientific and computational work. The open-ended nature of exploration of code and scientific ideas, as well as personal conversations between visitors and facilitators in such spaces can be quite complex (Helvaci Ozacar et al., 2020) and may even break disciplinary expectations of the exhibit designers (Sengupta & Shanahan, 2017). Although computer simulations of science in museum settings have been investigated as productive sites for science education, this body of work has typically focused on integrating visualizations, block-based or physical programming in the context of informal science learning (rather than text-based programming), and does not consider the role that museum facilitators play in shaping visitors’ learning experiences (e.g., Horn, 2018; Horn et al., 2009; Mesiti et al., 2019). The focus in these studies is device-centered (Ames, 2019; Hladik et al., 2021), that is, these studies typically focus on the effectiveness of technology design in these exhibits, with little or no attention to the complexity of facilitators’ experiences. In fact, interactions reported in these papers are typically between visitors and researchers who “stand in” for the facilitators.

The dearth of studies on facilitating informal computing education (we were unable to find any) stands in stark contrast to the burgeoning field of scholarship on classroom teaching in
computing education (Grover & Pea, 2013; Lye & Koh, 2014; Yadav et al., 2014). Filling this gap is important for several reasons for advancing scholarship in computing education in informal spaces. At the outset, we must recognize that the naturalistic experience in museum spaces is distinct from that in formal classrooms (Tran et al., 2007). For example, museum facilitators who are neither a part of the exhibit design team nor the research team – and may not even have relevant disciplinary backgrounds – often interact with visitors and shape their learning experiences. Facilitators may also have to interact with visitors across a wide range of ages. Research has also shown that facilitators’ personal epistemologies may also be heterogeneous, and this in turn may lead to different learning experiences of visitors (e.g., Allen & Crowley, 2014). In addition, the institutional norms and expectations of facilitation are different than in classrooms, and while often invisible in praxis, also shape the experience of facilitation, and as our study will show, even has the potential to limit visitors’ learning experiences.

A further source of complexity in facilitation arises from interactions with researchers in research-practice partnerships and design-based research projects (e.g., Allen & Crowley, 2014; Piqueras & Achiam, 2019). This body of work points to the heterogenous and complex experience of facilitation which must be understood in its own light, rather than being understood only as a form of teaching – a common problem, as noted by Tran et al. (2007).

Given this background (which we also explain in more detail in the following section), our study seeks to investigate the complexity of such experiences of facilitation in the context of a public computing exhibit as part of a research-practice partnership. Facilitating new forms of museum experiences, such as public computing exhibits, in ways that align with museum facilitators’
expertise, researchers’ expectations, and their institutional roles and responsibilities within the museum is both complex and challenging. Specifically, we ask the following research question: How do museum facilitators negotiate their personal epistemological stances toward learning, institutional norms and constraints, and the roles that they play as participants in a research-practice partnership?

Rather than characterizing facilitator actions that do not align with researcher designs or goals as “incorrect” and in need of remediation via further training – a deficit perspective that researchers have often taken about facilitators (Piqueras & Achiam, 2019; Tran et al., 2019) – we look for ways in which these negotiations can lead to new directions in design, especially for additional support systems for the exhibit’s success and sustainability. Support systems that are locally relevant and develop over time are essential to the long-term sustainability of these innovations. Star and Ruhleder (1996) describe these systems as infrastructures, while highlighting that they are not fixed or preplanned but relational and in constant development. Furthermore, Star and Ruhleder (1996) argue that it is often in moments of conflict between or breakdown of these support systems – a phenomenon that they termed “infrastructuring” – that infrastructures become visible. A key contribution of our work is that we identify how focusing on infrastructuring can help us develop a richer understanding of the complexity of labour of museum facilitators, especially in the context of research-practice partnerships in informal computing education.
Background

*Museum Facilitation as a Complex Practice*

Staff members in museums whose job is to interact with visitors are variously referred to as facilitators, docents, explainers, and educators. Museum researchers argue that these professionals can act as “front-line interpreters” (Ash et al., 2012, p. 24) as they introduce visitors to an exhibit, help them learn how to use it, and provide information about disciplinary ideas that may be relevant to exhibits. Facilitators also provide scaffolds for learning for individuals, families, and school groups, though these scaffolds must be carefully designed so as to not take away from the free-choice and playful nature of informal learning environments (Yoon et al., 2013). Furthermore, as Dawson (2019) noted, museum educators can play a key role in helping visitors feel welcome within a science museum, especially those visitors who may be minoritized and historically marginalized in informal science learning spaces.

Of direct relevance to our study is the role that facilitators play in family learning at museums. Pattison and Dierking (2012, 2013) showed that even informal, unstructured interactions with facilitators can help establish visitors' identities, negotiate roles and responsibilities, and set new learning goals as they interact with family groups. They found that facilitators initiated interactions using greetings, invitations and check-in questions; they facilitated learning by guiding, interpreting, demonstrating, and encouraging; and finally, they introduced new goals, which were typically science content learning goals (Pattison & Dierking, 2012, 2013). This last aspect was especially important within the context of family interactions, as adults in family groups acted as gatekeepers and could either promote these new learning goals or ignore them.
Facilitators play a key role in modeling what “doing science” looks like for visiting families (Rowe & Kisiel, 2012). They scaffold and shape the goals of visitor’s interactions through the use of different strategies, including “orienting visitors to the exhibits, proposing different types and levels of challenges, providing just-in-time explanations, showing appreciation, and helping visitors establish ownership over their experiences” (Pattison et al., 2018, pp. 7–8). Research has also highlighted the importance of language and metaphor in facilitator explanations of scientific content (Afonso et al., 2019). Furthermore, these strategies are also impacted by factors such as the size of group, age of children, and roles that adults play in family interactions, etc. (Pattison et al., 2018).

The complexity of facilitation practices also involves identity work and epistemological dimensions. For example, the intertwinenment of facilitators’ personal and professional knowledges and identities has been shown to play important roles in shaping the work of facilitation (Ash & Lombana, 2012; Tran & King, 2007). Ash et al. (2012) also argued that facilitators’ views of what it means for visitors to learn and how to scaffold them in museum settings – i.e., their epistemological perspectives (e.g., Hammer & Elby, 2002) specific to learning and scaffolding in science museums – also shape their facilitation practices. Ash et al. (2012) found that these two dimensions (identity work and personal epistemologies) are intertwined. They showed that by explicitly reflecting on their own roles within the museum and in their interactions with the families, facilitators can come to recognize their contributions (as well as that of the families) as central rather than peripheral to the work that takes place in the museum, and can also help them shift from a stance of “demonstrating” science to visitors to supporting visitors in their inquiries. This form of reflection on their practices, in turn, can
positively impact museum educators’ professional and personal identities, especially as they may not usually think of themselves as having power or voice in museum operations or administration (Ash et al., 2012).

Some researchers have pointed out similarities between the practice of museum educators and classroom teachers (Allen & Crowley, 2014; Tran, 2007). This is especially true when inquiry-based learning is taken up in classrooms, as classroom teachers must deal with similar challenges and tensions as in the free-choice, informal environment of science museums. For example, Chazan and Ball (1999) highlighted how mathematics teachers move beyond simply “not telling” students the answer to playing different roles in shifting focus and both provoking and managing disagreement – similar to how a museum facilitator may provoke conversation in a group of visitors. Teachers integrating discovery learning into their classrooms must deal with moments of uncertainty when they support student-directed learning that goes beyond a cookbook laboratory experiment with expected learning outcomes (Hammer, 1997), just as museum facilitators may be asked a question about an exhibit or field a request that was not covered in their training. Museum facilitators must balance goals of learning science content with sparking interest in science generally (Tran 2007; Uzelmeier, 2006), and classroom science teachers do the same with the addition of high-stakes standardized testing (Hammerness, 2004).

However, Tran (2007) argued that even though some museum educators have backgrounds in formal K-12 teaching, and even though some of them may transplant their pedagogies from the classroom to the museum floor, these two learning environments and professional roles cannot and should not be conflated. This is an important point of departure that is central to our work. Tran (2007) argued that it should be:
an urgent priority for educators working in informal environments to develop a professional language and identity *distinct from schools* that is based on a body of theoretical and empirical evidence, which acknowledges and highlights the value and contribution of education in museums (Tran, 2007, p. 293; emphasis added)

Our own observations within our research setting support Tran’s (2007) argument forcefully. As employees of the science museum, museum facilitators’ practice is bound by their institutional guidelines and rules in ways that are different from a teacher within a classroom, or a parent visiting the museum with their children. Facilitators typically have to interact with students across a range of age and grade, and they do not typically have familiarity with the learner prior to working together at an exhibit or delivering a school program (Tran, 2007). They also have to interact with multigenerational groups and families – not only children – and they cannot rely on in-depth understanding of the visitors’ interests and passions to guide the interaction the way a parent would.

Another difference between schools and museums that Tran (2007) alluded to involves institutional mandates and expectations that facilitators may be experiencing. This is particularly true in our context. Through our observations (reported later), it became clear to us that there were many institutional expectations and restrictions that impacted facilitator practice: they could not spend long periods of time at an exhibit, they were expected to roam the gallery and remain visible (to both visitors and other staff members), they were not allowed to use their personal devices when on the floor (even to help a visitor by looking up information about a particular line of code), and on top of facilitating the exhibits, they also had to maintain supplies, answer visitor navigational questions, and constantly monitor the state of the galleries. Though
participation in the research provided some reprieve (for example, facilitators were specifically scheduled at our exhibit for an extended period of time and therefore did not have to continuously move through the galleries), many of these restrictions remained.

Our work, therefore, arises from the concern that despite the importance of facilitation in supporting learning experiences of museum visitors, including families (Pattison & Dierking, 2012, 2013) as well as students and preservice teachers (Adams & Gupta, 2013, 2017), few studies have looked at the interactions between facilitator practice, institutional norms and constraints, and museum facilitator participation within design-based research (for exception, see Piqueras & Achiam, 2019). We use the term *practice* rather than knowledge because the work of facilitation in science museums involves both epistemic and representational work. It is now a widely accepted view in science education that science itself is the practice of modeling (Giere, 1988; Lehrer, 2009), and similarly, we believe that facilitation in science museums is also a form of modeling because involves considering disciplinary ideas that underlie exhibits as well as engaging with these ideas through the design and/or manipulation of disciplinary representations. But the work of facilitation in science museums is even more complex because it involves being able to work with a wide range of learners as well as adopting an approach to learning that recognizes the flexibility of conversations and learning experiences that can unfold around a single museum exhibit (Tran, 2008). In addition, as mentioned earlier, the identity work and epistemological dimensions further add to the complexity of the practice of facilitation.

As the complexity of facilitator practice continues to be recognized by educational researchers and managers, those who develop new training models for museum educators are shifting from deficit views that position them as receivers of new pedagogical and content
knowledge (e.g., Bevan & Xanthoudaki, 2008; Rowe & Kisiel, 2012) to experts who can reflect on their professional practice in ways that can lead to institutional change (Tran, 2008; Tran et al., 2013; Tran et al., 2019). Our paper aims to extend notions of museum facilitator agency specifically within the context of a design-based research project. Rather than adopting a deficit view of facilitators who would be expected to simply adapt to a newly designed exhibit in ways that align explicitly with the expectations and goals of designers, we seek to bring to light the interactions between their complex practice, institutional constraints, and participation in design-based research.

**Museum Facilitation and Design-Based Research**

Our work is situated within the methodological context of design-based research. While design-based research as a methodology continues to grow within informal education spaces such as science museums, the roles that museum facilitators play in the success of these new educational innovations is not always clear. For example, Allen and Crowley (2014) have written about the ways in which docents’ beliefs and practices changed as they took part in a project to implement an inquiry-based educational program on climate change. Though this study is a good example of an in-depth look at the complexity of museum facilitator practice and showcases the docents’ experiences related to the project, their contributions to the actual design and implementation of the program are obscured – the authors mention that the docents were part of ongoing debrief meetings and voiced challenges and changes they wished to see, but the exact nature of those changes and if/how they were implemented into the next iteration of the program is not included in the paper.
In another study, Pattison et al. (2017) conducted a design-based research project to iteratively refine a facilitation model for use at previously designed science museum exhibits. While facilitators were considered as part of the research insofar as they were video-recorded interacting with family groups at the exhibits and took part in short debriefs on what they considered to be successful/unsuccessful facilitation at the exhibit, it is unclear what level of input they had into the final reported facilitation model – a model that was based largely on their daily labour. From these examples, it can be seen that even when facilitators and their practice are the main “subject” of a design-based research study, their input into the actual design work may be limited.

Consider a contrasting example from Piqueras and Achiam (2019) who reported on a research project with an explicit focus on co-design and co-research between university researchers and museum educators. Both groups worked together to iteratively present, discuss, and adapt educational frameworks in ways that connected with learning theories and the educators’ on-the-floor experiences. The museum educators then began to use the frameworks in the creation of their own personally-led research studies at the museum, which they used to inform their own practice and institutional change. Across these studies, we can see considerable variance in the ways that facilitators’ complex and practice is used to inform design in science museum spaces. This variance may also be related to power imbalances between researchers and practitioners in RPPs, where despite their reported participation in the project as co-designers, the authority to make final design and research decisions often rests with the university researchers (Carlone & Webb, 2006).
Theoretical Framework: Infrastructuring

Star and Ruhleder (1996) proposed the notion of *infrastructuring* as a way to examine moments in which local practices and solutions intertwine with larger-scale structures and technologies, which can lead to the creation of stable systems that support new activities, but often in ways that are unexpected or novel. Star and colleagues (Star, 1999; Star & Bowker, 2002; Star & Ruhleder, 1996) argued that infrastructure is not a “what,” but rather, a “when”; it is relational, tied to people, things, and practices. For example, in their investigation of a new software intended to support collaborative work of biologists studying genetics, they found that the infrastructuring necessary for its success was related to interactions between computing expertise and resources, lab culture, organizational structures and processes (including who “owned” a particular application), and the desired frequency of application updates, all of which varied between the different research labs and across the community of potential users. Star and Ruhleder (1996) pointed out that an infrastructure needs to be more than a substrate that is built and maintained, as thinking about it in such a way causes it to “[sink] into an invisible background” (p. 112). Instead, in the same way that Engeström (1990) pointed out that a tool only becomes a tool *in practice, in situ*, they stated that an infrastructure is “something that emerges for people in practice, connected to activities and structures” (Star & Ruhleder, 1996, p. 112) – and therefore, we should ask “when” is an infrastructure, rather than “what” is an infrastructure.

The relational aspect of infrastructuring was highlighted in work related to participatory design by Karasti and colleagues (Karasti, 2014; Karasti & Baker, 2008; Karasti & Syrjänen, 2004). Karasti (2014) argued that infrastructuring is linked with and embedded within local
practices, necessitating the need to think about more than the design of objects. She also pointed out that infrastructuring brings together \textit{a priori} activities, such as design and deployment, with “design in use,” as the infrastructures are adapted, appropriated, re-designed, and maintained. Summarizing the infrastructuring practices of two different communities (a group dedicated to Long Term Ecological Research, and a Karelian Bear Dog community), Karasti and Syrjänen (2004) wrote:

\begin{quote}
At the heart of artful integrations are the socio-material relations of multiple, heterogeneous elements and the collective, situated interweaving of people, artifacts, and the processes that make up the working relations needed for, and sustain the visible and invisible work in, the design and use of technical systems. (p. 21)
\end{quote}

This infrastructuring included attending to the heterogeneity of usage of the same technology (e.g., information management systems) across different sites, making visible the practices of not only the workers but also buyers, advisors, and organizations, as well as an axiological dimension of \textit{caring} for the technical infrastructure (e.g., ongoing maintenance and support of core datasets) (Karasti & Syrjänen, 2004).

Pipek and Wulf (2009) positioned “points of infrastructure” as moments in which infrastructure in museums becomes visible to its users either due to its breakdown, or local innovation, both of which consist of shifts from simply using the technology to reflecting on it or modifying it in a responsive manner (Karasti, 2014). Infrastructures are constantly in flux, moving through processes of change and becoming (Karasti, 2014; Neumann & Star, 1996; Star & Bowker, 2002). For that reason, breakdowns in infrastructure cannot entirely be solved by better \textit{a priori} infrastructures put in place by managers or designers, such as facilitator training.
programs or design specifications for new museum exhibits. Rather, infrastructure emerges only over time in articulation with all people involved in a project or community (Karasti, 2014; Star, 1999). This is especially important within the design of museum exhibits, as museum educators are not necessarily included in these institutional processes of design and consultation (Ash et al., 2012), and yet, they are the ones who must continue to facilitate the exhibit long after the original designers have moved on to other projects.

Scholarship on infrastructure and infrastructuring has identified the importance of both heterogeneity and relationality in professional work in museums. Macchia et al. (2014) showed how visitors, curators, and institutional practices and expectations impact maintenance, replication, and innovation in museum spaces through a mutual relationship of mediation and shaping. They noted that curators design the exhibit to appeal to visitors, and visitors impact the exhibit and curators with their actions, sometimes leading to the creation and use of new infrastructures (e.g., webpages and social media). These *in situ* innovations are a hallmark of infrastructuring, and are a form of responsive improvisations that add heterogeneity to possible experiences of museum exhibits. But at the same time, it is also important to recognize that these improvisations also embody and shape relationships and work practices within the museum community (Macchia et al., 2014). Along similar lines, Dindler (2014) argued that museums need to move beyond simply designing exhibits and exhibit-visitor interactions and instead consider both the technical and social infrastructures that are necessary for deepening and broadening visitor engagement. This includes “establishing, nurturing, and developing relationships to institutions and people outside the museum in which these infrastructures may
come to function” (Dindler, 2014, p. 216). For example, webpages or apps can offer additional interfaces for direct and perhaps even remote interaction for visitors with exhibits.

Penuel (2019) positioned infrastructuring as central to co-design and research-practice partnerships. Although Penuel’s work was conducted in the context of partnering with teachers and school districts, several insights are directly relevant for our purposes. Within research-practice partnerships, attention to infrastructuring can make visible existing infrastructure that is otherwise invisible but play a significant role in shaping praxis. It also urges us to move beyond simple “develop and test” studies of effectiveness to instead look at longer cycles of design, implementation, and improvement. This in turn requires listening to and centering practitioners' voices, as well as pivots and shifts in design and methods, as researchers must navigate and meaningfully respond to existing policies and structures as well as new goals and desires of partner practitioners. Our aim is to extend the work related to infrastructuring within informal education settings, especially in the context of facilitating computational science exhibits. Instead of focusing on device centered approaches that seek to focus on effectiveness of computational innovations in museums, we examine how infrastructure is created and negotiated within a design-based research project. Our goal is to illustrate that facilitators are key actors in the process of infrastructuring that can help sustain a newly installed public computing exhibit in a museum space.

Methods

Setting

Hack the Flock, pictured in Figure 3.1, is a public computing environment located in the Open Studio gallery of -SCIENCE MUSEUM-, a workspace in which visitors are encouraged to
tinker, inquire, and work with professional tools of all kinds. The sign at the entrance of the Open Studio gallery, indicating its purpose and a definition of the verb “hack,” is pictured in Figure 3.2 below.

*Figure 3.1. “Hack the Flock” exhibit at MUSEUM-*
At Hack the Flock, Boids (bird-droids) continuously shift and flock around the screen, moving in relation to other moving Boids according to three forces (Reynolds, 1987): alignment (trying to steer in the same direction as neighbors), cohesion (trying to move towards the centroid of the flock), and separation (trying to keep some distance between itself and other flockmates). Visitors can use the computer terminal to directly change those forces through

Figure 3.2. Signage at entrance of Open Studio gallery in -MUSEUM-
changing parameters in the code as well as, for example, change their color, shape, speed, and size, and even add images of bees and monkeys to the screen.

**Data Collection**

We collected data in the form of video and/or audio recordings of interviews with facilitators who agreed to be a part of the research. A few of these interviews took place in January and February 2019, during which facilitators were not specifically scheduled to spend time at Hack the Flock, but chose to take some time out of their facilitation duties to speak with us. These facilitators agreed to be part of the research and signed a consent form before being recorded. Additional interviews took place during a second round of data collection in the summer of 2019. For two days each week through July and August, facilitators were scheduled to spend blocks of time ranging from 1-3 hours at Hack the Flock specifically. They were then asked if they wanted to be a part of the research project and, if they consented, took part in facilitator interviews. Due to facilitator scheduling, which was managed by the institution, we were able to interview some facilitators twice: once at the beginning of July, and then again at the end of August, to collect data about their experiences over the summer.

Overall, we interviewed 24 facilitators at least once, and conducted a total of 36 interviews. In these semi-structured interviews, we asked facilitators about their academic and professional background, their previous experience with and perceptions of computer coding, their experiences facilitating at Hack the Flock, how they felt about the exhibit, and how they thought it could be improved. These topics granted us insight into their professional practice at this exhibit specifically. These interviews lasted between 2 and 16 minutes. Additional data collection took the form of video recordings of facilitators and visitors interacting at the exhibit.
(ranging in length from 51 seconds to 71 minutes, median length of 15:06) and researcher field notes, which captured informal conversation between facilitators and researchers, as well as researcher perceptions of the interactions at the exhibit.

**Analysis**

For the purposes of this paper, we began by focusing specifically on the interviews of four facilitators: Janelle, Kaitlynn, Ashley, and Hilda (all names are pseudonyms). We focused on facilitators whom we had observed *in action* (i.e., interacting with visitors at Hack the Flock) multiple times, as this would indicate that they had an ongoing engagement at Hack the Flock, rather than only being assigned there once or twice. These facilitators were chosen because they each had:

- At least 6 video-recorded interactions with visitors at the exhibit
- Over 75 minutes of video-recorded interactions with visitors at the exhibit
- Completed at least 2 interviews, spaced out by a minimum of 4 weeks

This selection criteria ensured that the facilitators could draw upon their extensive experience of facilitating at Hack the Flock, at which they had worked with many different visitors for an extended period of time. It is important to note that these facilitators may have had much more experience than what was captured on video, as some visitors were unwilling or unable to give consent to participate in the research (such as children attending the museum as part of a summer camp, as their parents were not available to give consent). Additionally, by analyzing interviews that were spaced out by at least four weeks, we were able to see if and how their perceptions and actions at the exhibit changed over time as they grew more familiar with the exhibit. A chart of facilitator interviews can be found in Table 3.1 below.
Table 3.1. Facilitator interview breakdown

<table>
<thead>
<tr>
<th>Facilitator</th>
<th>Interview Date</th>
<th>Length (mm:ss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Janelle</td>
<td>Jan. 26, 2019</td>
<td>15:52</td>
</tr>
<tr>
<td></td>
<td>Jul. 16, 2019</td>
<td>7:11</td>
</tr>
<tr>
<td></td>
<td>Aug. 13, 2019</td>
<td>14:21</td>
</tr>
<tr>
<td>Ashley</td>
<td>Jul. 9, 2019</td>
<td>3:36</td>
</tr>
<tr>
<td></td>
<td>Aug. 20, 2019</td>
<td>6:55</td>
</tr>
<tr>
<td>Kaitlynn</td>
<td>Jul. 17, 2019</td>
<td>6:13</td>
</tr>
<tr>
<td></td>
<td>Aug. 14, 2019</td>
<td>10:04</td>
</tr>
<tr>
<td>Hilda</td>
<td>Jul. 2, 2019</td>
<td>2:30</td>
</tr>
<tr>
<td></td>
<td>Aug. 14, 2019</td>
<td>5:16</td>
</tr>
</tbody>
</table>

Each interview was transcribed. Then, drawing from Star and Ruhleder (1996), we looked for “when”s of infrastructuring that emerged from their interviews. We carefully identified moments in which a facilitator described hidden work that they or other facilitators were doing to support the exhibit and visitors’ experiences at Hack the Flock, as well as any moments where infrastructuring was made visible by its breakdown. These moments were often voiced by facilitators as an issue (or something not working “properly”) with either the exhibit itself (including its hardware and software) or within the facilitator’s practice of facilitating the
exhibit. They sometimes articulated how they were fixing those issues, which we view as times where they were conducting emergent, in-the-moment infrastructuring. In other times, they simply discussed a problem and, occasionally, provided a hypothetical solution. These hypothetical solutions could inform future infrastructuring at the exhibit. Finally, we triangulated these moments of infrastructuring with the video-recorded facilitation data, looking for instances in which these issues or solutions were apparent in facilitators’ on-site interactions with visitors, and researcher field notes.

Across each facilitator’s interviews, we found a total of 81 instances of “when”s, times at which either a breakdown (hypothetical or actual), or an innovation of the museum infrastructuring was mentioned. These instances were then openly coded to accurately describe the “when” of the breakdown. Using constant comparison (Glaser, 1965), these 81 instances were then collapsed into 20 higher-level themes, shown in Table 3.2 below.

*Table 3.2. Thematic analysis of 81 “when”s, broken down by theme and facilitator*

<table>
<thead>
<tr>
<th>Theme</th>
<th>Janelle</th>
<th>Ashley</th>
<th>Kaitlynn</th>
<th>Hilda</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHEN 1: Facilitator role requirements mean they can/can’t be/stay at exhibit</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>WHEN 2: Visitors read/don’t read/can’t read the comments</td>
<td>3</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Event Description</td>
<td>Count 4</td>
<td>Count 2</td>
<td>Count 0</td>
<td>Count 1</td>
<td>Count 6</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>WHEN 3: Facilitator can’t remember results/particulars of specific change (not necessarily requested by visitor)</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>WHEN 4: Facilitator isn’t sure how to/can’t make change specifically requested by visitor</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>WHEN 5: Facilitators want more information for themselves to better facilitate</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>WHEN 6: The code is broken and needs to be reset</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>WHEN 7: No training is provided to facilitators</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>WHEN 8: Working through the code and deliberately focusing on certain aspects OR ignoring others</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>WHEN 9: Interface is difficult for facilitators/visitors</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>WHEN 10: Visitors do not want to spend lots of time at Hack the Flock</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>WHEN 11: Facilitators want to provide more resources to an interested visitor</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>WHEN 12: Facilitators want to take coding beyond the screen</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>WHEN 13: Communication (breakdown) between designers/facilitators/researchers</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>WHEN 14: Resources and reality don’t match</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>WHEN 15: Visitors use exhibit in unintended ways</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>WHEN 16: A visitor does something unexpected with the code</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>WHEN 17: Facilitators cannot access online resources during work</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>WHEN 18: The exhibit is not noticed by visitors</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>WHEN 19: Facilitators think the exhibit is boring/unintelligible/scary</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Infrastructuring is carried out and its effects felt on multiple levels, from individual facilitation actions to labour and practices of the facilitator community as a whole. In order to highlight the ways in which infrastructuring both informs and is informed by museum facilitator practice at various scales, we conducted two different analyses based on the themes identified by the four most experienced facilitators as mentioned above. First, we zoomed in to investigate the heterogeneity of the relationship between infrastructuring and facilitator practice by comparing the facilitation practices and comments of the two facilitators with the most time spent at the exhibit: Janelle and Kaitlynn. Then, we zoomed out to understand the ways in which infrastructuring emerged from within the facilitator community as a whole, leading to a community of knowledge, training, and support.

**Zooming In: Heterogeneity of Infrastructuring as Related to Individual Facilitator Practice.** In order to investigate the heterogeneity in the ways in which infrastructuring both informed and was informed by facilitator practice, we chose to focus on facilitators Janelle and Kaitlynn as the two facilitators with the most experience and time spent at Hack the Flock. We note specifically that neither Janelle nor Kaitlynn had extensive previous experience with computing, as they discussed in their interviews: Janelle’s only experience was a conversation with a computer scientist about computing. Kaitlynn had more personal experience with HTML
as a teenager, teaching block-based coding in a summer camp setting, and Lego Mindstorms coding as part of an undergraduate course in education, but noted she has always found coding to be difficult. Statistics for their interview and video-recorded facilitation data is outlined below in Table 3.3.

Table 3.3. Interview and video-recorded interaction data for Janelle and Kaitlynn

<table>
<thead>
<tr>
<th>Facilitator</th>
<th>Interviews</th>
<th>Interview time (total)</th>
<th>Video-recorded interactions</th>
<th>Video-recorded interaction time (total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Janelle</td>
<td>3 - Jan, Jul, Aug 2019</td>
<td>37 mins</td>
<td>11</td>
<td>184 mins</td>
</tr>
<tr>
<td>Kaitlynn</td>
<td>2 - Jul, Aug 2019</td>
<td>16 mins</td>
<td>7</td>
<td>99 mins</td>
</tr>
</tbody>
</table>

In addition to their previously transcribed and coded interviews, we also transcribed all of their video-recorded interactions with visitors, noting all talk, gesture, physical actions, and changes to the code. The transcripts for each video-recorded interaction were then coded deductively, using the 20 themes of “when”s that emerged from the facilitator interviews.

Once all video interactions were coded in this way, we compared and contrasted Janelle’s and Kaitlynn’s emergences of and responses to the “when”s, looking for similarities and differences in the ways in which they responded to the “when”s of infrastructuring in their in-the-moment facilitation practices. We note that this is not a direct comparison; each facilitator was working with different visitors who had their own goals, histories, interests, and learning
experiences. Additionally, it is not a comparison of prevalence, as Janelle had many more responses to “when”s than Kaitlynn, likely due to having nearly double the video-recorded interaction time. Instead, these findings are an attempt to find discernable differences in facilitator actions that occurred when different facilitators encountered the same breakdowns in infrastructuring. Crucially, this is not an evaluation of facilitators’ responses as better or worse than others. Rather, our analysis showcases the ways in which infrastructuring gaps can have different impacts for different facilitators and visitors, and their individual and varied responses to these gaps can have implications for new infrastructuring that is needed.

**Zooming out: Emergent infrastructuring within the facilitator community.** Our second analysis takes a more holistic view of infrastructuring as it emerged from within the community of museum facilitators who worked at Hack the Flock and participated in the research. Specifically, this analysis highlights the ways in which infrastructuring led to a facilitator community that prioritized knowledge, training, and support, but was also intertwined with institutional roles, norms, and constraints. This thematic analysis drew primarily from the transcribed interviews of Janelle, Kaitlynn, Hilda, and Ashley, but also involved triangulation with video-recorded interactions at the exhibit and researcher field notes.

**Findings**

**Heterogeneity of Infrastructuring as Related to Individual Facilitator Practice**

After coding the video-recorded interactions in which Janelle or Kaitlynn facilitated Hack the Flock with visitors, we noted the number of instances in which each “when” came up in their videos, as well as their typical responses across videos. We have chosen to present the following five “when”s (see Table 3.4) as the most theoretically salient to our analysis, as they showcase
notable differences in the ways in which facilitators responded and the implications for infrastructuring.

Table 3.4. Janelle and Kaitlynn’s responses to “when”s 2, 4, 12, 15, and 16

<table>
<thead>
<tr>
<th>WHEN</th>
<th># instances, Janelle</th>
<th># instances, Kaitlynn</th>
<th>Janelle’s response(s)</th>
<th>Kaitlynn’s response(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2) Visitors read/don’t read/can’t read the comments</td>
<td>0</td>
<td>4</td>
<td>N/A</td>
<td>Directs visitor’s attention to comments, specifically focused on the “limits” in the comments</td>
</tr>
<tr>
<td>(4) Facilitator isn’t sure how to/can’t make change specifically requested by visitor</td>
<td>12</td>
<td>4</td>
<td>Redirects to something that is possible, experimentation (with added commentary and explanations to visitor so they are working together), asks researcher</td>
<td>Redirects to something that is possible, asks researcher</td>
</tr>
<tr>
<td>(12) Facilitators</td>
<td>11</td>
<td>2</td>
<td>Uses colour cubes and fill bucket, uses arms to</td>
<td>Uses colour cubes</td>
</tr>
<tr>
<td>want to take coding beyond the screen</td>
<td>mimic axes, uses hands to demonstrate behaviour of boids (current, or in relation to a parameter such as alignment), mimics child’s actions, uses hands to “squish” number or image</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(15) Visitors use exhibit in unintended ways</td>
<td>8 1</td>
<td>Lets child try, supports visitor brainstorming, engages in brainstorming possible ways to make what the child wants, offers another option or redirects visitor, asks researcher if they know how to do it</td>
<td>Says she doesn’t know how to do that</td>
<td></td>
</tr>
<tr>
<td>(16) Visitor does something unexpected with</td>
<td>19 13</td>
<td>Explains mistake, fixes mistake or directs child to fix the mistake, points</td>
<td>Points out the error, doesn’t let the child try something that</td>
<td></td>
</tr>
<tr>
<td>the code (including causing compiler errors)</td>
<td>out how to tell if the code is broken, lets visitor “try the code” with the error, encourages ownership of “weird” code</td>
<td>she thinks won’t work (sometimes redirects, sometimes just says no), is flustered at times when code is broken</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

We note here that while the distinctions between “when”s 4, 15, and 16 were fairly obvious in the interviews, coding of the video interactions led to some ambiguity in the codes. We chose to merge “when” 4 and 15 in the findings, because regardless of whether the visitor specifically requested the change of the facilitator or just started working on their own, the types of code changes were similar (e.g., trying to make the Boids two colours at once) and the strategies used by facilitators in those moments were also similar. “When” 16 almost always refers to when the visitor made a code change that caused an error, such as inputting letters where the code expected numbers or deleting a large section of code. Other actions in this section included code that led to unexpected or strange behaviour or appearance as noted by the facilitator.

We explore each of these five “when”s, Janelle and Kaitlynn’s responses, their connections with and implications for infrastructuring in the subsections below.

**Reading Code and Comments (WHEN 2: Visitors read/don’t read/can’t read the comments).** At the Hack the Flock exhibit, the text on the screen can be categorized in two different ways: it is either lines of code which can be changed by the guests (such as functions or
variables that change the colour or size of the Boids), or it can be part of the comments, lines of text which are ignored by the computer when it runs the program, but that provide some instruction or explanation to the visitor. Our observations reveal that reading code and comments constitute an important element of visitors’ engagement with the exhibit, and this also leads to moments of infrastructuring. When the code comments were used by visitors or facilitators, they acted as infrastructure for the exhibit, serving to provide additional explanation that the exhibit designers felt would be particularly useful at times when a facilitator was not present to help visitors work with the exhibit. However, as noted by multiple facilitators in interviews or during casual conversation, visitors rarely read the comments (or other signage for that matter). Our analysis also reveals that the use of comments was not necessarily a uniform strategy for all facilitators, as Janelle and Kaitlyn offer two contrasting perspectives. Figure 3.3 below shows some lines of code (lines 66 and 71) and their respective comments (lines 63-65 and lines 68-71). Note that comments must begin with a double slash (“//”) and are a light grey in the text, while lines of code are a mix of black and coloured text.

Figure 3.3. Example of code comments (seen in light grey)
Kaitlynn: Directing Attention and Purposeful Scaffolding. In her facilitation with visitors who demonstrated that they could read, Kaitlynn specifically directed the visitor’s attention to the code comments. She suggested that by reading the comments visitors could find new aspects of the code to change, especially when they had a specific change in mind. For example, as Kaitlynn was working with a child who wanted to find the line of code that needed to be changed to add images of animals to the screen, she made the following remarks while the child was scrolling through the code:

Excerpt 1

Kaitlynn: You’re at the end of the code.
Child: Oh.
Kaitlynn: So what were you looking for? You were looking for animals, right?

Okay, so you’ve got to read, where do we find them? Similar to when we were looking for triangles.

Child: Hmmmmmm [looking at code]
Kaitlynn: We found triangles because it said the word triangle [in the comments] right? So if we were looking for the word monkey, could we find it somewhere?
Child: [reading comments and scrolling, stops] Right here?

In this instance, the written comments served as a wayfinding tool within the code. The visitor wanted to add images of animals to the screen, so Kaitlynn directed their attention to the code comments in order to find the line of code that was used to add animals to the screen by
focusing on the particular words she could look for in the sea of text and numbers ("animal" or "monkey"). She reminded the visitor of how they previously had located the code to change the shape of the Boids to triangles in a similar manner, offering an explanation of how the code was organized and tools with which the visitor could navigate the code file.

Kaitlynn’s other main use of the code comments was as lower and upper limits for the values of the different variables throughout the code, such as those that controlled the Boids’ size and speed. In order to provide the visitor some guidance when they were at the exhibit without a facilitator, the designers included lines in the comments such as “try changing 3 into 300” above a line of code that had a default value of 3. Kaitlynn used these lines of code consistently in her facilitation, using them as limits for the value that the visitor could choose. She either read those values out loud to the visitor and ask them to brainstorm a new number within them (such as in Excerpt 2) or remind the visitor to read the code comments and determine those limits for themselves (Excerpt 3):

Excerpt 2

Kaitlynn: Do you want to change how fast they’re going?
Visitor: Yeah.
Kaitlynn: Okay, so that’s this one here, so you can go between 3 and 300. … Now what number comes between 3 and 300 that you want to use?

Excerpt 3:
Kaitlynn: You’re going to change this number here, the same way that we just did. Between… what does it say?

Visitor: [reading code comments] Uh try changing 3.0 to 300… no wait, that was the last one. 1 into 1000.

Utilization of the comments was a form of infrastructuring that Kaitlynn used to scaffold the visitor’s experience and learning at the exhibit. It actually served as scaffolding in two different ways. Firstly, it scaffolded the visitor’s engagement with changing the code by offering suggestions or limits that would constrain their choices and perhaps make it easier for them to choose a value that would result in code that both worked correctly and lead to a noticeable change in the simulation behaviour. Rather than confusion related to what would be possible (e.g., are negative numbers or very large numbers “allowed?”), visitors could have some guidance as they contemplated their desired changes to the code. Secondly, Kaitlynn used these code comments to scaffold her own understanding of the code and support given for the visitor. As we will explore later in the findings section, rather than using these comments as suggestions (which was the intent of the designers), Kaitlynn interpreted these numbers as hard limits – she would not allow visitors to change the number to values outside of those limits, refusing or redirecting the visitor.

We need to be explicit here: this response of Kaitlynn to treat the comments as limits does not showcase a personal or professional fault of her. Instead, this highlights a rupture, a gap in the infrastructuring that the comments were supposed to fill. Not all comments were written in ways that made exactly what the visitor or facilitator “should” or “could” do explicit, some were
ambiguous, and others were not very useful at all, such as a comment line stating that “alignment changes the Boids Alignment.” In addition, a lack of training for some facilitators at the exhibit (which emerged as another “when” from their interviews) meant that facilitators were not necessarily given proper explanations or time to explore the utility of the comments and exactly what they meant. Kaitlynn’s interpretation of the comments as limits was a result of this lack of training, aligning with her personal and professional desire to ensure the visitors were using the exhibit in ways that would “work” and be enjoyable.

**Janelle: Comfortable Without Comments.** There were not any responses to this “when” evident in the video-recorded interactions with Janelle’s facilitation. However, in this case the absence is telling and highlights how the infrastructuring of code comments can have different impacts on different facilitators. While Kaitlynn used the code comments extensively to make up for a lack of training at the exhibit, Janelle was quite comfortable working with the exhibit, having had spent more time facilitating it with visitors and in discussion with researchers over the course of the year. Her only use of the code comments was to highlight their structure to visitors – that commented lines of code started with // – so that visitors could understand how to “turn on and off” various lines of code to change shapes or add images to the screen. For everything else, Janelle instead relied on her own interpretation of the code and offered her own verbal explanations for the different functions and variables. Additionally, and in contrast to Kaitlynn, Janelle never used the comments as suggestions or limits for the values of different variables. She encouraged visitors to try whatever numbers they wanted, including negative numbers, very large numbers, or letters (which would cause an error in the code). Her lack of discomfort in letting the visitor experiment was due to the fact that she knew how to identify and
fix code errors, and even reset the code if her other strategies couldn’t solve the problem. In this way, the code comments and how they were used were not critical infrastructuring to Janelle’s success at the exhibit.

**Reading Code and Comments: Implications for Infrastructuring.** Within this section, we can see how different aspects of infrastructuring are intertwined. At the very outset, this might indicate that professional learning opportunities must be designed to emphasize the importance of scaffolding visitors’ interactions through reading, as well as to further support facilitators’ interpretation and use of code and comments. Janelle’s improvisations led to not encouraging visitors to read, and even when Kaitlyn encouraged reading the comments, her own interpretations may not have been mathematically sound. The code comments and their utilization by visitors and facilitators were therefore a form of infrastructuring with considerable implications for facilitator practice: serving sometimes as wayfinding tools or extra explanation, but other times as constraints on the creativity and desire of visitors (as a case in point, most young visitors were not satisfied with 300 as the “max speed” of the Boids and regularly inputted numbers much larger than that). We can also see how this particular element of infrastructuring (scaffolding visitors through reading) interacts with existing practices and norms in the museum space: Janelle’s approach was based on her observation that visitors do not like to read, while Kaitlyn’s scaffolds for reading contradicted this normative behavior and expectation. This is particularly poignant in light of recent research that suggests that commenting code can be a powerful experience for learning to code (Vieira et al. 2019), and also suggests that this might necessitate a more normative shift in expectations for museum visitors from an institutional perspective.
Unexpected Changes to the Code (WHEN 4: Facilitator isn’t sure how to/can’t make change specifically requested by visitor + WHEN 15: Visitors use exhibit in unintended ways). Many facilitators had specific strategies to engage visitors. For example, some facilitators almost always suggested that the visitors start by changing the size or shape of the Boids, as these changes were fairly easy to implement (involved changing numbers in the code) and had a clearly visible effect on the simulation. Other times, facilitators walked visitors through particular changes or parts of the code that they were most comfortable with. By the end of the summer, most of the facilitators were confident in their abilities to change most variables in the code and knew how to change the shape or add images to the screen by commenting or uncommenting lines of code. However, despite initial training and their growing personal experience with the exhibit, facilitators were sometimes faced with situations in which they did not know how to make the particular code change requested by the visitor, such as adding images to the screen that weren’t stored in the program’s memory or making the Boids into a shape that wasn’t a square, rectangle, circle, or triangle. Several visitors also simply stated what they wanted to do (e.g., use multiple colours at the same time) and facilitators had to figure out how to help them implement these changes. Our interviews and observations reveal that in many cases, this would lead to uncertainty for the facilitators, who were not even sure whether those changes were possible in the first place. In this section, we show how both Janelle and Kaitlynn used some strategies in common, but also highlight how Janelle’s commitment to
experimentation as a method for learning at the exhibit allowed her to support the visitors’ programming in ways that were expansive and empowering.

**Common Strategies: Asking an Expert or Redirecting.** Both of the researchers who were typically present during data collection (myself and another PhD student) had some experience in computer coding and with the exhibit code in particular. For that reason, if a visitor requested a particular code change that the facilitator wasn’t sure how to do, the facilitator would sometimes ask the researcher who was standing nearby behind the video camera. Sometimes the researcher was able to provide some clarification or suggest a code change, and the facilitators not only used these explanations or suggestions to make the desired code change of the visitor, but also learned and grew from these interactions (in more than one case, a facilitator who asked the researcher a question in one interaction was observed directly using that knowledge in a subsequent interaction with a different visitor). However, this expert advice wasn’t always successful; in one video-recorded interaction, the visitors at the exhibit wanted to make the background of the simulation two different colours: green on the bottom and blue at the top. Janelle wasn’t sure how to do that, and engaged in an off-camera discussion with the researcher to try and figure out if it was possible. While this led to a few different ideas, the group was ultimately unsuccessful in making that specific change to the simulation.

If the facilitator was unable to make the desired code change, they felt the need to pivot the activity in order to keep the visitor engaged at the exhibit. We draw upon one of Kaitlynn’s interactions to illustrate this point:

**Excerpt 4**
Visitor: How about yellow and blue [colour of the Boids]?

Kaitlynn: Uh we can’t do just yellow… [to researcher] Can we do yellow and blue?

Following this question to the researcher (which did not receive a response), Kaitlynn directed the visitor to start with one colour, and they would find out how to make it two colours together. While she was unable to make the fill colour of the Boids yellow and blue at the same time, she redirected the visitor’s desire into giving the Boids a blue fill and a yellow outline – a task that she knew how to accomplish. This is an example where Kaitlynn found a somewhat different way forward while still adhering partly to the visitor’s desire.

Another example of pivoting can be found in Janelle’s interactions, where she drew upon the visitors’ interests and previous actions to redirect the activity to something else they thought they would like. This can be seen below when Janelle, while working with a child and their father who wanted to make the size of bees larger. Janelle noted that the bees were as big as they could get, but they could make the other animal images larger instead:

Excerpt 5

Child: So big! [waves arms, indicating that he wants the bees to be as big as he is showing]

Dad: I think that’s as big as they get.

Janelle: So big, that’s as big as I can get it. But we can make big birds come as well.

Child: I want big birds!
After this exchange, Janelle and the child worked together to make the size of the bird images as large as possible, just as they had done previously with the bees, to the delight of the child. This redirection to a different code change was sometimes difficult, requiring negotiation between the facilitator and the visitor(s). In some cases, the parents also helped to support the facilitator’s shift, highlighting the different ways that visitor roles, especially family members, can impact interactions in museums.

Excerpt 6

Janelle: You want, what do you want?
Child: A tree.
Dad: A tree [repeating for clarity]
Janelle: A tree? Oh my gosh, I don’t have the code to make a tree.
Dad: [chuckles] We can’t make a tree.
Janelle: But we can make some birds or some bees?
Child: Bees. Or mosquito.
Janelle: A mosquito? Aw, I don’t have the code to make a mosquito either.
Dad: Bees are good.
Janelle: But that’s a good idea. Do you have other good ideas?
Child: Um, make a bee.

In the excerpt above, we can see how Janelle’s strategy to redirect the child from a tree or mosquito into bees or birds was supported by the dad’s comments. His support, then, can be
viewed as an important element of infrastructuring: their actions can support facilitators as well as play an important role in centering the child’s interests.

While both facilitators used this redirection strategy in similar ways, their determination of *when* to use it differed: while Kaitlynn often redirected immediately when she wasn’t sure how to make a particular code change, Janelle typically only did so after her main strategy – experimentation – failed to create the appropriate result, which we describe next.

**Janelle’s Focus on Experimentation and Play.**

Excerpt 7

Visitor: I… I want to try mixing all of these! [referring to the different colours]

Janelle: [Gestures at all of the colour cubes] You want to try mixing all of these colours? How do we mix all of those numbers at once?

Visitor: [pause] Let me try!

Janelle: I’ll let you try.

In her facilitation practice, Janelle focused explicitly on the importance of experimentation and play. This was both a personal value she articulated during her interviews, but also can be considered part of the normative expectations in museums, where free-play, experimentation, and choice are valued (Dierking et al., 2003). Signs encouraging visitors to play and experiment were scattered throughout the museum, and noted as important to them by all facilitators (including Janelle) in their interviews with us. Additionally, disciplinary norms in computing mean that coding is often portrayed as a top-down, structured activity, something that Janelle sought to challenge with a more playful and exploratory approach. As we will see in the
excerpts in this section, this approach to facilitation and coding was particularly helpful when Janelle ran into situations in which she did not know how to make the code change the visitor wanted. Rather than immediately redirecting the visitors to a different code change, Janelle would adopt a co-learning approach in which they all experimented together to try and make their desires possible. Also visible in these interactions was the agency of the visitor, as Janelle often let the visitor take the lead in the experimentation process.

In one interaction, the children wanted to make one part of the Boid (called the “cone” in this excerpt) a brown colour. While the exhibit had facilitation tools which included cubes with different RGB colour representations on them, there was not a brown cube, and therefore Janelle did not have an easy reference for brown in RGB. However, rather than redirect to a different colour, she jumped right in to provide a launching pad for experimentation:

**Excerpt 8**

Janelle: This is the colour for the cone. So we want to make it more brown, so… which of the colours that we currently have is the closest to brown?

[gesturing at colour cubes]

Visitor 1: Yellow! [grabs yellow cube]

Visitor 2: Yeah.

Janelle: Yellow is the closest to brown?

Visitor 1: Yeah.

Janelle: Okay, so let’s make it yellow first… [reads out numbers off yellow cube as visitor types them in]. And then for yellow the code [for blue] is 40, and
I think we should make it a little bit bigger to try and make it brown.

[After some experimentation with the various values, the children succeed in making the cone a brown colour]

In this excerpt, we can see how Janelle drew upon the children’s previous experience with RGB code from changing the colour previously and used it as a starting point for their experimentation. She moved between letting the children lead the experimentation (choosing which colour to start from) and drawing upon her experience (suggesting to make the blue value bigger).

Janelle’s experimentation was also punctuated with ongoing explanations and commentary as they worked together, explaining her understanding of code as it was relevant and offering explanations for why their code change was (or wasn’t) successful. Janelle almost never made a code change without first explaining what she wanted to do and why, and asking the visitor if they wanted to do it. In another, much longer interaction, Janelle and a visitor spent several minutes trying to create Boids in the shape of 5-pointed stars. While she had the 10 lines of code needed to create the stars on a piece of paper from a previous facilitator, there had been some error(s) in translating it to the exhibit: instead of 5-pointed stars, they had a different shape with only 4 points and a notch. Over several minutes, Janelle explained she wanted to add another triangle (to create the fifth point), asked the visitor what she noticed (the triangle was pointing in the wrong direction), followed the visitor’s directions to “change it back” to what it was previously, and made suggestions for how to change a vertex of the shape in the hope that it
would form the stars. While they were never successful in creating perfect stars, Janelle used the opportunity to draw the visitor into the code and learn about coordinate geometry.

*Unexpected Changes to the Code: Implications for Infrastructuring.* In general, we can see how the actions of Janelle and Kaitlynn depended on what infrastructure was available to them: whether that was the presence of the “expert” researcher whose experience they could draw upon, or which lines of code in the simulation were easier to change than others. In addition, their own practices acted as infrastructuring when they ran into scenarios in which the other infrastructures (expert advice, training, etc.) were not available or adequate. Put another way, actions such as redirection and experimentation were deliberately chosen practices, involving social and physical interactions with both visitors and the exhibit, that served to ensure visitors and facilitators had feelings of success and contentment, even as they worked through challenges at the exhibit.

Infrastructuring is also connected to institutional norms and practices, and we can clearly see in Janelle’s facilitation how she leaned upon the science museum’s explicit commitment to experimentation (seen across their galleries and in institutional media) in scenarios in which she wasn’t sure what to do with the code. If the institution instead had a culture which was very rigid, involving the delivery of scientific facts and content, visitors and facilitators alike may have felt “stuck” when they weren’t sure how to make particular code changes and instead choose to stick to what they knew how to do, thereby constraining the interactions and learning that was possible at the exhibit. The institutional valuation of experimentation meant that Janelle felt empowered to use that strategy at the exhibit, just as she would with any other exhibit in the museum, which also aligned with the goals of the exhibit designers to promote computing as
something more exploratory and playful than it is typically portrayed. Janelle’s use of experimentation drew visitors deeper into the code, offered learning opportunities, and also reframed experiences of “failure” (i.e., the code “breaking”) as opportunities to experiment and play, as we will detail later in these findings.

However, the heterogeneity in facilitators’ disciplinary background is also an important factor that goes beyond institutional culture for supporting experimentation. Moments of rupture appear when visitors want changes to the code that facilitators are unfamiliar with, and a really important finding here is that facilitators are still able to improvise and still offer valuable scaffolds to visitors. The open access and open-ended nature of public computing also adds further ground for heterogeneity in visitors’ explorations, which we believe has implications for computational science exhibits in general. In such exhibits, visitors and facilitators must contend with diverse experience levels with code, lots of options for changing the code, multiple ways to address the visitors’ desired code changes, and also many opportunities for things to “go wrong.”

In order to support facilitators to deal with such expected uncertainties, perhaps a form of infrastructure that can be put in place is a set of professional learning sessions in which facilitators do not follow step-by-step instructions from experts but instead experiment freely with the code in a safe and supportive environment. Such opportunities can break down expert/novice binaries and empower facilitators to find particular aspects of the code that interest them and share different facilitation strategies with others in their community.
Unfolding Code to Scaffold Visitors (WHEN 12: facilitators want to take coding beyond the screen).

Using Physical Blocks to Scaffold Visitor Interactions. The original exhibit, as installed, consisted only of the simulation screen and the computer monitor, mouse, and keyboard used to make changes to the code (as seen in Figure 3.1). However, only a few months after the exhibit was fully opened to the public, the researchers noticed that a wooden block had been placed at the exhibit, pictured below in Figure 3.4.

![Physical block with “tips to get started” at the exhibit](image)

*Figure 3.4. Physical block with “tips to get started” at the exhibit*

We discovered that the block had been designed by one of the exhibit designers (they/them) with whom we had been partnering through the prototyping process. When asked about it, they said that they felt the block would add extra instructions for visitors to help them get started at the exhibit, especially when a facilitator was not available to help them. It provided easy-to-follow steps of how to make a change in the code and run the results, as well as how to fix any errors. Additionally, it included an explanation of the *fill* function used in the code to set the colour of
the Boids. Building on this block, the researchers worked with the facilitators to design and prototype additional “blocks” that would serve as facilitation tools at the exhibit, pictured below in Figure 3.5.

![Figure 3.5. Prototyped physical blocks explaining RGB colour with examples, and high vs. low values of alignment, cohesion, and separation](image)

These blocks were well-received by facilitators. Both Janelle and Kaitlynn used these blocks as facilitation tools during their interactions with visitors. The most popular blocks by far were the paint bucket and colour cubes. Janelle and Kaitlynn both used the paint bucket to
explain RGB colour notation to visitors, pointing out how each parameter in the `fill` function corresponded to the amount of red, green, or blue in the colour. They also used this block to help visitors draw connections with the colour on the screen and the actual numbers in the code, as shown by Janelle below:

Excerpt 9

Janelle: Yeah, they’re kind of orange-y. So I’m going to show you for computers the way… [grabs paint bucket, mimes painting with her hand]. Have you ever painted and mixed your colours together?

Visitor: [nods]

Janelle: Computers do that too, and they mix together red, green, and blue to make every colour [points at paint bucket]. So we’ll put, right now to make orange we have a little bit of red, I mean a lot of red and a little bit of green. Because green kinda is like yellow. And we have no blue. [points at numbers in code]. We can change what we’re mixing to make a new colour.

In Excerpt 9, we show how Janelle used the paint bucket to help the visitor understand how the numbers in the code “mixed together” to form the orange colour of the Boids. Another way to help visitors understand the colour mixing was to draw from the examples of the colour cubes. Each cube had written on it the RGB values for its colour. Both Janelle and Kaitlynn used these
cubes as examples of possible colours to make, often using the cubes in tandem with the paint bucket, as illustrated in the excerpt below:

Excerpt 10

Kaitlynn: Yeah, so RGB in that order. [points at code, grabs paint bucket]. So it determines how much of that colour you have. So these are, um, some of the colours [grabs colour cubes] that we’ve just determined, like, easy to just plug in if you want that colour.

Janelle sometimes built on that explanation, using the black and white colour cubes to discuss how lower numbers tended to lead to darker colours, while higher numbers created lighter colours. In short, the paint bucket and colour cubes were used extensively by facilitators as infrastructuring for a part of the code that they thought was of high interest to visitors of all ages, but was also somewhat abstract and difficult to understand without concrete examples.

**Translating Code into Embodied Actions.** Beyond using physical blocks to support visitor understanding of colour, Janelle in particular sought out new ways to take coding “beyond the screen” through the use of embodied actions in the form of representational gestures (Nathan et al., 2013; Novack & Goldin-Meadow, 2017). For example, Janelle combined the use of physical blocks depicting what high vs. low alignment, cohesion, and separation would look like with physical hand gestures to explain the mathematical relationships between those parameters
as specified in the computer code. This helped her animate the relationship between parameters in a dynamic manner, in contrast to the static representations of drawings on the blocks.

Excerpt 11

Janelle: Okay cool, so we have three different things. We have alignment, cohesion and separation. So alignment kinda means… do you see how they’re all just kinda moving around? [gestures at Boids on the screen] If they’re very aligned they’re all going to move around in the same [direction] as each other [gestures with hands moving in same direction]. If they’re not very aligned, they’re all going to go their own way.

Visitor: And what’s the separation?

Janelle: Separation, yeah, if you make it bigger they’ll go farther apart from each other [moves hands apart]. Smaller, closer together.

Figure 3.6. Janelle’s gestures to explain alignment (left) and separation (right)
In the excerpt above, Janelle used her hands to explain the ways in which the forces of alignment, cohesion, and separation would impact the flocking pattern of the Boids. She used the gesture of both hands pointing in the same direction to represent alignment between two Boids, and an increasing gap between two hands to represent separation between two Boids. In another video, Janelle used gestures to explain another invisible aspect of the code: coordinate geometry. Holding her arms perpendicular to each other, she demonstrated the x-axis and y-axis which played a role in determining the position and movement of the Boids.

Janelle also used representational gestures to explain the ways in which changing particular numbers in the lines of code which controlled images impacted their appearance. Within the images code, separate numbers controlled the amount of vertical or horizontal scaling of the images. While by default these numbers were set to the same value, resulting in an image with its default aspect ratio, visitors sometimes changed only one of these numbers to surprising (and often, delighting) results. In the excerpt below, Janelle explains how changing the image width without changing its height resulted in the monkeys being “pulled up”:

Excerpt 12

Janelle: Yeah, the monkeys got pulled up. [gestures pulling something apart with her hands]. So you made their width really big [gestures with hands moving apart horizontally] but you didn’t change the height puts hands together vertically] so they just got dragged out like that [pulls hands apart horizontally]
Finally, Janelle also used embodied actions and gestures to build relationships with the visitors at the exhibit. For example, when asking a young visitor how big he wanted the Boids to be, he put his hands up above his head and exclaimed “really big!” Janelle then copied that gesture, checking her understanding: “really big?”, before helping the visitor change the Boids’ size. In a different interaction, she connected a visitor’s gesture with the conceptual understanding of making a number smaller by removing some digits (thereby making it shorter):

Excerpt 13

Janelle: So how do we make our number smaller?
Visitor: Like this [mimes flattening something with hands]
Janelle: This? [copies child] Can you do that? Can you make it like [mimes gesture again] squish it up by deleting some digits?
Rather than relying on the keyboard and backspace button, or a mathematical explanation of a smaller number (which could have the same number of digits), Janelle uses embodied acts to the concept of making a number smaller by “squishing” it, reflecting the visitor’s understanding in a way that helped them to achieve the desired result.

**Unfolding Code to Scaffold Visitors: Implications for Infrastructuring.** Taking code “beyond the screen” is itself a form of infrastructuring at the exhibit. This was amply evident in our interviews with facilitators, most of whom noted that they could offer better support to visitors when they were able to use physical objects and gestures during facilitation, rather than being limited to pointing at the lines of code on the screen and only relying on verbal explanations. The physical blocks played a key role in offering additional explanations and transforming abstract computational representations and ideas into physical forms. Thus, abstract symbolic representations such as the RGB colour notation used in the code, which uses a form of data structure known as “arrays,” could be transformed into an annotated, physical form: a bucket of colors to choose from, with annotations on the bucket itself explaining what the three numbers in each RGB array mean (how much red, how much green, how much blue). The symbolic meaning that remains otherwise hidden is now visible and manipulable, and as our analysis shows here, becomes key infrastructure at the exhibit. Within our collected data, we found these physical blocks to be particularly helpful when facilitators were working with younger children (i.e., < 4 years of age), as they had something they could physically hold and look at, connecting what they saw on the screen with what they were holding in their hands. However, we can also look to the ways that facilitator practice can further inform this infrastructuring – facilitators also reported to us that there are several aspects of the code which
are particularly underserved by the written explanations and may benefit from additional forms of explanation (such as visuals or diagrams). Kaitlynn in particular was adamant that written or verbal explanations were not accessible to all learners, especially younger learners or those with disabilities, and advocated strongly for physical tools (including a physical facilitation guide) that included different images and graphics to explain parts of the code. In co-design sessions held later in the year, we worked with facilitators to solicit ideas for further unfolding code, a process that is currently ongoing. Similarly, we can see how facilitators unfold code “beyond the screen” by drawing on embodied gestures and acts. These acts can serve two different purposes.

Firstly, they act as visible models that explain particular aspects of the code, such as alignment/cohesion/separation in relation to flocking behaviour or explaining why an image appears to be “squished,” translating an idea that is only represented symbolically into dynamic explanations. Secondly, they can be ways for facilitators to connect with visitors, something that may be initially difficult when both parties are only staring at a computer screen. Copying gestures can lead to shared understandings of the code as it exists outside of the confines of the computer screen. In other work, we have also showcased how embodied acts can serve to center the visitors’ learning experience at the exhibit (Helvaci Ozacar et al., 2020), therefore becoming infrastructuring not just in explaining code but in developing positive relationships between the visitor, facilitator and exhibit. Moving away from device-centered approaches, we note that a “positive” interaction with an exhibit is much more than the visitor “understanding” the exhibit; instead, it involves building these relationships and disciplinary understandings in ways that are fun and playful.
Errors and Open, Broken Code: To Play or Not to Play (WHEN 16: A visitor does something unexpected with the code, including compiler errors). While facilitators had some strategies related to which lines of code they encouraged visitors to change, based on their experiences and what they thought would provide the most fun and learning opportunities for visitors, they generally did not constrain visitors to those code changes. With the entire flocking code available to them, visitors frequently made code changes that went beyond simply making a value bigger or smaller. They made apparently small changes – for example, inputting letters where the code expected a number – that would result in a compiler error. That is, because the text-based code had to “compiled” by the computer using an intermediary program (a compiler) that interprets user code in terms of instructions for computer hardware, the code would “break” (to use the language of facilitators), resulting in the simulation vanishing from the screen. This would also (usually) result in the appearance of a red bar underlining the line of code that had the error. We note here that the fact that the code can be “broken” is not, in itself, a rupture in infrastructuring. The designers had specifically chosen a text-based programming language with the capacity for compiler errors to represent authentic, professional practice in computing, given their commitment to public computing (Sengupta & Shanahan, 2017). Understanding what the program “expected” and what caused an error was considered by the designers to be an important aspect of learning to code, as was debugging (i.e., identifying and correcting) these errors. Moving away from a device-centered perspective, here we focus on the facilitator responses to these errors as moments of infrastructuring (rather than the errors themselves),
which highlights how they improvised and facilitated learning for the visitors, and what additional infrastructuring may be needed to support facilitators in such moments.

**Common Strategies: Noticing, Explaining, and Fixing Errors.** Facilitators were often quick to notice when the visitor’s code change caused an error. One of the key indicators of a compiler error was that the simulation screen would go blank, with only the background colour visible and no Boids or images moving on the screen. In these situations, both Janelle and Kaitlynn would follow a similar pattern of behaviour: (1) helping the visitor notice an error had occurred, drawing on the visual cues of a blank screen and red error bar in the code, (2) explaining what had caused the error, and (3) helping the visitor to fix the error. This pattern is evident in the excerpts from Kaitlynn and Janelle below:

**Excerpt 14**

Visitor: [runs new code, screen is blank]

Kaitlynn: What? Oh no!

Visitor: I don’t know where [the Boids] are.

Kaitlynn: We accidentally… you know why? ‘Cause look. [points at error in the code]. You accidentally typed two R’s. We need to delete them…

Visitor: [Deletes extra R’s from the code and reruns it]

**Excerpt 15**

Janelle: Oh, do we see them? [simulation screen is blank]. One second… do you
know what we did wrong? Do you see how this is red? [points at red in code that indicates a compiler error] That means something’s wrong! Do we have a bracket in the middle of our brackets?

Visitor: [shakes head]

Janelle: No? So you see these like kinda backwards [makes bracket shape with hand briefly]... They kinda look like macaroni? Do you see that macaroni?

Visitor: [nods]

Janelle: [nods] We have too much macaroni! Can you delete that one?

One interesting aspect of this pattern is that the depth of facilitators’ explanations varied. For example, in the excerpts above, they explained that something in the code should or shouldn’t “be there,” but not necessarily why. Kaitlynn did not mention how the extra R’s in the code would stick out to the compiler as incomplete functions or other parts of code, and Janelle did not discuss how bracket mismatches in code can cause issues with functions and parameters. In contrast, when a visitor typed in numbers in front of the variable (e.g., “56 size=”), Janelle provided a deeper explanation that if the numbers are before the “words” (i.e., the function or variable), “the computer doesn’t know what to do with those numbers,” as they are not tied to a particular function or variable when written in that order. The heterogeneity in facilitators’ explanations and supports may be related to both their diverse disciplinary backgrounds, and may also orient us toward the need for more carefully designed professional learning opportunities around this specific issue.
While their responses to unexpected code errors were similar, as seen above, other facilitation videos showcase Janelle and Kaitlynn’s different approaches when they saw the visitor typing something that would cause an error before running the code. As we explain next, Janelle would actively encourage the visitors to type code that makes errors, as she felt that it was part of learning how to code. Kaitlynn, on the other hand, tried to minimize errors by pointing them out beforehand and redirecting the visitor, showcasing a desire to keep the exhibit in an error-free state.

**Janelle: Encouraging Errors as Part of Learning Code.** Janelle explicitly encouraged visitors to make errors in the code, as she felt that it was part of the process of learning about code. In her interview, she noted that when the code has an error, it provides facilitators with “another opportunity to discuss how code works, and I guess how it interacts with the machine” (interview, Jan 2019). This approach to code errors aligned nicely with her other infrastructuring of encouraging experimentation with the code, linked to her playful and experimental stance on science learning in the museum. As an example, consider the excerpt below. Janelle had previously explained that the line of code they were working with expected numbers. However, the young visitor immediately began typing characters other than numbers into the code.

**Excerpt 16**

Visitor: [types on keyboard]
Janelle: Woah, are those numbers? [points at the code the visitor has just typed]
Visitor: [nods head, giggles]
Janelle: No they’re not! Is this dash a number?
Visitor: [shakes head]
Janelle: No, should we get rid of those?
Visitor: [nods slightly]
Janelle: Or do you want to try with those? What do you want to do?
Visitor: I want to try it.
Janelle: Okay, should we try right now with those? [runs code]
Visitor: [nods]
Janelle: [points at blank screen] Did it work?
Visitor: No. [shakes head]
Janelle: No. See that red right there? [points at red error bar in code]. That means something’s wrong! Do you think it’s wrong because we have not-numbers? Should we get rid of the not-numbers?
Visitor: [nods]

In the situation above, Janelle knew that inputting characters that aren’t numbers would cause a compiler error, and she had just explained that to the visitor. She even pointed out these non-number characters, such as the dash, to the visitor. However, when she asked the first time if they should be deleted, the visitor seemed hesitant. Wanting to give the child agency in his interactions with the exhibit, she asked if he would like to run the code with the “not-numbers” to see what happens, to which he happily agreed. After running the code and causing the error, Janelle explained the error again and asked if the visitor would like to fix it now, and he agreed. In this way, Janelle gave the child agency to make whichever code changes he would like, even
if they cause an error, and then used the error as a learning opportunity to discuss how the code was working.

In other videos, Janelle was happy to let children delete important parts of the code, delete variables (such as the BoidSize variable), type in letters, or even choose non-typical values for variables (such as a size or speed of 0) to see what happened, often causing an error or other strange effect in the simulation. In these situations, Janelle appeared to be calm and confident. Some of this confidence is likely linked to her experience at the exhibit; many of the common errors that visitors made were errors she had seen before and knew how to fix, and in the case where the code was “too broken,” she knew that they could perform a hard reset of the code to get it back to a working state. Therefore, Janelle did not have to worry about ending up in a situation where the code was un-fixable and continued interaction with the visitor was at risk.

Additionally, Janelle’s experimental and playful approach to the code in general led her to encourage ownership of what she called “weird code,” times when the visitor’s code changes did not work in a way that was expected, but were still interesting. In one video in particular, Janelle had worked with a girl to create five-pointed stars from existing code written on a piece of paper. After more than 12 minutes, they had still been unable to create the proper star, instead resulting in a different polygon. When the visitor moved on to change the colour to pink, Janelle said:

Excerpt 17

Janelle: Okay, so I know our stars are kinda weird… but they’re our pink weird stars, right?
Visitor: Yeah.

In this interaction, unexpected behaviour or an inability to create exactly what they wanted was not framed as a bad thing, but rather as an opportunity to take ownership of unique simulation behaviour or appearance.

**Kaitlynn: Minimizing Broken Code.** Unlike Janelle, Kaitlynn tended to stop visitors from making a code change that would cause an error. In her interactions with visitors and informal comments made to the researchers, it was clear that she strongly preferred to have the exhibit in a “working condition.” Part of this stemmed from her frustrating experiences in the gallery, as when a facilitator was not present as part of the research, she argued that the exhibit was almost always broken and had to be reset constantly. For that reason, Kaitlynn was hesitant to let visitors try something that she knew would cause an error in the code, quickly pointing it out before they ran the code and telling the visitor how to fix it. She also used the same strategy if a visitor was making a code change that she felt would not have an effect on the simulation, usually (but not always, as we will see below in Excerpt 20) redirecting them to a different code change.

**Excerpt 18**

Kaitlynn: Oh, go back, go back. You’ve gotta type in your number there again. Because you accidentally erased that one. [points at code] …

Visitor: [inaudible]

Kaitlynn: I know, but you’ve got to fix that one first or else it’ll get broken right?
Excerpt 19

Visitor: [choosing a value for speed] 10-hundred.

Kaitlynn: [using the value of 300 from the comments as the maximum] 10-hundred is more than 300.

Visitor: [nods] 700

Kaitlynn: 700 is more than 300 too. So, what comes before?

Excerpt 20

Visitor: Yeah, let’s do like one hundred zeros, like a million zeros.

Kaitlynn: Uh, nope. Because it’s not going to do anything anyways, right? You’re just going to be typing a bunch of zeros for no reason.

Visitor: Well, thank you. [leaves exhibit]

Kaitlynn: Yeah, you’re welcome. See you later!

In the examples above, we can see a stark contrast between Kaitlynn’s facilitation practice and Janelle’s practice when it comes to code errors. Kaitlynn sought to stop code errors before they happened, viewing them as detracting from the learning experience and being a source of frustration for the visitor and facilitator, rather than an opportunity to learn more about code. Her own discomfort with code errors was evident in her manner when they appeared unexpectedly – her tone of voice and language suggested frustration in trying to get it to work, noting in one interaction that “honestly, like the tiniest little thing can change it [cause an error].”
As mentioned previously, Kaitlynn was also less comfortable with the exhibit than Janelle, so this lack of training and experience may have left her feeling unprepared in dealing with all of the possible code errors that could result from an open, text-based code file.

*Errors and Open, Broken Code: To Play or Not to Play: Implications for Infrastructuring.* Analysis of this “when” makes it increasingly clear that infrastructure gaps are perceived differently by different facilitators, and that their infrastructuring solutions may also need to be different. All facilitators knew that making errors was an intended part of the exhibit, as it had been communicated to them by the exhibit designers and researchers. However, their level of comfort in moments where the code was “broken” varied wildly. For Janelle, this may not actually be perceived as a gap in infrastructuring at all – she had the experience and training to know that errors were expected, and also knew how to fix even the most serious issues with the code. She was actually able to leverage moments of broken code as infrastructuring for the exhibit, aligning with the view of computing that the exhibit designers wanted to portray – one that is playful, exploratory, and where making mistakes is all part of the process. For Kaitlynn, on the other hand, errors in the code were frustrating, as she felt it would take away from the learning experience at the exhibit. This has a few implications for infrastructuring.

Firstly, we again see how a lack of training or support for facilitators can lead to moments in their practice where they feel as if they do not have the tools or content knowledge to support the visitor, especially in moments where the exhibit behaviour is unexpected. Therefore, additional training specifically in debugging code can help facilitators who are less comfortable with code errors. However, this training cannot be exhaustive – with a text-based programming language, the number of different potential code errors that can arise is incredibly
large. Therefore, if designers want to create an exhibit that can wind up in states that feel "wrong" to visitors or facilitators, they must also include support for facilitators in that moment, including which strategies in particular they might employ to deal with that uncertainty. For example, even learning that control+Z would undo previous code changes was something for which facilitators were incredibly grateful, as it took some of the guessing out of debugging: they didn’t have to find the exact code error, they could just undo previous changes until the code worked again.

Secondly, and of utmost importance for computational science exhibits, we can see how infrastructuring is intertwined with epistemology – what coding is/should be, and what informal STEM facilitation is/should be. The designers wished to impart a vision of computing as playful and exploratory, where causing errors is not a mistake but an opportunity for further learning about computing. This epistemology can come up against canonical understandings of computing as requiring technical mastery, something that is carried out systematically and carefully (Ensmenger, 2015; Turkle & Papert, 1990). Therefore, infrastructuring is necessary to support epistemologies that are in tension with those that may be held by visitors and facilitators.

**Summary: Infrastructuring Informing Practice, Practice Informing Infrastructuring.**

In each of the “when”s above, we can clearly see the ways in which infrastructuring and practice inform each other in a mutual manner, and that since facilitator practice is necessarily heterogeneous (as it is impacted by the values and experiences of each facilitator), therefore infrastructuring must be heterogeneous as well. Janelle and Kaitlynn experienced gaps in infrastructuring in different ways. Sometimes, a gap that was particularly problematic for one facilitator was not even noticed by another. This led each facilitator to create
their own infrastructuring in order to seal those gaps. For example, Kaitlynn focused on reading the code comments and encouraging visitors (implicitly or explicitly) to stick with code changes she was familiar with, in order for her to provide what she felt was the best facilitation practice she could give and ensure the code was always in a working state. On the other hand, Janelle created opportunities for the visitors to have successful interactions by drawing on key values of experimentation and encouraging breakages in the code, drawing on her previous experience and comfort with code.

In this way, showcasing the variety of responses to “when”s of infrastructuring highlights the complexity of facilitator practice in such spaces, especially as they work with newly-designed exhibits. Each facilitator has their own set of experiences, values, practices, and tools to draw upon when they work with visitors, and therefore we must attend to the ways in which infrastructure such as training programs, facilitation guides, social interactions, and technological components can have varying impacts on each facilitator. In some cases, this infrastructuring (or lack thereof) can constrain facilitator practice, blocking them from tools or actions that they would habitually use. Illustrating this point, Kaitlynn felt comfortable letting visitors experiment with many of the other exhibits in the gallery, including the “take-it-apart” station and stop-motion animation exhibit. However, as she discussed in her interviews, her lack of experience and training at Hack the Flock meant she was less comfortable with experimentations with the code. In contrast, the training and technology infrastructure at Hack the Flock created space for Janelle to offer playful and exploratory approaches to coding. In particular, the use of a text-based programming language combined with her knowledge of how to fix the exhibit when it “broke” meant that she had wider opportunities for experimentation and learning at the exhibit.
than would be afforded by an exhibit that provided step-by-step, carefully articulated instructions for “how to code.” Infrastructure and infrastructuring therefore informed their practice in heterogeneous ways.

Flipping the idea on its head, we can also see ways in which the facilitators’ practice can inform infrastructuring at the exhibit. As they experience infrastructuring gaps in different ways, they also have different ideas for how to bridge those gaps. For example, Kaitlynn’s use of the code comments led her to offer ideas about how to improve them, including ideas such as using language more appropriate for younger visitors, providing more explanation in the comments of what the visitors can actually do with the code, finding a way to “lock” the comments so they can’t get deleted by other visitors, and supplementing written comments with visuals. All of these infrastructuring ideas came out of what she felt was needed to support her practice at the exhibit. Another idea that nearly every facilitator voiced was the need for a “reset button” at the exhibit, a large button that could be pressed by the facilitator or a visitor to automatically reset the code to its original, working state. Facilitators wanted to be experimental and encourage play at the exhibit, but in order to feel supported in doing so, they wanted easier ways to handle the inevitable compiler errors and other code issues that would come up. Even Janelle, who was quite comfortable with fixing errors through control+Z or performing a hard reset of the exhibit, noted that having a reset button would be easier and save time for facilitators and visitors when dealing with tricky code errors, taking away some of the discomfort of making unknown code changes. Thus, infrastructuring wasn’t just informed by what facilitators felt they couldn’t do at the exhibit, but also by what they wanted to do, imagined actions and strategies that facilitators
wanted to use in order to better engage visitors in learning about code in authentic, exploratory, and fun ways.

**Emergent Infrastructuring Within the Facilitator Community**

Once facilitators started spending larger periods of time at the exhibit in the presence of researchers, a community of knowledge, self-organized professional learning, and support began to emerge through interactions with facilitators and sometimes researchers as well. We view these social interactions, technologies, and facilitation strategies as infrastructuring that emerged specifically from within the facilitator community. By viewing the infrastructuring of the facilitators in a collective manner, we can see the ways in which it emerged in response to institutional constraints which impacted their practice at Hack the Flock.

During data collection, researchers were present at the exhibit, either behind the video-camera or nearby. These data collection sessions were not intended as training sessions, but many facilitators seized the opportunity to work directly with the researchers, who they viewed as “experts” in code and the exhibit, to learn more about the exhibit, programming, and the research more generally. Hilda voiced that by taking part in the research she was able to have more discussions and learning opportunities with the researchers, which in turn helped her gain a deeper understanding of the exhibit. However, these learning opportunities were not limited to facilitator-researcher partnerships. Field notes showed that Kaitlynn would share her new knowledge with other facilitators, such as passing on her knowledge of how to make the Boids flash random colours (which she had learned from one of the researchers) to the next facilitator scheduled at the exhibit. Additionally, facilitators also began to rely on each other to learn and
understand the code, which began to show itself in various new aspects of their professional practice.

Excerpt 21

Ashley: Even if I can't remember, I can ask my teammates to help me out and we can…

al teach each other. (Interview, Aug 2019)

Ashley stated that if she ran into a scenario where she could not remember a particular code change, she could easily ask other facilitators for help. Beyond simply offering assistance, facilitators could all teach each other, which was particularly useful if one facilitator learned something new while working with the researchers. They could then excitedly pass it on to other facilitators, calling them over to say “Hey, look at what I made!,” which happened multiple times during our data collection. In one video recorded interaction, Hilda, together with a visitor, had been experimenting with the Boid and background colours to create new colours and a visual effect of the Boids leaving a “trail” on the screen. Hilda told the researcher multiple times to write down the RGB values of the new colours she had made in the researcher’s field notes, and more than once left the exhibit to find the other Open Studio facilitator to show them the cool new effect and how she and the visitor had created it (video-recorded interaction, Jul 2019). This type of infrastructuring was emergent throughout the duration of our data collection, and slowly grew in both number of facilitators and the code changes, eventually including both verbal and written instructions for how to make the Boids flash rainbow colours or become 5-pointed stars, among many other creative changes. As facilitators wanted to learn more about the exhibit and
create their own hacks, they shared them with their colleagues in person, via written text, or even over social media. What may have begun as a one-off comment or photo sent to others led to sustained infrastructuring as changes in their practice to create a community for Hack the Flock knowledge and support.

The facilitator community also worked together to address the perceived lack of formal training at Hack the Flock, which can be viewed as an institutional constraint. Kaitlynn did not simply wait around for formal training. Instead, she asked other facilitators to explain the exhibit to her, although the ever-busy lives of facilitators meant that those explanations were often limited to “ten second rundowns.” Kaitlynn built on those explanations and chose to figure out Hack the Flock on her own by sitting down and working through the code and comments during times in which the gallery was slow, despite her negative perception of the comments’ instructional value. She improvised her own training, as constrained by her responsibilities within her role as a facilitator. This training, done on her own, involved reading through the code and making code changes to try and figure out how it all worked (and, presumably, to pass on that knowledge to visitors). She was able to modify her professional practice to include time spent learning and understanding the new exhibit so that she could be a better facilitator.

This community-based, emergent infrastructuring is particularly important as it addressed an institutional constraint that had a significant impact on their practice. Facilitators were expected to constantly move around the entire gallery, and this expectation, on top of their other job duties such as getting more hot glue gun sticks and helping visitors with wayfinding in the museum, meant that they could not spend longer periods of time at the exhibit. Multiple facilitators mentioned this as a frustration, as without spending extended time at the exhibit, it
was difficult for them to help visitors deeply understand the exhibit and the ways in which they could interact with it, and also challenging to spend time learning with other facilitators. Thus, passing off notes with “cool” code changes, giving each other short rundowns of the exhibit, sharing knowledge via texts and social media, and even just taking a few seconds to call over another facilitator to view what they had recently made at the exhibit was infrastructuring that took place within the confines of their institutional constraints. This interaction between infrastructuring and institutional constraints is only visible if we consider facilitator practice as labour, looking beyond “what they do at the exhibit” to attend to institutional norms and restrictions, power dynamics, and community-building.

Discussion

Seeing and Connecting Infrastructuring Within the Institution

Overall, our analysis showcases the hidden work that facilitators are doing to make this exhibit – and likely, other exhibits in the science center – “work.” Specifically, it brings to light the complexity of the professional practice of museum facilitators, something that we believe to be largely absent from the literature regarding DBR in museum spaces. As is visible through our findings, this professional practice is linked to epistemologies, values, and institutional norms and regulations. Additionally, this practice is not homogenous across all facilitators; there is variation in their epistemologies and values, which in turn causes variations in their practice and the potential infrastructuring that they carry out on a day-to-day basis. We wish to be explicit here that infrastructuring is not just another term for museum facilitators’ professional practice. Rather, as Star and Ruhleder (1996) have argued, infrastructuring is a “when,” occurring at the nexus of heterogeneous practices, norms, epistemologies, values, and other factors within the
museum. Figure 3.8 below highlights the ways in which infrastructuring both informs these other aspects of a lived-in world, and is informed by them. Examples of each connection between infrastructuring and the other aspects are detailed in Table 3.5 below.

Figure 3.8. Connections between infrastructuring and the institutional context

Table 3.5. Examples of connections between infrastructuring and aspects of the lived-in world of the science museum
<table>
<thead>
<tr>
<th>Aspect of lived-in world</th>
<th>Example of connection to infrastructuring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professional practice</td>
<td>Kaitlynn using the code comments as infrastructure to ensure that visitors can always make what she considers to be “successful” changes to the code, such as staying within the “limits” while changing values of variables</td>
</tr>
<tr>
<td>Institutional roles and norms</td>
<td>The expectation that facilitators are there to help visitors understand the exhibit and keep working with them, even if the facilitators are unable to do the specific thing the visitors asks, caused Janelle and Kaitlynn to both use the strategy of redirection to a different code change</td>
</tr>
<tr>
<td>Institutional restrictions</td>
<td>The inability for facilitators to spend large amounts of time at the exhibit outside of research data collection led them to create their own opportunities for peer professional learning at the exhibit</td>
</tr>
<tr>
<td>Epistemology re: museum learning</td>
<td>Janelle’s focus on experimentation and play while working with the code and dealing with compiler errors, drawing on her personal epistemology of what museum learning should look like (and institutional culture)</td>
</tr>
<tr>
<td>Epistemology re: scientific disciplines</td>
<td>Janelle drew upon code errors as an opportunity to learn more about computing, while for Kaitlynn, these moments highlighted infrastructure gaps as she was not comfortable with “broken” code</td>
</tr>
</tbody>
</table>
Kaitlynn argued for wording and visuals in a facilitation guide, signage, or code comments that would be more appropriate for younger visitors or those with disabilities – a visitor group that was important to her.

Discussions between facilitators and the design team led to various designs of physical blocks acting as scaffolds at the exhibit.

Sense of community amongst the facilitators led them to share different code changes and ideas, both written and digital through social media, that they could then draw on in their facilitation and for their own knowledge building.

Though Table 3.5 presents the connections between aspects of the museum facilitation world and infrastructuring separately, we wish to call attention to the fact that these aspects may (and often do) overlap as well. For example, Kaitlynn’s desire to steer the learner away from making code errors is tied to her viewed of what “good” computing looks like (i.e., writing correct code and avoiding mistakes; epistemology of computing), her belief that a visitor’s learning experience at a museum should not be too frustrating (epistemology of museum education), the importance of following code comments (her professional practice), and institutional restrictions that made it difficult for her to look up corrections for common code errors on her phone (a restriction coming from her employment norms) or easily reset the code with the push of a button (a technical restriction of the exhibit itself). Thus, connections between practices, epistemologies, and institutions must be understood as both complex and
heterogeneous; they are interlinked, and infrastructuring becomes visible when these links are tenuous or broken.

The reality of the heterogeneity of practice and infrastructuring is made clear in the comparison of Kaitlynn and Janelle’s experiences at Hack the Flock. Rather than positioning one facilitator’s practice as “better” than another, this analysis clearly showed that infrastructuring and facilitator practice are heterogeneous – they may hold different personal values, different epistemologies, be impacted differently by institutional restrictions, and be positioned differently within the facilitator community. Even aspects of their work environment that may be assumed to be constant, such as institutional norms, may be taken up differently. Recall that this science museum had an explicit emphasis on an experimental and playful approach to science. That approach meshed well with Janelle’s epistemologies of museum learning and computing, and therefore she was able to leverage it in situations where the visitors were making unexpected changes to the code. In contrast, Kaitlynn had received the same messaging and training from the institution, but it was not enough to overcome her personal epistemology of computing that prioritised “correct” code, leading to differences in their facilitation practices with visitors. In this way, our research showcases the reality of designing, facilitating, and maintaining a computational science exhibit that is part of an institutional ecosystem involving people (facilitators and visitors), practices, and expectations – of visitors, employees, managers and researchers.

By calling attention to the ways in which the original exhibit design and infrastructuring fell short for facilitators, we also point out the futility of aiming for that “perfect design” that will meet every need and expectation of every person interacting with the exhibit. It is naïve to
assume that researchers and designers, who are often external to the context in which the exhibit will be placed, will be able to create a design that aligns with every possible epistemology regarding museum learning or computing, or with every aspect of each facilitators’ professional practice. However, designers can work with practitioners in ways that go above and beyond simple user profiles, focus groups, and testing in order to refine the design into something that takes into account the heterogeneity of infrastructuring and practice in these spaces. We argue that extended time spent in the field is necessary to recognize and value the hidden work of facilitators, something that is crucial to ongoing infrastructuring and the success of the exhibit.

**Recognizing and Valuing Hidden Work of Facilitators**

As we began working with the facilitators, observing their practices *on-site*, meeting with them and working with them together to re-design the exhibit, it became clear to us that the visitor experience of coding science at Hack the Flock was greatly shaped by their presence and their work. This is the labor on which museum designers rely, and yet, we were unable to find papers that focused on understanding the nature and complexity of the experiences that entail facilitation by museum floor-staff as they work with new educational designs, whose institutional position offers different constraints and affordances than facilitation by parents or peers. Instead, we found ample evidence that museum designers and scholars have adopted a position of “solutionism:” where the goal of the research focuses more or primarily on improving facilitation through professional learning and development opportunities of the facilitators such that they can carry out the designers’ visions for content, pedagogy, and professional practice (Ash et al., 2012; Pattison et al., 2017). Our work challenges this stance and reveals the hidden
work that facilitators must perform in order to make computing exhibits work in science museums.

The issues identified here, we believe, are not merely limited to Hack the Flock, rather, are most likely to be evident in other museum or science center contexts as well. A non-masculine vision of coding and technoscience is fundamentally conversational and dialogical, inviting and acknowledging epistemological heterogeneity, and engaging people new to computing and technoscience playfully, yet authentically (Ames, 2019; Harding, 1992, Sengupta et al., 2021). The open-source nature of Hack the Flock and the use of professional programming languages (as opposed to block-based programming languages such as Scratch) also open the space for multi-layered conversations, which can benefit greatly from conversations with facilitators. This attempt to move away from technocentric (Papert, 1987) approaches to computing in our design – those which prioritize the hardware and software over other experiences of technology – is echoed in our analysis. The difference between “when” 15 (Visitors use the exhibit in intended ways) and “when” 16 (A visitor does something unexpected with the code, including compiler errors) was subtle, but important, as it was not solely based on the change to the code. They were related to people and practices as well: in “when” 15, visitors often wanted to make changes to the code that designers had not covered in their training sessions and documentation as those that would be common, interesting, or easy to implement at the exhibit. Thus, these “unintended” changes were not necessarily impossible to implement at the exhibit from a technical standpoint (they are not “errors” in interacting with the exhibit), but instead showcased a gap between what visitors wanted to do at the exhibit and what facilitators had been trained to do, or what designers expected visitors to do. Additionally, while “when” 16
did include instances of compiler errors at the exhibit, these were not necessarily considered to be “mistakes” from the point of view of the facilitators. As we saw from Janelle’s video-recorded interactions with visitors, she often used the existence of compiler errors as another way to more deeply explore concepts in computing, or as opportunities for playful exploration of the code. In this way, simply calling all of these different situations “errors” or “mistakes” while working with the exhibit would erase the nuance of these actions within their contexts, and this technocentric approach would mask the complex and hidden work of facilitators as they navigate these situations. Therefore, the hidden work of the facilitators reveals the complexities one must navigate both as facilitators and designers in this space. We discuss the implications for designers and researchers in the next section.

**Implications for Design and Design Research**

How an exhibit works in theory or initial field testing is very different from the lived reality of an exhibit enmeshed in the ecosystem of informal learning environments such as museums. Some educational designers may feel that the gaps in infrastructure that we have identified could be solved with subsequent iterations of the exhibit’s design, or additional training given to facilitators. However, this perspective creates a power dynamic that positions designers or those responsible for “training” facilitators in a position of power over the facilitators; that it is somehow up to us to ensure that our exhibits are well-designed, and training is comprehensive enough that facilitators do not need to deal with these infrastructure gaps (as they are not viewed as having the expertise or institutional power to deal with them). Such power dynamics have already been illuminated in formal classroom settings involving collaboration
between science teachers and scientists (Shanahan & Bechtel, 2020), and this view only reproduces these issues in informal education spaces.

Just as “cookbook” laboratory experiments in school science may distort ideas about scientific practice in ways that smooth over the complexity in scientific practice (Roth & Roychoudhury, 1993), a “step-by-step” guide for an exhibit would attempt to constrain and simplify a facilitator’s professional practice into a series of bullet points. Ash et al. (2012) have written a compelling narrative of how participating in reflective training caused museum facilitators to shift their practice from more “telling” to scaffolding and engaging more deeply with museum visitors, and that this shift in practice also led to changes in how they viewed themselves. The goal in our current work is not to showcase a similar shift from one style of professional practice to another; rather, we wished to bring to light the complexity of facilitators’ practice that is not so easily summed up as a particular “type” of practice that can be changed through exhibit design or training. Their practice is deeply integrated with their epistemologies, values, and institutional norms, and yet facilitators still find ways to innovate and perform infrastructuring that aligns with these realms. The shift away from solutionism, here, requires an orientation toward understanding the complexity of their hidden work, and centering it within research-practice partnerships in order to have successful co-design opportunities.

This work also has implications for future research on infrastructuring. Infrastructuring goes beyond the semiotic nature of computational exhibits, mandated institutional policies, training meetings for facilitators and written guides to help facilitators and visitors. Infrastructuring comes to life in the actions, words, and viewpoints taken up by people at particular moments in time, especially when designers and museum administrators are not
around. Designers of informal learning environments would do well to remember this when they are trying to support innovative exhibits and educational programming. Whatever the designers put in place to support their designs, such as training or physical tools, cannot exist on their own. They should not only be tested and implemented in those spaces, along with the facilitators and educators as design partners. Costanza-Chock (2020) wrote that a design justice approach “is interested in telling stories that amplify, lift up, and make visible existing community-based design solutions, practices, and practitioners” (p. 134). Museum facilitators’ hidden work must be accounted for and valued in order for new designs to work, and including them as co-designers is a great way to let our designs be changed by their experiences and insights. This is an essential humility, that can bring to light new interactions and tools that can better contribute to the emergent infrastructuring that facilitators do in museums and informal learning environments.

To conclude, our research strongly advocates for the formal inclusion of museum floor staff, including facilitators, within all research-practice partnerships in museums, as well as design and research taking place in less formal partnerships. It is clear to us that without a deep understanding of the emergent, complex practice of museum facilitators, other parties in a research-practice partnership are not able to fully understand the impacts that their design decisions may make. Drawing upon the wealth of infrastructuring experience that these facilitators have by inviting them into the design process as co-designers may lead to new design ideas contributed in order to create successful museum experiences – something that these professionals do on a daily basis.
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Chapter 4: Centering Praxis in Design-Based Research: Insights from an Informal STEM Research Practice Partnership

“No one has ever asked us about this stuff!” exclaimed one museum facilitator as they left the design meeting we had facilitated, in which we invited them to explore their perceptions of a computational science exhibit that had been in place at their science museum for nearly two years. We had asked museum staff responsible for on-the-floor facilitation of the exhibit to reflect on its affordances and challenges with respect to facilitation with visitors and collectively brainstorm potential solutions to these challenges or provide new design ideas. This comment was the latest in a series of interactions and conversations with museum facilitators that were a part of our lived-in experiences of the tension between the designed exhibit and relationships with participants throughout our multi-year research-practice partnership (RPP) in a science museum. This paper offers an account of how we – as researchers and designers of an informal computing and science exhibit in a science museum in a major Canadian city – learned over the course of a multi-year design-based research project to recognize the complexity of facilitators’ work and centering their praxis, rather than relying on technocentric and instrumentalist approaches. Furthermore, we also illustrate methodological shifts from both epistemological and axiological perspectives that also result from such recognitions.

The specter of technocentrism – the fallacy of referring all questions about technology to the technology itself, rather than inquiring about the socially and institutionally constructed meanings and experience of technology – looms large in technoscientific spaces, and in particular, in the field of computing education (Hladik et al., 2021; O’Neill, 2019; Papert, 1980). Technocentric designs imply an emphasis on device-level engagements (Rosner, 2018; see also
Ames, 2019), orienting our attention primarily toward the software and hardware involved in computing in studies of learning, rather than the phenomenological complexity of the participants’ experiences (Sengupta et al., 2021). In informal STEM education research, the emphasis on device-level engagements is evident in the form of a predominant focus on the effectiveness of the designed technologies and exhibits (see for example, Horn et al., 2009). Such device-centered approaches are not likely to recognize the complexity of the work of facilitation, which therefore remains an unfortunate omission in the literature on informal science, STEM, and computing education (Chapter 3 in this dissertation). The focus on the technological device may be further emphasized when researchers in technoscientific spaces such as science museums engage in design-based research (DBR), a methodology that has traditionally focused more on the efficacy of the designed intervention and less on the social and political threads that weave together researchers, practitioners, and their (rarely identical, sometimes conflicting) needs and practices.

Given this background, our work is an effort to move toward understanding the work of facilitators in the design process as mediated praxis (Gutiérrez & Vossoughi, 2010), which offers a contrasting imagination – methodological, epistemological, and axiological – that challenges reductive views of practice and practitioners in DBR. In mediated praxis, “changes in practice necessarily involve changes in the ways we think about practice [and] individual shifts in thinking and participation influence (and are influenced by) changes in the activity itself” (Gutiérrez & Vossoughi, 2010, p. 105). Design, Schön (1983) argued, interweaves action and reflection. So, it follows that if praxis is to be centered in DBR, there must be methodological, epistemological, and axiological implications of such centering. To this end, we argue that
listening (Schön, 1983) to facilitators’ voices plays an essential role in the context of design in informal science centers and museums, and present an investigation of the epistemological, axiological, and methodological shifts that result from centering their work and their voices in the context of a multi-year RPP.

We begin by reviewing the relevant literature on staff facilitation and computing education in science museums. We also present an overview of design-based research, including its critiques and the increasing attention paid to RPPs. Next, we devote a section to the specific articles, authors, and concepts relating to DBR that informed a shift in our own perspectives of our DBR project over time – here, we pay particular attention to ideas of mediated praxis, power, axiology, and partnerships. Following a methods section that includes details about the particular setting and collected data, we present our findings which follow a phenomenographic approach (Marton & Booth, 1996). Drawing upon the ideas in our theoretical perspectives section, we present a chronological accounting of how our project shifted from one that was centered on the technological device – the exhibit – to one that focused on praxis, centering the voices and contributions of museum facilitators more strongly in the work and inviting new forms of participation in the project.

**Literature Review**

**Staff Facilitation in Science Museums**

Researchers have positioned facilitators in science museums – also referred to as explainers, docents, or educators – as “front-line interpreters” (Ash et al., 2012, p. 24). They introduce visitors to an exhibit, help them learn how to operate it, and provide additional disciplinary guidance to deepen their understanding and learning. They may also scaffold (Wood
et al., 1976) visitors’ interactions with the exhibits in ways that do not take away from the playful nature of museums (Yoon et al., 2013). Pattison and Dierking (2012, 2013) have noted that museum facilitators use a variety of approaches to initiate interactions and establish identities; to facilitate learning by interpreting, demonstrating, guiding, and encouraging; and to introduce new science content learning goals for family visitors to a science museum, even in informal and unstructured interactions. Additionally, facilitators may model what it looks like to be “doing science” (Rowe & Kisiel, 2012). In these ways, science museum facilitators play a critical role in visitor sense-making (Afonso et al., 2019; Hayward & Hart, 2015) – and their on-the-floor presence may lead them to be considered as the public face of their institutions (Dragotto et al., 2006).

Despite their importance in science museums, research on the roles, experiences, and practices of science museum facilitators is scarce (Pattison et al., 2018; Tran, 2007). Dawson (2019) found that museum facilitators can play a key role in helping visitors who have been historically marginalized in science or science museums to feel welcome and that the science museum is “for them.” For facilitators, there is an intertwining of personal and professional knowledges and identities that shapes their facilitation practice (Ash & Lombana, 2012; Tran & King, 2007). For example, Ash et al. (2012) argued that facilitators’ practice was influenced by their views on what it means to learn in museums, and how to scaffold that learning. Additionally, reflection upon their roles with families and within the science museum as a whole helped them to shift their stance from “demonstrating” science to families to supporting them in scientific inquiry (Ash et al., 2012). This shift in their practice and in how they positioned themselves, as educators who could recognize their contributions had a positive impact on
facilitators’ professional and personal identities (Ash et al., 2012). However, these moments of empowerment may be few (Ash et al., 2012), and must struggle through frequent deficit positionings of museum facilitators in their institutions (Tran, 2007). There is a considerable number of research studies which report on the design and implementation of training programs for science museum facilitators, pointing out that museum educators have a lot to learn from the learning sciences (e.g., Bevan & Xanthoudaki, 2008), and omitting the potential for learning and understanding that museum facilitators can create for informal educational researchers. In these studies, museum facilitators are positioned as in need of training (in content knowledge, pedagogy, etc.), and there is little mention of the wealth of experiences, identities, and practices that they bring to their work, and their potential to serve as a base for new theory building in informal learning. This deficit positioning of museum facilitators impacts more than research findings; it also has implications for their participation in educational research projects. In light of the dearth of literature on museum facilitators’ experiences, their frequent deficit positioning, and their limited participation in educational research projects, it is clear that as researchers and learning scientists, we must (re)consider the ways in which we partner with museum facilitators.

**Computing Education in Science Museums and other Informal Learning Spaces**

Just as computing and computational thinking have become more popular within K-12 schooling, science museums and other informal learning spaces have also begun to look for ways to include computing in their exhibits and educational programming. In the project titled “Math on a Sphere,” Hsi and Eisenberg (2012) designed a large, public sphere to hang in a museum, on which students could create their own personal designs and learn about 3D geometry using a modified version of Logo. The children showed an increase in their interest in programming.
Also in a science museum, Horn (2009, 2018) compared traditional graphical programming languages with a tangible language, wherein visitors connected wooden puzzle pieces together to program a robot to complete various tasks. The tangible language better supported active collaboration with visitors and child-centered learning than the traditional keyboard and mouse programming. In other public spaces, such as entrance halls to scientific institutions, games have been piloted to teach computational thinking to children by having them maintain a garden (Pellicone et al., 2019) or compete for resources (Sung & Berland, 2017).

Instead of games, public computing reinvents public spaces such as walkways and museum galleries by inviting visitors to engage authentically with computer science simulations. Public computing, as introduced by Sengupta and Shanahan (2017), is “a new form of open-ended, public learning environments, in which visitors can directly access, modify and create complex and authentic scientific work through interacting with open source computing platforms” (p. 1124). Our previous work has included various simulations based on the complex systems behavior of flocking birds (Reynolds, 1987), spanning across multiple screens in a public walkway in a Canadian university as well as a permanent exhibit in a science museum – and it is this exhibit that is the site of the research reported in this article. Our ongoing research has focused on the role of professional vision as pairs of visitors interact with the simulation and code (Hladik et al., 2018), how facilitation moves by parents and museum staff can serve to center (or decenter) the child’s experience of coding at the exhibit (Helvaci Ozacar et al., 2020), and an in-depth investigation into the in-the-moment improvisation and extended infrastructuring that museum facilitators carry out on a day-to-day basis in order to make the exhibit “work” (Chapter 3 in this dissertation). Rather than focusing on the detailed interactions between visitors
and facilitators at the exhibit, this manuscript intends to zoom out, looking at the ongoing DBR and RPP as it spans across years of relationships, decisions, data collection, and growing understandings.

**Design-Based Research and Research-Practice Partnerships**

Design-based research (DBR) is a key methodology for Learning Sciences research. First articulated by Brown (1992), DBR was positioned as a “paradigm for the study of learning in context through the systematic design and study of instructional strategies and tools” (The Design-Based Research Collective, 2003). Marking a sharp departure from traditional paradigms in psychological research where theories and data are often clearly delineated, DBR acknowledges the intertwined nature of educational designs and practice and is expected to lead to contributions in both practice and theory (Barab & Squire, 2004; McKenney & Reeves, 2012; The Design-Based Research Collective, 2003). DBR involves research in authentic settings rather than laboratories, investigating how interventions are “enacted through interactions between materials, teachers, and learners” (The Design-Based Research Collective, 2003, p. 5). These enactments bring into focus what Bielaczyc (2013) calls a two-layered model of design: the design as conceived by researchers, and the design as conceived by practitioners in their contexts. “Mutual adaptation” occurs when an innovation is re-invented to better match the norms and capability of the adopting organization, leading to improved sustainability and scalability of the intervention (Fishman et al., 2004). However, these adaptations, often necessary for an intervention’s success in a complex setting, come into conflict with values of traditional laboratory research which espouse a need for empirical control (Sandoval & Bell, 2004). Additional critiques of design research highlighted by Engeström (2011) include a
vagueness in discussing the context in which the design is occurring, highly linear descriptions of the design process, and a focus on variable-oriented approaches. A concern with more than the intervention under study has begun to emerge as well; Engeström (2011) pointed out that researchers often fail to question who takes part in the design and why, a question mirrored by Philip et al. (2018) in their article which calls upon researchers to articulate the how, the for what, the for whom, and the with whom in Learning Sciences research (including design research) to better attend to how power can shape learning opportunities, and their values and consequences.

This essential tension between the interventionist nature of educational design and a commitment to praxis emerges especially when DBR takes place within research-practice partnerships (RPPs) and is at the heart of our paper. DBR taking place within RPPs necessarily must also focus on building and managing longer-term relationships and understanding the roles and experiences of the researchers and practitioners working together for mutual benefit (Coburn & Penuel, 2016; Penuel et al., 2015). Bevan (2017) pointed out that these partnerships are more than simply sharing knowledge between researchers and practitioners, but rather involve knowledge co-creation through shared exploration of problems, determination of research questions, data collection, and analysis. The tension between the design of the educational intervention and commitment to praxis can result in boundary crossing for both researchers and practitioners, leading to work that may “not fit squarely in any of the partners’ primary institutional sanctioned roles and responsibilities” (Penuel et al., 2015, p. 194). These new partnerships can bring new voices into discussions and designs that can lead the way to, for example, more equitable participation in science (Penuel, 2017). However, researchers must
guard against historical power imbalances between researchers and participants in order for knowledge building and decision making to be truly collaborative (Henrick et al., 2017), something that can be difficult even when researchers attempt to explicitly attend to power dynamics in their projects (Carlone & Webb, 2006).

In summary, design-based researchers are beginning to widen their focus from a strict preoccupation with the designed intervention and instead pay attention to the wider political and social contexts in which their design work is situated. As we convey in this paper, our own design work reflects a similar shift. In the following section we explore more deeply certain perspectives and themes in DBR which influenced the ways in which we viewed aspects of our project including researcher-participant relationships and desired project outcomes. These include the idea of mediated praxis (Gutiérrez & Vossoughi, 2010), as well as other perspectives on axiology and power in DBR and research-practice partnerships, which we explain next.

**Theoretical Perspectives: Epistemology, Methodology, and Axiology**

Our work attempts to address questions of epistemology, axiology, and methodology within DBR and RPPs. We understand these three strands as intersecting within our research project, and therefore locate our work in spaces where these concepts overlap, as illustrated in Figure 4.1.
Figure 4.1. Intersections of epistemology, methodology, and axiology in our work

Our ongoing reflection along these strands and shifts in our theoretical perspectives within our RPP have been strongly influenced by previous work examining mediated praxis, axiology, power, and partnerships. According to Gutiérrez and Vossoughi (2010), mediated praxis “promotes expansive forms of learning in which individual and collective zones of proximal development coalesce, as individual participants ‘act a head taller than themselves’ in ways that lift the activity towards its future, emerging form” (p. 111). Occurring within the context of social design experiments which aim for transformation through “mutual relations of exchange” (Gutiérrez & Vossoughi, 2010, p. 101), learning ecologies have the potential to be
reorganized or re-mediated as participants productively work through the tension between present and future social realities. The focus on learning ecologies, rather than learning technologies or learning environments, speaks to the interconnectedness of people, institutions, histories, objects, and power dynamics that make up a research site such as a science museum – aspects that are frequently assumed to be a part DBR’s stated focus on “context,” though the word often goes undefined in DBR literature (e.g., Barab & Squire, 2004; The Design-Based Research Collective, 2003). We were again reminded of the dangers of technocentric thinking that would place the technology – in our case, the computational science exhibit – at the center of the project and treat visitor/staff perspectives, facilitation practice, and institutional constraints as tangential or as “variables” of the context to be measured or tweaked to bring the exhibit to its peak performance. The tensions inherent in these learning ecologies reflect how when a researcher pulls on one string, it is inextricably tangled with others in ways that are made invisible or go unchecked when the technological innovation is assumed to be at the center of the web.

One such string in our web was the labor and practice of museum facilitators, which we found extended far beyond the boundaries of physical and verbal facilitation of the exhibit with visitors. Gutiérrez and Vossoughi (2010) wrote that researchers committing to mediated praxis “[make] visible the routinized practices of work and educational spaces and [bring] to the surface possible contradictions between these practices and the objects or desired outcomes of the activity” (p. 104). While they did not explicitly draw upon the idea of mediated praxis in their article, Jurow et al. (2016) provided a powerful example of how attending to routinized (and invisible) work practices can lead to dramatic shifts in not only DBR’s intervention, but also to
deeper understandings of the ways in which research, labor, and partnership are intertwined - something we view as an axiological innovation within their work. Within the context of a participatory design project focused on creating and sustaining community gardens and a fresh food co-operative, they focused on the contributions of the *promotoras*, individuals who worked directly with the neighbourhood families to help take care of their gardens. The researchers discovered that aspects of their work, including physical labour, creating on-the-fly contingencies to solve problems, and developing lasting relationships with residents were instrumental in the success of the project, and yet was largely invisible to the white project directors, leading to a lack of support for *promotoras* and the reification of systemic inequalities related to access to education and professional networks. The design of an app to collect more data and support work provided a way for the *promotoras* to represent their work to researchers and directors and disrupted the division of labor at the company. Jurow et al. (2016) noted,

> Our participatory design research has led us to focus on how power dynamics, connected to different forms of positionality and privilege within the nonprofit, have shaped how the *promotoras’* labor is represented so as to create greater opportunity for learning and professional advancement. (p. 212)

Their surfacing, naming, and acknowledging of the previously invisible work of the *promotoras* had direct implications for not only the act and product of design within the partnership, but also the sustainability of the partnership between researchers, directors, and the *promotoras*, and thus the success of the food justice nonprofit.

Work along this vein is necessary in our own project, as informal STEM education scholars rarely focus on the *work* and experiences of science museum facilitators (Ji et al., 2016;
Tran, 2007; Tran et al., 2019). When museum facilitators are the focus of the study, the goal is often to design and implement new training to improve their facilitation ability – a view which makes clear the deficit lens through which they are frequently positioned and studied (Tran et al., 2019). This is doubly true in relation to computation and coding, the disciplinary contexts of our exhibit (Sengupta et al., 2021). Coupled with the power dynamics inherent within an RPP and computing, it was very difficult not to fall into the trap of thinking, “If only these facilitators had more training, if they understood why we had designed the exhibit this way, their viewpoints on the exhibit and coding more generally might change!” However, our extensive time spent with the facilitators challenged this naïve viewpoint, shifted our understandings, and surfaced the invisible labor of museum facilitators. We began to view the challenges and differing opinions voiced by facilitators as points of productive divergence (Bielaczyc, 2013) that were necessary to explore to support long term success of the new exhibit. Just as for Jurow et al. (2016), we realized that imagining new designs and creating new futures would be impossible without a deep understanding of the current practices and the social and political contexts which collectively influence the people and infrastructure of our research site.

Mediated praxis calls for researchers and practitioners to collectively surface differences between what is and what could be, providing space for the co-analysis and co-construction of potential solutions (Gutiérrez & Vossoughi, 2010). Ehret and Hollett (2016) drew upon the idea of mediated praxis to explore the ways in which expanded agency of participants, the ability to actually make change themselves, could surface contradictions which are then re-mediated through new tools and ongoing social interaction. They brought an axiological lens to bear on the connections between present and future, attempting to bridge the divide between what is and
what should be (Cole & Engeström, 2006) and situating future possibilities within ethical and cultural-historical realms – something that is not possible without attending to affect within research. To that end, Ehret and Hollett (2016) asked the question “how do we, as researchers, not only study side by side, but feel side by side with participants toward a form of knowing the affective life of [educational programs] – the very feeling of making change?” (p. 252).

Changing what is into what should be implies axiology, an aspect of design-based research which has gone largely unvoiced in the literature, even as a growing number of learning sciences scholars call for projects that challenge historical systemic inequities in education. We explain this next.

Among these scholars are Bang and colleagues, who in 2016 built off existing theoretical work on ontological innovations (DiSessa & Cobb, 2004) to define and promote axiological innovations in design-based research. Axiological innovations are “the theories, practices, and structures of values, ethics, and aesthetics – that is, what is good, right, true, and beautiful – that shape current and possible meaning, meaning-making, positioning, and relations in cultural ecologies” (Bang et al., 2016, pp. 28-29). Axiological innovations were central to giving greater attention to subject-subject relations, including relational, historical, and ethical dimensions of partnering, within their participatory design research (Bang & Vossoughi, 2016). This centering of subject-subject relations, rather than subject-object relations, echoes a rejection of technocentric notions of design and DBR and widens the research focus: “the domain of the ‘researched’ in a given project is expanded to include the relational, pedagogical, and design-based activity of researchers themselves” (Bang & Vossoughi, 2016, p. 174). Re-mediation of individuals’ roles may be necessary to attend to critical historicity, power, and relational
dynamics that impact both researchers and practitioners in the partnership (Bang & Vossoughi, 2016; Gutiérrez & Vossoughi, 2010). Thus, a research project which only studies interactions between people and a science museum exhibit obscures the ways in which axiological positionings, such as deficit positionings of museum facilitators, shape the ongoing interactions amongst the exhibit, researchers, practitioners, and institutions. Finally, Bang et al. (2016) argued that axiological innovations can make visible and challenge presumed neutralities and value hierarchies within research partnerships in order to collectively move toward transformative agency, agency which is key in our ongoing attempt to challenge historical views of what “counts” as computing, and who can take part.

Weaving together these perspectives, the act of partnering is understood to be complex, involving careful navigation of the shifting values, theories, truths, and positionings held by all involved. Centering the complexity of practice, Coburn, Penuel and colleagues highlight that researcher-practitioner relationships, as well as institutional mediations, are not merely contexts that need to be “addressed” in our designs; rather, they are the sites of mutual engagement and negotiations between researchers and practitioners (Penuel, 2015; Coburn & Penuel, 2016). Failing to attend to relationships, hierarchies and the meaningful actions of all involved as part of the design or reform activity, leaves the status quo intact and constrains the possibilities for real and meaningful change in educational settings (Carlone & Webb, 2006). Truly collaborative design work cannot exist without attention not just to who is involved but how they are understood and valued by others. In our findings, we present the ways in which new understandings of our DBR project emerged through ongoing engagement with both our research
participants (primarily museum facilitators) and the theoretical perspectives we have discussed in this section.

Methods

Setting

This paper reports an ongoing, multi-year RPP with a Canadian science museum around the design, visitor experience and facilitation of a public computing exhibit called *Hack the Flock* pictured below in Figure 4.2.

![Hack the Flock exhibit](image)

Figure 4.2. Hack the Flock exhibit

At Hack the Flock, visitors can interact with a simulation of flocking, in which boids (bird-droids) continuously shift and flock around the screen, moving in relation to other moving boids according to three forces (Reynolds, 1987): alignment (trying to steer in the same direction as neighbors), cohesion (trying to move towards the centroid of the flock), and separation (trying to keep some distance between itself and other flockmates). Visitors can use the computer
terminal to directly change those forces through changing the underlying code and parameters, and they can also alter the parameters using a microphone and a steering wheel. Through changing the code, the visitors, for example, change the color, shape, speed, and size, and even add images of bees and monkeys on to the screen.

Data Collection

We have collected data in multiple forms throughout the multi-year RPP. Researchers kept written field notes of their experiences in the overall research project, and these field notes reflected the diversity of roles that researchers took on as part of the research: as observations of visitor and facilitator interactions, as exhibit facilitators themselves, and as designers and researchers. With consent, visitor and facilitator interactions with the exhibit were video recorded. Interactions ranged in length from a few minutes to over an hour, and the recordings captured physical interactions with the exhibit, code changes, gestures, and spoken remarks. We also conducted video or audio recorded interviews with museum facilitators, in which we asked them about their academic and professional background, their previous experience with and perceptions of computing coding, their experiences of facilitating at Hack the Flock, how they felt about the exhibit, and how they thought it could be improved. Finally, we also conducted design meetings with facilitators which lasted approximately 50 minutes. These design meetings included a summary of ongoing research at the exhibit, presented by the research team, followed by small group discussions in which the facilitators focused on solutions to address existing problems at the exhibit as well as their thoughts about the ongoing research.
Analysis

We adopted interpretive and phenomenographic approaches for the analysis. Phenomenography (Marton, 1986) focuses on identifying participants’ enframing of situations, and an object or an event, in this view, must be interpreted in light of the “complex of the different ways it might be experienced” (Marton & Booth, 1996, p. 538). Phenomenography offers an essential alignment here between methodology and epistemology, as the emergent conceptualization of objects and events allows us to recognize the device-centered approaches in our work, as well as identifying how we were able to move beyond device-centeredness through recognizing the complexity in the praxis of facilitation. Star and Ruhleder (1996) poignantly argued that support systems or infrastructures that are locally relevant and develop over time are essential to the long-term sustainability of innovations, and that it is often in moments of conflict between or breakdown of these support systems – a phenomenon that they termed “infrastructuring” – that infrastructures become visible. The interpretive analysis we conducted was based on Thorne et al. (1997), who argued that it is essential for analytic frameworks to accommodate both participants’ enframings as well as disciplinary enframings. In our context, disciplinary enframings included theoretical constructs such as device-level engagements and infrastructuring, and interpretive analysis involved inductively refining the match between our data and the conceptualizations implied by these constructs, which also guided how we selected the cases reported in this paper.

Through our analysis, we interpretively broadened and appropriated the notion of device-level engagements to *device-centeredness* to describe a stance in our research that relied on conceptualizations of interactions both on-site (e.g., interactions of visitors and facilitators with
Hack the Flock) and away from the exhibit (e.g., interviews with facilitators) as resulting in changes to computational artifacts. Similarly, we interpretively adapted and expanded the notion of *infrastructuring* to *improvisational infrastructuring*, in order to indicate another stance in our research that recognized and prioritized the work of facilitators. Our findings illustrate the chronological shift in our stances from device-centeredness to a more praxis-centered approach, and how this resulted in us learning to value improvisational infrastructuring through acknowledging and centering the complexity of praxis in DBR within an informal education RPP.

**Findings**

*Early Device-centered Framing of “Redesign”*

The initial creation and formalization of the research-practice partnership with the science museum, as well as the initial design of the computational exhibit, were led by my co-authors, Pratim and Marie-Claire. They were both Primary Investigators on the research project and lead designers of the Hack the Flock exhibit. The goal of this partnership was to create a new permanent interactive exhibit to teach computational science to learners of all ages. Marie-Claire and Pratim, along with other design team members, built off their existing work in the realm of public computing (Sengupta & Shanahan, 2017) to design and create an exhibit consisting of visually appealing simulations of complex systems alongside various interfaces that allow visitors to interact directly with the simulations and with the open-source code behind them.

Pratim was present during each of the pilot implementations along with two other lab members (research assistants) who contributed to software and hardware design. Both Marie-Claire and Pratim attended regular debrief meetings with the museum designers some of which
were held along, Additionally, Pratim served as my supervisor and Marie-Claire was my on my PhD committee. It is important to note their roles in the project because they undoubtably impacted power dynamics within the research-practice partnership, both with respect to how they were perceived by different staff members at the science centre, as well as their dynamics with graduate students working on the project. For example, Pratim and Marie-Claire’s presence on site would often mean that facilitators were less critical of the exhibit design. Furthermore, even when the focus of the six pilot studies (the science centre termed this “user testing”) carried out between Nov 2016 – Jan 2018 was on attending to experiences of the visitors, the outcome of each study was usually identifying specific elements of the software and the physical infrastructure that either needed to be built by Science Centre employees in the in-house manufacturing facility or ordered from an approved vendor. This indicates that our stance as design-based researchers at this point was device-centered. Furthermore, during this period, in almost all interactions with visitors (with one or two exceptions) members of the research team served as facilitators. This framing is also in line with the interventionist approach to DBR as outlined by The Design-Based Research Collective (2003), wherein bringing in an alignment between the designed environment and the desired learning experience is the key focus, rather than recognizing the importance of the work of facilitators.

The device-centered perspective was also evident in subsequent conceptualization of research studies, including an early version of my dissertation proposal. While I acknowledged that the exhibit was part of an ecosystem “including design staff, volunteers, facilitators, signage, technology, and other exhibits in the gallery,” the exhibit itself was at the center of the main research questions, with other aspects of the “ecosystem” being present and yet tangential. The
goal of this research proposal was both a redesigned exhibit and a design framework for feminist learning environments in museums. Note that this formulation is again centered around the design of the exhibit – understandings of facilitators’ wider experiences of facilitation, such as pedagogical strategies and professional development opportunities, were not solicited. In the proposal, the design process was specified as a “co-design experience,” and facilitators were listed as one of the groups of people taking part to help us design a better exhibit (a device-centered approach). However, we were not aware of the institutional constraints and the power dynamics that the facilitators had to navigate. For example, as employees who often have little power within their institutions (Ash et al. 2012), the facilitators may not feel comfortable critiquing design decisions of other museum employees or university researchers who are perceived as holding power within research-practice partnerships (Carlone & Webb, 2006).

**Recognizing Infrastructuring and Developing Relationships with Facilitators**

After the exhibit was installed in March 2018, collecting initial facilitation and visitor interaction data required the research team and administrators from the science museum to work together, and it was during this phase that we began to notice institutional constraints and expectations that facilitators had to navigate. This was our first encounter with *infrastructuring* (Star & Ruhleder, 1996), i.e., breakdowns in support systems around the exhibit. Firstly, a job requirement for museum facilitators at this science center was that they were expected to roam around the galleries to help guests and they were not supposed to spend longer periods of time (beyond a few minutes at the most) at any one exhibit. Therefore, collecting video observations of facilitators and visitors working together meant that a facilitator had to be specifically stationed at the exhibit, something that was unusual for the institution, and another facilitator
would need to be working to cover their typical duties. Shrinking budget allocations affected facilitator time allocation, and the wages of the facilitators spending time at Hack the Flock were negotiated to be covered by the University, so that the museum floor would not be understaffed. Additionally, high turnover of employees has been noted in museum facilitator roles (Moore et al., 2020). This was true at our own research site and meant that although we had led a training session to introduce facilitators to the new exhibit when it was first opened in March 2018, by the time we were prepared to collect this data (July-August 2019), many facilitators had not attended that initial training session. Additionally, due to confusion as to who was responsible for additional training (the science museum or the university researchers), follow-up training sessions never occurred. The result was that some facilitators who were scheduled to spend time at Hack the Flock (and were therefore eligible to consent to be part of the research) had never worked at Hack the Flock previously.

The infrastructuring that resulted from issues was quickly visible as data collection began. Facilitators generally did not like the exhibit, as they did not know how to facilitate it due to lack of experience, time spent at the exhibit, and training. Some discomfort with the topic of coding and technical difficulties with the first exhibit iteration, such as needing to reset it if a visitor “broke” the code, compounded the negative viewpoint of the exhibit. In fact, before they were scheduled to spend blocks of time at the exhibit, some facilitators actively avoided facilitating the exhibit:

Ashley: So when you want to like, try to get [the visitor] in you’re like, “yeah just do this.” They just like, “oh yeah, sure.” They just walk away most of the time. I don’t come here, I only come here to reset [the exhibit]. (Interview, Jul 2019)
Facilitators felt that they had been “thrown into” the exhibit without any training (interview, Kaitlynn, Aug 2019), the physical interface was difficult to use (multiple facilitator interviews, Jul-Aug 2019), and had only been able to have a few good, extended interactions with visitors (multiple facilitator interviews, Jul-Aug 2019). Thus, their institutional regulations, coupled with negative personal experiences, oriented them away from Hack the Flock. However, through spending time with PhD student researchers at the exhibit, facilitators slowly began to reorient themselves towards the exhibit and its possibilities.

Many facilitators’ opinions of the exhibit grew more positive as they discovered how to use it, practiced different facilitation techniques, and came up with new and exciting code changes to show guests. For example, working at the exhibit for extended periods of time improved both Ashley’s knowledge and perceptions of coding:

Ashley: OK. Um, it's helped me like know coding, ‘cause I've asked a lot of questions and also helped me with the exhibit itself. So before all we did was add monkeys or birds or bees and change the speed or alignment. […] But now we know we can add shapes, we can change the outline of the shapes, we can do a lot more. And that helped me as well. Cause now I'm like, Oh, if I ever have kids I'm going to teach them how to code. (Interview, Aug 2019)

Kaitlynn’s original perception of the exhibit as boring was also challenged as she spent longer periods of time at the exhibit, working with researchers to create collaborative and personal “hacks” including having rainbows flock across the screen:

Kaitlynn: Like when I first saw that I had to [be at Hack the Flock]. It was like Oh God, what am I going to do? I'm gonna just have to sit there and I don't know how to do
anything. And it's always really boring over there... but it's actually not boring when you have the time to sit there and learn how to actually do stuff. So I think like this was more like an opportunity on like how to actually learn to do things and learn more about like coding and stuff in general. (Interview, Aug 2019, emphasis added by authors)

As Kaitlynn’s quote makes clear, a contributing factor to this shift in perceptions was that facilitators actually had blocks of time dedicated to Hack the Flock, in which they interacted with the researchers and got a chance to improve their understanding of the exhibit. Previously, facilitators were assigned to the entire gallery and were expected to move continuously throughout it, spending some time with visitors and answering any questions, but not spending too much time in one place. The data collection protocol, which involved having facilitators spend 1-2 hours at Hack the Flock specifically, disrupted institutional and practice norms in ways that allowed facilitators to get to know the exhibit (and the researchers), ask questions, and just “try things out” – all of which helped to shift facilitator perceptions of the exhibit.

Lily: I think um, like having like a block [of time] like this where I, I can have a chance to like spend more time with [Hack the Flock] and ask questions and try things out. Like just if we all know a bit more about it. I think it would be really helpful. Um, and then also, yeah, just like, yeah, having a change to, to be around it more on a daily basis I think. ‘Cause we often just have to leave it to go like attend [to] other things. (Interview, Jul 2019)

Shifting these perceptions was only possible through the emotional and care work that resulted in growing relationships between the PhD students and the facilitators. Throughout the 99 scheduled hours, 29 hours of interactions and interviews were recorded. During many of the
other 70 hours, facilitators and researchers discussed topics both related to and different from the research. Researchers gave improvised training sessions, or researchers and facilitators worked together to create new code changes, such as creating slices of pizza on the screen – the beginnings of mediated praxis. Facilitators asked about the PhD students’ dissertations and asked for updates on the research project. Facilitators were particularly interested in the research questions, how the video recordings would be analyzed, and if the researchers had “learned anything yet,” reiterating that they hoped the researchers would share their results when they had them (researcher field notes, July 30, 2019). As graduate students, rather than university faculty members, and as researchers who were not original designers of the exhibit, the power gap between them and the facilitators may have narrowed. This shift of power was important – knowing that the PhD students were not the original exhibit designers and that their opinions were solicited and valued, facilitators felt empowered to critique the exhibit, explain their facilitation challenges and improvised solutions, collaboratively pushing the exhibit beyond its current form by imagining possible future changes and directions.

It became increasingly clear that the most important factor in the success of Hack the Flock was not the exhibit design, but the work that facilitators do to support it. We began to notice hidden work that facilitators did while at the exhibit – such as improvising on the spot when the code did not work, writing down a favorite code change to show visitors later, and creating their own training opportunities. It was at this point that our research interests pivoted from exhibit redesign to the hidden work that facilitators were doing to make the exhibit “work” – an ontological innovation (DiSessa & Cobb, 2004) we later termed facilitator infrastructuring. This work was initiated by facilitators (rather than other museum staff members or researchers)
and was largely invisible to the researchers until they spent extended time in the field and strengthened relationships with the facilitators. This work went beyond the previously defined roles for facilitators at the exhibit (i.e., to facilitate it), and instead showcases ways in which the museum facilitators began to redesign the exhibit’s ecosystem. This invisible but important work is similar to the work that the promotoras were doing as ambassadors and assistants for the food co-op in Jurow et al.’s (2016) work. We recognized that this work was creative and grounded solidly in their professional experience, and also that this work could lead to powerful ideas about exhibit design and changes in informal education more broadly.

**Improvisational Infrastructuring as Hidden Design Work**

The complexity of facilitator infrastructuring emerged from their interviews and observations of their interactions with visitors. Whether planned or emergent, this infrastructuring, and the rationales and strategies behind it, could be deeply explored to inform future re-design of the exhibit. Beyond that, however, it also served as a pivot in our DBR project and a widening of the scope beyond the redesign of the exhibit to include facilitator practice and innovation. Facilitators improvised, in the moment, to deal with challenging situations with visitors. For example, Janelle used experimentation when she could not remember the results of a particular code change:

Janelle: So I'll be like, with a kid when I forget, I just kind of experiment. So I'm like, let's see what happens when we do this. I was like, oh, what if we do the opposite?

(Interview, Jan 2019)

This points to the ways in which facilitators draw upon their experiences and values to engage the visitor even in moments of uncertainty. Additionally, Janelle spoke further about a
facilitation strategy she enacted in which she specifically chose which aspects of the code to highlight and guide the visitor to change, and which she ignored:

Janelle: Size is usually pretty visible, we're changing things. [inaudible] And like sometimes that's okay. Why like cohesion, alignment and separation, to be confusing like through experimentation maybe we can figure out what the differences are. So looking at colors are always really fun to change and then also just showing them how to shut off and on the code with the dashes. Um there are other functions. There's some I might sometimes skip.

Researcher: There's a couple that it's not obvious what they do, and taking them out can break the code.

Janelle: So I don't touch those ones and I don't show people those ones. (Interview, Jul 2019)

While not voiced as design ideas, these comments provide insight into which aspects of the exhibit were used to draw visitors in or were well-understood by facilitators, and which were confusing and could cause the code to “break,” or the screen to go blank from a compiler error. These insights could lead to changes in code order, better explanations of existing lines of code, or new additions to the exhibit that were more “visible” and “fun” for visitors. With continuous prompting from the PhD students, facilitators also offered new design ideas for the exhibit and its surrounding infrastructure based on their experiences facilitating at Hack the Flock. For example, facilitators mentioned wanting more images (as children always asked for dinosaurs) and creating a facilitation guide that would be full of explanations and images to help both
visitors and facilitators be able to more deeply explore the exhibit, whether a facilitator was present or not.

More important than the design ideas, however, was the creation of a community of practice (Lave & Wenger, 1991) around Hack the Flock that showed promise of persisting even after the researchers had left. Facilitators began to self-organize around the exhibit, creating a sense of community and increasing feelings of ownership, both over the exhibit and in the research project more generally. Facilitators created a community in which they were eager to help each other learn about the exhibit, often teaching each other in lieu of formal training. They did not have to depend on researchers or exhibit designers who would not necessarily be available to them at all times on the museum floor, as explained by Ashley:

Ashley: Even if I can't remember, I can ask my teammates to help me out and we can… all teach each other. (Interview, Aug 2019)

Facilitators would share new code changes with visitors, the researchers, and other facilitators, such as when Hilda created her new “favorite color” using RGB color representation and told the researcher to write it down before running off to find another facilitator in the gallery to show off her creation (video-recorded interaction, Jul 2019). One volunteer even left behind a snippet of code as his “legacy” of working at the exhibit once his tenure at the science museum was over. Knowledge was not just shared in-person in the galleries, but also via institutional and personal social media. What began as one-off comments or a photo sent to others led to sustained infrastructuring and greater facilitator ownership over exhibit knowledge and practice. Finally, near the end of the data collection period, one facilitator voiced her desire to have a training or get-together for facilitators to share the cool things they had learned over the
summer (field notes, Aug 28, 2019). Her use of language is noteworthy: while the initial choice of “training” was rooted in existing power dynamics and hierarchies (in which facilitators were placed at the bottom), a “get-together” represented a less formal group interaction among colleagues for both knowledge sharing and community building.

At this point in time, the complexity of the facilitators’ improvisational infrastructuring became apparent to us, and we clearly acknowledged it as valuable design work in the context of our ongoing research. It became the “talkback” from the situation (Schön, 1983) to which we then reoriented our subsequent research focus. We asked ourselves: if this is the design work that they do, unprompted, without institutional or research team support, what might they be able to do when explicitly positioned as co-designers? It also alerted us to axiological aspects of our research – how was this design work being valued by us as researchers? We felt we had an ethical responsibility to promote this work that facilitators were doing, both to their managers and the educational research community at large that tended to rely on deficit positioning of museum facilitators (Tran et al., 2019). This led to the next phase of our research – organizing co-design meetings with facilitators where their hidden work was not just acknowledged but celebrated, and they were explicitly positioned as expert co-designers whose perspectives would have significant impacts on every aspect of Hack the Flock, including its hardware, software and facilitation practices. These co-design meetings became sites for researchers and facilitators to engage in mediated praxis, joint work in which we could elevate the research project (and the exhibit) towards a future form.
Making Space for Facilitators as Co-designers

During December 2019, our goal was to run multiple 1-hour design meetings specifically for facilitators so that they could collaboratively reflect on their experiences at Hack the Flock and brainstorm potential solutions to the challenges they voiced throughout the project. The solution determined by both researchers and science museum staff was that the 1-hour design meetings would be integrated into a 3-hour mandatory training session for facilitators. It is important for us to note that while facilitators would be positioned as knowledge-creators in our design meeting hour, they were positioned as knowledge-receivers for the rest of the training session (mirroring trends in the literature). Our design meeting had two components: firstly, at the request of facilitators throughout the project, the researchers gave a review of the data they had collected so far, what analyses were ongoing, and what future research directions might look like. For the rest of the time, facilitators worked in small groups to brainstorm exhibit improvements and discuss their perceptions of the research.

Facilitators drew upon their extensive experience to make a wide variety of design suggestions, encompassing everything from hardware components and props to new ways of inviting visitors to engage with Hack the Flock. Some suggestions included using a prop from a previous exhibit that explained RGB color representation; replacing the keyboard and mouse with a touchscreen interface, improving in-code instructions; writing a guidebook that could be used by both visitors and facilitators; creating challenge cards, easter eggs, competition modes, and ways to save and display work; an easier way to reset broken code; and incorporating more photos or text explaining real-world applications of computing (video recordings and written documents, design meetings, Dec 2019). Their understandings of the exhibit extended well
beyond its hardware and software and were grounded in the need for interaction between visitors and facilitators. These design meetings also provided a space where multiple perspectives on the exhibit could exist simultaneously, such as those from the researchers as well as those of the facilitators who had to work with it on a daily basis. As Jasmine explained:

Jasmine: I kind of understand like, kind of like both perspectives. Like I understand that like the purpose of the Hack the Flock and having it introduced in this way is because you want to put out the code as it is, and not kind of like, ummm, like code it in a way that is not what it is anymore. Like you want it to be, people to be interacting with the actual thing, which like I totally understand. And um, I also understand how people are saying like, well, if you’ve never been introduced to this kind of language, like it’s really hard to just be approached with it like as it is right away. Like you kind of need a little bit of like an introduction to it. (video recording, facilitator design meeting, Dec 2019)

She explained that having the researchers explain why they had designed Hack the Flock to use text-based code in this way and what they were hoping to learn from the exhibit was something she could understand and respect. At the same time, she and other facilitators were having difficulties jumping right in to the exhibit with visitors. Understanding and acknowledging these different viewpoints meant that facilitators and researchers could then engage in joint work together to design solutions to problems that could align with both of them – finding new ways for visitors and facilitators to interact with the exhibit that would not compromise the epistemology of computing that researchers wanted to promote.

In the research summary we were explicit about the research process. We explored epistemologies, such as what we felt coding “could become” as part of an exploratory,
collaborative journey between visitors and facilitators, and I briefly mentioned (but did not explain) how she drew upon feminist epistemologies of science to guide my research. This was something that multiple facilitators drew upon later in the design meeting:

Liam: I think like the feminist perspective that she was talking about is interesting and I think demographics in general would be really interesting to see what kind of interactions we're getting with [Hack the Flock]. [...]

Tracy: I had that happen once to me. I had some girls up, they were trying to figure out like it wasn't set up, it needed to be reset. So I got it reset, and once they saw it pop up they were, “Oh this is for boys” [shakes head]. Like, that was their response and I was like, “No it's not.” And then we sat and coded through it. They were totally fine. Like once they got into it and got rid of that… (video recording, design meeting, Dec 2019)

Liam later brought up how he had tried to disrupt gendered norms at a sewing exhibit by recreating the costume of comic book hero Captain America. Facilitators were deeply interested in the epistemologies mentioned by researchers, as well as the data collection process, analyses, and research questions being explored. Facilitators were explicitly asked if they had any questions they felt they could answer by working in partnership with the research team. It was clear from these interactions in our design meetings that facilitators were interested and willing to engage more deeply in the research process than simply being a participant giving an interview or being observed. However, museum facilitators working as co-researchers in museum education projects is rare (for exception, see Piqueras & Achiam, 2019), and trying to overcome traditional power hierarchies between researchers and practitioners can be difficult (Carlone & Webb, 2006). While we acknowledge that our project in its current form falls short
of the participatory design research commitments articulated by Bang and Vossoughi (2016) in that the data collection, analysis, and dissemination remained firmly in the realm of the researchers, these interactions with facilitators showcase the potential for our project to shift in its future iterations.

Finally, we also saw in the design meetings the impact of the previous care work that took place between researchers (mainly the PhD students) and the facilitators who spent time at the exhibit during the summer. Facilitators who had taken part in the research and worked closely with the researchers were able to advocate for the project’s strengths and positive impact on themselves, personally – especially to those who had not taken part in the research previously and still held the negative views towards the exhibit we saw originally. For example, take this interaction between two facilitators, Kevin (who had not taken part in the research) and Dean (who spent six hours working with researchers at the exhibit in August):

Kevin: In terms of the lay person there's not much in terms of like why, why should I have an incentive to sit here and learn a dry [programming] language I don't know?

Dean: Okay, look at it this way. Until I actually became a part of the research process of it, like, I didn't know anything about how [Hack the Flock] worked. Like what, what was this? I know I knew how to reset it. Like all the hard, like basically all the hard facts that we needed to know, but what I didn't know was um actual coding itself. And how you can manipulate a few different things just by changing the words of it or by changing the numerical value of the different things. So. But I ended up learning in like the span of three research sessions. So if I can learn, I feel like a kid could learn too. (video recording, design meeting, Dec 2019)
Note how Dean discussed the impact of being part of the research process rather than just having experience at Hack the Flock. He was impressed with the amount that he could learn in “the span of three research sessions” and quickly grew to enjoy creating new things at Hack the Flock. He came up with coordinate representations of new shapes, such as birds and five-pointed stars, and video-recorded interactions with visitors show him excitedly explaining the shapes to young children and creating a shooting star effect on the screen. He disagreed with Kevin that it was a dry language that could not engage visitors; instead, he was adamant that if he could learn it, so could the visitors. In this way, he became somewhat of a spokesperson for the exhibit (and the research) to other facilitators, and voiced his belief that both the exhibit and its surrounding research were important to them as facilitators – something that was highly impacted by the ways in which he and the PhD students interacted and built rapport during the data collection periods.

**Discussion: Intertwined Shifts in Epistemology, Axiology, and Methodology**

The findings above highlight the different ways in which epistemology, axiology, and methodology were intertwined within our work. In Figure 4.3 below, we showcase the ways in which these three strands became visible to us in our work. Methodology was a key aspect of our research throughout the project, though as we will discuss below, the ways in which we conceptualized and implemented design-based research shifted throughout. While epistemology is of course always relevant in research work, we note that during the early stage of our work which relied on a device-centered redesign framing, our epistemology was not explicitly stated or addressed – it was unacknowledged, hiding in the background of our research and design decisions. It was only once we began to work more closely with the museum facilitators that our
understandings of what computing is/should be and what informal STEM facilitation is/should be were brought into the open, highlighting essential tensions which led to deeper understandings of researchers and facilitators in the project. Finally, an explicit focus on axiology began when we built relationships with the museum facilitators, acknowledging their labor and hidden work, and leading to questions of who should be part of the design and research process, and how we could make space for their contributions to be heard and valued.

![Figure 4.3. Axiology, epistemology, and methodology over the phases of our study](image)

In terms of methodological shifts in our work, our analysis illustrates that *listening* carefully involved learning to think together with facilitators on an ongoing basis, through creating continued opportunities for joint engagement, which in turn involved recognizing the relevant institutional constraints and challenges that facilitators had to navigate on an ongoing basis, such as scheduling and expectations of moving rapidly between exhibits. Our methodological imagination was no longer limited to creating conditions for “observations” of facilitation, rather to support and empower a community of facilitators contextualized around Hack the Flock. This methodological shift was deeply intertwined with an epistemological shift.
from centering materiality of the exhibit and intentionality of designers to more deeply considering who (Philip et al., 2018) takes part in design, especially given that it is the labor of the facilitators that enlivens the exhibit. We acknowledge that taking part in mediated praxis, re-mediating roles and learning environments, and productively navigating tensions between researchers and practitioners is itself labor, for both researchers and practitioners in RPPs. Asking individuals to partner with us in research is then a request for labor that may fall outside of their typical institutional duties, and researchers should be especially mindful of the demand that participating in a research project may place on workers who are already dealing with high workloads, precarious job security, and a lack of empowerment in their institutions – all of which impact museum facilitators (Bailey, 2006; Ji et al., 2016; Moore et al., 2020; Tran et al., 2013).

Our findings showcase the ways in which the move away from device-centeredness led to space in which mediated praxis (Gutiérrez & Vossoughi, 2010) could take place, promoting “expansive forms of learning in which individual and collective zones of proximal developments coalesce” (p. 111) and causing both facilitators and researchers to “act a head taller than themselves,” moving the current project and the RPP towards a new, future form. We have noted how facilitators went above and beyond their initial roles within the research project (i.e., to facilitate the exhibit) by sharing their hacks, innovating new scaffolds for visitors in the forms of a guidebook and facilitation strategies, and engaging in deep conversations with the researchers. Maintaining a device-centered approach to the project may have caused us as researchers to focus solely on the possible software and hardware upgrades to the exhibit and to treat the facilitators’ infrastructuring as interesting but tangential. Mediated praxis meant that we were pushed by facilitators’ actions and discussions to engage in learning and reflection centered on
their infrastructuring – their labor. Gutiérrez and Vossoughi (2010) wrote that the researcher, as a stranger, is “important to making visible the routine practices of work and educational spaces, bringing to the surface potential contradictions between these practices and the objects or desired outcomes of activity” (p. 104). As our findings illustrate, our presence in the science museum caused a disruption in routine labor carried out by museum facilitators and made visible the ways in which their institutional requirements such as scheduling and expectations to circulate the galleries came up against not only our research objectives (i.e., to collect facilitation video data) but our educational goal to create a space in which experts and visitors could come together to discuss and hack computational simulations. In our design meetings, facilitators used these differences to creatively brainstorm new solutions in which visitors could be supported even if a facilitator was not physically present, such as video or audio instructions or a guidebook for visitors with explanations and images. Mediated praxis provides opportunities to experience what could be in ways that impact what is (Gutiérrez & Vossoughi, 2010). In this project, researchers and practitioners found ways to mediate between their historical, institutional practice, the disrupted state caused by researcher intervention, and a shared future vision that looked at what could be from both positions at the same time.

From an axiological perspective, one could reframe the iterative core of DBR in RPPs as an ongoing quest to reflect upon our own roles as researchers and designers in contexts of praxis, by continually asking how we can better consider historical, institutional, and sociocultural contexts of design to create opportunities for mutual growth and understanding within RPPs. We have shown that axiological innovations shaped positioning and relations within our research: by noticing, valuing, and inviting museum facilitators to participate more centrally in the project, we
built trust and understanding that made it possible for us to explicitly position them as co-designers, and for them to feel empowered to take up that positioning. Additionally, axiological innovations can challenge presumed neutralities and look at values within RPPs (Bang & Vossoughi, 2016). We realized that as researchers, we also had to reposition ourselves in ways that created space for facilitators to more clearly articulate their values with respect to the project – not just what they valued in the exhibit design as it pertained to their facilitation practice, but also the research directions and questions they felt would be personally or professionally valuable to them. “What is good, right, true, and beautiful” (Bang et al., 2016, p. 29) is different for each individual, no matter their role in the project, and an honest and productive conversation about individual perspectives is only possible when researchers and participants come together to create a research community based on trust and praxis. While our project has not yet taken on a fully participatory organization, where community participants are not just designers but take on the roles of researchers as well (Bang & Vossoughi, 2016), our work fits within this larger tradition of rethinking relationships between researchers, practitioners and community members.

Finally, it is clear that these intertwined shifts in methodology, epistemology, and axiology led to the building of a community of practice around the exhibit for the museum facilitators, creating new opportunities for assistance, learning, and design that would have gone unnoticed or unvalued in a device-centered viewing of the exhibit. Most importantly, this community came to life without any intervention from the researchers on site. This has significant implications for DBR projects, as designs may struggle to persist beyond than the research project created to test and implement them. For example, Moore et al. (2020) lamented that while their researcher-led reflective practice sessions for museum facilitators were very
successful, they did not continue after the researchers had completed the project. This may have been due to the facilitators not feeling empowered to lead the sessions themselves, or an institutional culture that did not prioritize that work outside of research-practice partnerships. The infrastructuring examples discussed previously were completely initiated and led by facilitators within our partnership, and point to the exhibit’s potential for success long after researchers had “finished” the design project.

In conclusion, dismantling traditional power structures and methodological frames in design projects can be difficult. Power differentials do not just exist between researchers and participants, such as the researchers and teachers in Carlone and Webb’s (2006) study; they can also exist between groups of participants, such as teachers and scientists (Shanahan & Bechtel, 2020), and between participants and others in their workplaces – even if those managers or other employees are only tangentially involved in the research. Almost all learning environments, whether they are school classrooms or museums, are also work environments in which people labor. When employees or volunteers in these environments participate in educational research projects, they are performing even more labor that is required for praxis, labor that is shared by researchers but may be bound by different institutional constraints and power dynamics, which may be explicit or implicit. Bringing to light and attempting to challenge these power differentials and institutional demands on labor is necessary for researchers and practitioners within RPPs to begin to understand the complexities of praxis and work towards an imagined future, together. Thus, implications for centering praxis in DBR are epistemological, axiological, and methodological, extending far beyond reductionist accounts of accommodating or
negotiating institutional challenges, and bringing into light the hidden labor of practitioners who enliven the designers’ innovations.
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Chapter 5: Discussion and Conclusion

The work presented in Chapters 2, 3, and 4 provide insight into the (hidden) labour, daily practices, infrastructuring, identity development, and relationship building that take place within the context of a long-term design-based research project centred around a computational science exhibit. Chapter 2 outlined the ways in which museum facilitators are positioned within their institutions and in educational research projects, and how those positionings are intertwined with their labour and power. Chapter 3 showcased the previously hidden infrastructuring work that museum facilitators must do every day to ensure the success of a computational science exhibit, as they grapple with tensions between design, epistemologies, and institutional norms. Finally, Chapter 4 zoomed out to provide a reflective understanding of how methodology, epistemology, and axiology impacted and were impacted by facilitator participation and engagement within the research. All of these have implications for future work in the Learning Sciences, as explored in the three strands below.

Attending to Labour in Informal STEM Facilitation and DBR

There is a need to more deeply understand the complexity of facilitation practice and labour in informal STEM learning environments. Feminist perspectives on labour acknowledge that workplaces can be sites of inequality (Acker, 2006), and that some labour (such as emotional labour and mentorship) is frequently made invisible in a world that prioritizes technological production and capitalist goals (Fletcher, 1999; Hochschild, 1983). Even as researchers acknowledge the ways in which informal STEM learning environments can create new opportunities and trajectories for learning, especially for learners who have been historically marginalized in STEM (Horn et al., 2012; Rahm et al., 2005; Rahm & Ash, 2008), the focus is
frequently on the particular activities or technologies in such spaces, or on the actions and learning of the students; the facilitators and educators who enliven these environments and work to guide the learning are rendered invisible. The complexity of facilitation practices in these spaces cannot be simply reduced to a job description (which, as shown in Chapter 2, may be broad, vague, or limited). Neither should their practice be thought of solely in terms of the actions they perform: giving an explanation of a scientific concept, demoing an experiment, or working with a learner at a hands-on exhibit. Behind each of those actions is labour: cognitive labour to make in-the-moment decisions regarding the depth of an explanation or which elements to cut out of a lesson plan because a bus was late, physical labour of acting during a demonstration or cleaning up a spill in a gallery where the “no drinks allowed” signs were ignored, and emotional labour as they maintain positive attitudes and friendly dispositions in the face of visitors who may look down on their assumed lack of content knowledge or pedagogical expertise.

Observations of a museum facilitator at work may only provide a surface-level understanding of the complexity of their practice, failing to get at the reasoning or experience behind their on-the-floor decision making. As researchers, we must strive to surface the hidden labour that may be invisible when we are only in the field for a short period of time. Prolonged engagement over time with museum facilitators and other staff members, multiple methods of data collection, and a focus on building strong relationships between researchers and practitioners can help make visible the labour behind their practices, leading to new conceptualizations of informal STEM facilitation as it pertains to the labour of the skilled individuals that engage with diverse visitors on a daily basis.
Additionally, informal STEM facilitators’ positions as employees (whether within a museum, after-school club, or other setting) mean that they are working within an established employer-employee power dynamic and are therefore subject to institutional constraints that may not be visible to non-employees. Within RPPs, researchers may spend long periods of time in the practitioners’ settings and even carry out similar work, such as facilitating the exhibit they had previously designed. However, while performances between researchers and practitioners may seem identical on the surface, researchers are not subject to the same constraints as employees. In this dissertation research, researchers were able to spend long periods of time focused on one particular exhibit, did not have to worry about how their performance at the exhibit would impact their jobs, and were not even marked in terms of dress as employees (who wore specific orange shirts), meaning they were rarely approached by visitors looking for the bathroom, or more hot glue gun sticks, or for help with a different exhibit. Facilitators, on the other hand, were public facing employees of the museum who had a duty to provide the visitors with the best possible experience at the exhibit, even in the face of a lack of training or off-putting aspects of the exhibit design. Even as participation in the research removed some institutional constraints, such as the necessity of facilitators to continuously circulate the gallery and therefore only spend a few minutes at a time at Hack the Flock, others remained – researchers were happy to look up RGB colour values or online P5 documentation on their phones, whereas facilitators were strongly discouraged (or perhaps explicitly banned) from using their phones while working. These institutional constraints impacted the range of facilitation actions they had at their disposal to answer a visitor’s question or troubleshoot an issue, and they therefore laboured to find workarounds that fit within the institutional norms, such as experimenting with the values,
skillfully redirecting a visitor to a different line of code, or working to keep the visitor engaged in conversation while they manually reset the code. Thus, when researchers and facilitators worked together at the exhibit, their labour was not identical, and true boundary crossing (Penuel et al., 2015) was out of reach.

Finally, it is worth remembering that participation within a research project, especially an ongoing DBR project is labour in itself. Some participation blurred the lines between research and their normal employment, such as facilitating an exhibit, which is part of their expected job duties. Even their facilitation labour may be much higher when faced with long blocks of time at an exhibit they don’t particularly understand or enjoy – a sentiment mentioned by more than one facilitator at the beginning of our data collection. Participating in the research turned their typical facilitation labour into something that was (at first) more difficult, tedious, boring, or annoying. In DBR projects, where educational innovations such as new exhibits or facilitation methods are being piloted and tested, even “expert” facilitators must grapple with the additional labour required to shift their practice – and this additional labour is rarely, if ever, reported. Other aspects of the project, such as participating in interviews and focus groups, are additional labour that they would not typically perform. And this labour can lead, in turn, to more labour – you facilitated at the exhibit, so would you like to give an interview? You gave an interview, would you like to participate in a focus group? Your focus group ideas were great, would you like to co-design? While Chapters 3 and 4 showed how ongoing, deepening participation in the research was essential to the success and sustainability of the exhibit, it cannot be forgotten that each step of further participation represented additional labour that facilitators performed as research participants, above and beyond the work duties they were still expected to carry out. Feminist
research methodologies acknowledge an ethics and duty to care for participants (Leavy & Harris, 2019), and this should extend beyond considering the topics and activities of research but the physical, cognitive, and emotional labour that is required to engage with those topics and activities as well. Researchers must not take this labour for granted, and instead look for ways to make it visible, celebrate it, and reward it – publicly within partner institutions, within written accounts of the research, and via appropriate incentives or remuneration.

Thus, it is important that researchers in informal education spaces go beyond studying learning in these spaces and also attend to the labour that makes that learning possible. This requires a definition of labour that goes beyond the physical and cognitive work that goes into facilitation and exhibit or demonstrating an experiment – though more research into those aspects, especially beyond observational studies, is needed as well. Research in classroom teaching has acknowledged the complexity of the daily labour of teachers, from emotional labour of caring for students (Bodenheimer & Shuster, 2020; Isenbarger & Zembylas, 2006) to navigating administering pressures (Pelletier & Sharp, 2009). Feminist investigations of labour have led to deeper understandings of labour, especially service work, as gendered and classed (e.g., Hochschild, 1983; Kang, 2010), and by making this labour visible, we can begin to imagine new routines, processes, and systems that allow for more equitable distributions of this labour. Therefore, investigations of and new definitions for labour in informal education spaces can bring to light the emotional and institutional aspects of their daily labour (as I have started to do in this thesis), and also challenge institutions and researchers to imagine what more equitable workplaces and research projects could look like. This work will have implications for practice, such as hiring, job duties, and professional development in informal learning spaces, as well as
research, in the form of new forms of partnerships and methodological choices that acknowledge and celebrate this labour as crucial to learning in these spaces.

**Infrastructuring for Sustainable Computing Education**

Both sociocultural approaches to education and the methodology of DBR emphasize the importance of context: understanding is constructed through interactions between learners, educators, and educational interventions, and draws upon their histories, identities, and goals. When many DBR researchers describe the context in which they are working, they often discuss participant demographics and histories, classroom norms, and physical and intangible aspects of the learning environment. However, their discussions of the context are often missing a critical component: the researcher themselves. Despite the prominence of subjectivity statements and use of the personal pronouns I/we, researchers may present their own participation in the data collection or testing in broad strokes: they designed the new educational tool, they led the training session, they observed participants in action, etc. These descriptions may not include the continuous stream of smaller, sometimes unconscious actions that the researcher performs throughout the project. The researcher acts, in some sense, as the “man behind the curtain,” organizing participants, providing just-in-time training, making subtle adjustments to the educational intervention on the fly, and convincing participants (and managers) of the value of the research. Thus, understanding learning and the performance of a designed educational intervention in context means paying attention to the ways in which the researcher impacts its success – and especially, what happens once the researcher leaves the research site.

Discussions of the sustainability of an educational intervention are largely absent from the DBR literature. A notable exception, Fishman et al. (2004) argued that the high level of
support that DBR researchers provide while piloting or testing their innovations leads to challenges for scalability and sustainability of those innovations. This support can create favourable conditions at the research site for the intervention to flourish – but also means that once that support is removed (when the researcher is no longer present), the intervention and the practitioners who are expected to work with it may struggle. Moore et al., (2020) provided an excellent example of the struggle for sustainability in their discussion of a reflective practice tool for supporting facilitators in a science museum via a series of debriefing sessions. Despite positive reactions from facilitators who found that the tool/sessions helped them to better understand their own role in maker activities, facilitated peer sharing of knowledge, opened up space for difficult conversations, and helped them to gain confidence in their professional practice, these sessions did not continue once the research study was complete. Potential reasons for this discontinuation were the fact that researchers had led the debrief sessions themselves and therefore other staff members did not know how to lead them, or that the culture did not prioritize reflective practice outside of the participation in the research study. Either way, the sustainability of the tool was at risk without direct researcher support, as the infrastructure or scaffolding necessary for continued use of the tool was missing.

Cases such as Moore et al. (2020) strengthen Fishman et al.’s (2004) argument regarding sustainability and point to a need for deeper understandings of the infrastructuring that is necessary for a designed educational intervention to succeed within and beyond the period of dedicated support from researchers. As discussed in Chapter 3, facilitators struggled with aspects of Hack the Flock’s design even with a researcher literally within arms’ reach, and without a researcher present, some facilitators explicitly avoided the exhibit except when absolutely
necessary. Ongoing infrastructuring from museum educators was needed to make connections with and bridge gaps between the exhibit and the local practices, routines, and institutional constraints. Facilitator infrastructuring at the exhibit resulted in “mutual adaptation” (Fishman et al., 2004), in which the exhibit was re-invented to better match the norms and capability of the science museum – such as the design of physical blocks and other facilitation tools. In this way, their infrastructuring led the exhibit to be more approachable, easier to facilitate, and therefore more sustainable with respect to the daily practices and institutional constraints that facilitators navigated on a daily basis.

While the infrastructuring discussed in Chapter 3 was largely the result of the labour of the museum facilitators, this is not to suggest that researchers can simply push the entire responsibility for mutual adaptation onto the shoulders of the practitioners. Fishman et al. (2004) argued that researchers and practitioners must work together to close infrastructure gaps. I wish to emphasize two points along these lines that are critically important for educational designers to understand: firstly, the design for an educational intervention will never be perfect, despite our best intentions. Regardless of the number of design iterations, hours of time spent prototyping and testing, and depth of engagement with all of the stakeholders within the educational setting, there will always be gaps between the existing situation and the “optimal” environment for the educational intervention, especially since what is “optimal” changes depending on who, where, when, or under what conditions we are considering. Educational researchers and designers must acknowledge the existence of these gaps and specifically look for them throughout the testing process, which requires a careful acknowledgement of their own role(s) within the research and what holes may be left behind with their departure at the end of the study. This also means
understanding the ways in which their presence or research design disrupts the routines, norms, and constraints of practitioners, such as the ways in which our data collection procedures at Hack the Flock gave facilitators the freedom to spend large periods of time at the exhibit – something that would not be possible once we left and they returned to their normal routines.

Secondly, and most importantly, while infrastructuring is not the sole responsibility of the practitioners, it must follow from their practices, values, and institutional constraints. If researchers attempt to conduct all of the infrastructuring from their experiences they may at best create infrastructures that are unsustainable without the researcher present, or at worse reproduce deficit views of practitioners that insist that they just require more training to use the intervention “properly” or to its “full potential.” Looking to the daily labour of practitioners and providing space for them to voice the ways in which their practices do (or do not) align with the needs of the exhibit can lead to infrastructuring that persists and leads to the success of the intervention beyond the presence of researchers. For example, Chapter 4 provides a sample of the various solutions that museum facilitators came up with to deal with facilitation and technical challenges at Hack the Flock – a reset button, a touchscreen interface, a facilitation guide, etc. It is important to note that none of these ideas required the presence of a researcher at the exhibit, and some of the ideas voiced by facilitators would not have even crossed the minds of researchers, such as using a prop from an entirely different exhibit to explain RGB colour notation. We were then able to work with the facilitators to further refine their ideas, navigating the tensions between facilitator ideas and the view of computer science that researchers wanted to portray with the exhibit. Therefore, though infrastructuring is a dual responsibility of researchers and practitioners, it must centre the labour and practitioners that enliven the educational intervention
on a daily basis. Only then can the success and sustainability of the educational intervention be ensured beyond the timeline of the research study.

The importance of infrastructuring in this research was not immediately apparent to me. While I thought that the ways in which facilitators were adapting their professional practice and creating their own infrastructuring was certainly interesting, my initial impression was that studying this infrastructuring was a tangent that would take me further away from my original goal of redesigning the exhibit. Perhaps some of their innovations could be worked into the redesign, but it is so easy to fall into the trap of thinking that the facilitators just needed more time or more training to be more comfortable with the exhibit and facilitate it in ways that aligned with the epistemology of computing that the original designers wanted to promote. The importance of infrastructuring becomes visible when it is connected back to the museum educator literature – many other articles focusing on the design of new educational innovations in the museums have deficit positioning of facilitators, as Tran et al. (2019) have noted, and even if they are welcome as members of the design team, the actual ideas that they contribute are obscured or missing entirely from the written account. Therefore, noticing and making this infrastructuring visible highlights the creativity and expertise of facilitators throughout a DBR project in ways that have not been seen before. Put another way, the minimization of the labour, expertise, and ideas of facilitators (whether built into methodology or just not included in the academic writing) was something that was not visible to me until I was surrounded by their infrastructuring on a daily basis. It was only after I began to value their infrastructuring as design work that I went back into the literature looking for how they contributed to other DBR projects in their institutions, and came up empty.
Additionally, the why of infrastructuring grew in complexity and importance as I located infrastructuring within the DBR project as a whole, over four years of work. Infrastructuring was facilitators exercising agency in the absence of support – a lack of training, a lack of consultation with designers, a lack of agency within their institutions to change the exhibit or voice their design ideas. That lack of support is something that is baked into methodology; it is the result of choices of who gets to participate, what their roles are, what data will be collected, and what research activities they take part in – and which they are not invited to take part in, such as final design decisions or dissemination of results. These methodological decisions are influenced by historical and contextual factors. That is, if we simply follow what previous researchers in museum contexts are doing, we may default to observing or interviewing facilitators rather than including them more centrally in the design team. This problem is not something that the individual facilitators can solve. It is systemic issue, across institutions (Ash et al., 2012) and research projects (Chapter 4). Realizing the absence of infrastructuring in previous studies led us to consider methodology and axiology more centrally in our project, causing us to shift our choices for research activities and data collection in ways that, on the surface, diverged from the original “redesign” goal, but in fact became critical to our understanding of what (re)design in a museum space actually looks like. In conclusion, the impact and axiological importance of facilitator infrastructuring (Chapter 3) becomes visible when we look across historical positionings of facilitators in DBR (Chapter 2) and how infrastructuring was the key to our pivot into new methodological decisions (Chapter 4).
The Intertwinement of Methodology, Epistemology, and Axiology

Chapter 4 illustrated the ways in which methodology, epistemology, and axiology were intertwined throughout the research described in this dissertation. In order to create meaningful change, whether it is taking place in a classroom, a museum, or other educational space, we must attend to the relationships, hierarchies, and meaningful actions of everyone involved as key aspects of design or reform activity. Otherwise, we risk reproducing the status quo at best, or making things worse. This requires widening the focus of DBR from the educational intervention to a more ecological perspective, directly mapping relationships of knowledge, practice, and power. This work is not easy – DBR has historically positioned researchers as “in charge” of the project (regardless of how much input the practitioners have into the design of the intervention), and especially within educational research, researcher epistemologies may differ from those of practitioners. And, just as in our project, it can be tempting to want to break through these tensions by privileging the viewpoints of researchers. Some may say, isn’t that the point of a researcher being involved? To provide new (implicitly: better) perspectives on a problem of practice? To generate new theories for learning in context (which must inherently be better than the way we are doing things now)? If only we could help practitioners understand (read: accept and defer to) our perspectives, we could revolutionize education! These sentiments rapidly lose their appeal when we can make visible the ways in which they oppress and devalue the knowledge and complex practices of practitioners, artificially limiting the space for solutions while also having dire implications for the sustainability of the new intervention.

While not mentioned explicitly in Chapter 4, attention to ontology as it is intertwined with epistemology, axiology, and methodology is also important. Gupta et al. (2010) wrote that
ontologies are dynamic and context-dependent, especially the ontologies that are at play in
STEM education. This is especially true in a research-practice partnership that involves shifts in
people, objects, and practices over time. It is not just a question of what exhibits exist, or what
roles researchers or facilitators can play, but what exhibits could exist and what roles researchers
and facilitators could play in the future. These aspects of ontology, being and becoming, are
directly related to epistemology, axiology, and methodology. Some DBR methodological
commitments can create strict boundaries for what “counts” as DBR (and therefore, what roles or
designs can exist as part of it). Ideas of what “counts” as computing or STEM facilitation
directly impacts what exhibits and practices become part of the science museum. And, most
importantly in my view, axiology impacts whether or not we recognize these things that exist or
could be as inherently true, right, and ethical. Therefore, while it is important to consider what
roles may be played by facilitators in future research, we must also consider whether or not those
roles are valued, both within their institutions and educational research more broadly. Providing
space for facilitators as co-designers and co-researchers shifts into tokenism if that additional
labour is not valued and recognized as important in research and practice. Those roles become
meaningless without the necessary shifts in openness, dialogue, and decision making that truly
characterize the collaborative aspect of engaging in co-design and co-research – all of which
become part of the power dynamics that can be challenging to overcome, but also the productive
tensions that can be the source of innovation in partnership and educational research.

Vadeboncoeur and colleagues have also grappled with issues of axiology, ontology, and
practice, bringing them together in an articulation of what they call “moral imagining”
(Vadeboncoeur & Vellos, 2016; Vadeboncoeur et al., In Press). The moral imagination
refers to the dynamic learning, unlearning, and transforming of how we create social relationships with others, how we see ourselves in relationships, how we value our relatedness with others, and how we make decisions regarding what it means to become a supportive or empathetic person in relation (Vadeboncoeur & Vellos, 2016, pp. 308-309). Working in partnership with others – whether it is a teacher working with a student in alternative education program, or a researcher working with a facilitator in a museum – requires attending to that relationship and its dynamics, how we value and support each other with shared goals in mind. Vadeboncoeur and Vellos (2016) argued that rather than just relying on the label of supportive (a supportive teacher, a supportive researcher), working with the principle of accept and build in mind can help both parties “work toward accepting what each other has to offer in the present, while together building new social futures” (Vadeboncoeur & Vellos, 2016, p. 308). Their work centred around alternative education programs, and how students and teachers in these spaces worked together to make visible their unique situations, experiences, and aspirations for schooling, collaboratively imagine future identities as students who were capable of learning, and then transforming the school (via physical space configurations, policies, and teaching practices) into a space where these students could succeed. I believe that similar work can be carried out in museum-based DBR. As seen in Chapter 4, it took sustained communication and open dialogue for researchers and museum facilitators to “see it from both sides,” referring to the desired epistemologies and design aspects of the designers as well as the on-the-floor realities and needs of the museum facilitators. Researchers and practitioners had to make explicit their desires, needs, and perspectives so that, as a group, we could accept each viewpoint as equally important in the design project. We were able to productively acknowledge tensions in our
discussions and move together imagine possible future designs and ways to collaborate. Additionally, just as students imagined new future identities in their alternative schooling program, museum facilitators were able to imagine themselves not just as guinea pigs for new educational designs, but as empowered collaborators and co-designers in the process whose expertise was essential to overcoming design challenges. In this way, a new moral imagining of museum-based DBR can shift our understandings of partnership and research methodology in ways that can lead to more equitable collaborations with museum facilitators as well as innovative pedagogies and exhibit designs.

Thus, acknowledging and “staying with the trouble” of the epistemological and axiological tensions within DBR, to borrow a phrase from Donna Haraway, is necessary if our goals as researchers are loftier than publishing the next academic article. In the next section, I discuss the implications of attending to the ways in which epistemology, axiology, and methodology are intertwined in DBR, both for DBR as methodology and future work in computing education.

**Implications**

1. **Widen the methodology of DBR beyond the intervention to consider relationships, power dynamics, and institutional constraints as crucial to design**

   Firstly, the Learning Sciences as a field must move beyond intervention-centred DBR and pay deeper attention to DBR as it takes place within a broader context, filled with relationships, power dynamics, and institutional constraints. Scholars including Kris D. Gutiérrez, Shirin Vossoughi, and Megan Bang have provided exemplars of this work over the past decade: research that prioritizes communities, Indigenous knowledge systems, relationship-
building, and ethics as essential aspects of design work. Considering epistemology and axiology as part of DBR requires researcher subjectivity statements, explicit naming and (as much as possible) challenging of power dynamics within the research, voicing of participant epistemologies and acknowledging how they are similar to or different from those of researchers, space and time to reflect and then pivot in response to discomfort or tension, and giving everyone, participant or researcher, the permission to make mistakes – as long as they learn from them. Rather than conceptualizing DBR projects as a mostly linear path from ideation, design, test, and implementation, we must allow the project to breathe and shift in response to epistemological or axiological perspectives – possibly resulting in longer timelines, which are necessary to build relationships, address concerns, and follow new strands of thought. The who, how, and why of design must be elevated to the same level of importance as the what (Philip et al., 2018).

(2) Include relationships, reflection, and participants (beyond those who are considered the “intended audience”) more centrally in the writing

If these aspects are important, then they need to be included in the writing. Reports of DBR projects, whether informal or formal, must include deeper reflection beyond the ways in which the designed intervention changed in response to data of some kind. This needed reflection is personal, reflecting a situated perspective of the research project as a whole. It includes a deeper understanding of the motivations, more clearly linking background to theoretical perspective to initial design considerations. It means being explicit about participants beyond demographics, including detailed explanations of not only the roles assigned to them by researchers, but what they actually did as part of the research – especially as, noted in Chapter 2,
there may be discrepancies role descriptions vs. daily labour. Power relationships that may impact the research methods, data collection, efficacy of the designed intervention, and implications must be articulated and acknowledged. Finally, the tensions in epistemology and axiology that researchers navigate throughout the lifespan of a project should be reported, not as failures, but as opportunities for productive discussion, relationship building, and idea generation. There are challenges in conducting DBR beyond “the design isn’t working as planned,” and if experienced scholars in the field make these challenges (and their responses to them) clear, newer scholars can gain a deeper appreciation for the tensions that they may have to navigate, and how they can be reconceptualized as opportunities rather than barriers to be overcome.

Is this extra work – the extra writing, time spent in the field, cognitive and emotional labour to productively navigate tensions – worth it? As my discussion of infrastructuring in Chapter 3 and research timeline in Chapter 4 highlight, attending to the intertwining of axiology, epistemology, and methodology can certainly result in extra work. But it also can make visible labour and practices that were previously invisible, labour and practices that are critical to both our understanding of how learning takes place in context (a key claim of DBR) and how our interventions can be more sustainable. Beyond that, taking the time to address issues of axiology and epistemology can result in stronger design work, that is, better DBR. Rather than serving as detached masterminds or designers behind the scenes, it puts researchers right in the middle of the messy design work, giving us an up-close look at the technical, social, political and ethical implications of our educational interventions. This wider perspective can result in deeper understandings of when and how to intervene in DBR, solidifying the different points on the axis
with “detached observation” at one end and “stepping in to immediately solve every tiny possible problem with the design” on the other. Agency is both negotiated and shared between researchers and practitioners, resulting in new possibilities for design and practice. Additionally, knowing when and how to intervene can result in stronger findings and implications for the success, sustainability, and scalability of educational interventions, as researchers have a more nuanced understanding of the conditions (technological, social, political) under which their design can flourish, and the ways in which those conditions can be created via infrastructuring. All of this is to say that approaching DBR from a perspective that looks for the ways in which methodology is linked with epistemology and axiology provide a much more robust understanding of the context in which they are designed, tested, and implemented, across space and time.

(3) Make visible the epistemological and axiological commitments in design-based computing educational research

Attending to epistemology and axiology within design-based computing educational research is incredibly important for challenging canonical ideas of the discipline and who can participate, centrally, within it. Otherwise, we risk trying to solve the problem in a technocentric, device-centred manner (as discussed in Chapter 4), or worse, fail to challenge the status quo and reproduce existing patterns of inequity and marginalization. To this end, I offer a series of questions for researchers who conduct this manner of research to consider throughout their project, from conceptualization to recruitment, data collection to dissemination. These questions are inspired by existing feminist approaches to science (e.g., Abbiss, 2011; Brickhouse, 2001; Clegg, 2001; Faulkner, 2001; Haraway, 1988; Harding, 1991; Keller, 1996; Wajcman, 2007),
labour (e.g., Acker, 2006; Fletcher, 1999; Hochschild, 1983), research methodology (e.g., Fine & Torre, 2019; Leavy & Harris, 2019) and my own research experiences over the past four years.

- What does it mean for someone to “know” or “participate in” computing?
- What computing knowledge is assumed, privileged, valued, or missing?
- Who is participating in the design process, and what are their motivations?
- How are histories (disciplinary and personal) acknowledged and/or challenged within the design process?
- What power dynamics or binaries are at play in this project (e.g., technical expert vs. novice, subject matter expert vs. educator, technical vs. social, etc.) and how can they be explicitly challenged throughout?
- How is design labour made visible, acknowledged, and celebrated?
- What institutional constraints are at play that may impact the work of participants, especially constraints that are not applied to researchers?
- What agency do participants have in leading the research and design process?
- Who gets to make design and research decisions?
- How will the researcher create a safe, collaborative space for new perspectives and ideas?
- How will the voices of participants be included in dissemination of the work?

Of course, this list of questions is not exhaustive. But it provides a starting place for researchers to ask questions beyond “did my design work, and why?” These questions are essential in work that strives toward equity and social justice: we cannot assume that views of what computing “is” or “should be” are universal. Neither should we look for step-by-step instructions for how to carry out a research project with more equitable computer science as the
goal—it will pivot, shift, and drift in response to the participants and researchers, who
themselves change as well. I hope that this dissertation research provides an interpretation of
DBR that is fluid, messy, and filled with tension, but also real, based on relationships and
histories, and grounded in the labour and experiences of everyone who has contributed to the
research project in big or small ways.

Limitations

One major limitation of this research is related to the recruitment and participation of
museum facilitators. As per research ethics guidelines, facilitators working at the museum were
not automatically enrolled into the research as participants—they had to opt-in via a consent
process. The majority of the data collection took place with facilitators who had opted into the
research and then spent extended blocks of time scheduled at Hack the Flock. It is possible that
other facilitators who were not comfortable with the exhibit or the discipline of computing may
have chosen not to participate in the research at all, and their voices and perspectives would
therefore not be included in this research. Thus, the comments and perspectives included in my
discussions of infrastructuring and exhibit design may be somewhat biased towards those
facilitators who felt more comfortable with computing (regardless of whether or not they had
experience in the discipline) or who had more positive opinions of the exhibit or the research
project more generally.

Relatedly, it is impossible to completely minimize the power dynamics between
researchers and participants in a research project, despite explicit goals of partnership and co-
design (Carlone & Webb, 2006). We attempted to reduce the impact of this power dynamic by
collecting data without the initial exhibit designers present, ongoing work to build and support
relationships between the research team and museum facilitators, repeatedly stating that their participation in the research would have no impact on their employment, and explicitly positioning the museum facilitators as co-designers later in the project. However, despite these measures, facilitators may have been hesitant to share all of their thoughts with the researchers, especially strong negative opinions of the exhibit or the research. I cannot ignore the fact that the museum facilitators knew that we were in contact with and had working relationships with their managers and other museum staff members, and despite commitments to anonymity and confidentiality, they may have been worried that their comments would be heard by museum staff members and negatively impact their employment – employment which, as outlined in Chapter 2, is already precarious.

Next, it can be seen across the empirical research in Chapters 3 and 4 that institutional constraints played a considerable role in the experiences and practices of the participants. As mentioned previously in this chapter, these institutional constraints may be invisible to researchers, who are “outsiders” and therefore may not find their practices constrained in the same way as hourly employees. Some of these institutional constraints were only visible to researchers after we had circumvented them, sometimes unknowingly, with the research design – such as participation in the research requiring facilitators to spend large blocks of time at Hack the Flock, something that was impossible in their previous work. In this way, the very presence of researchers at the exhibit will have impacted the institutional constraints that facilitators had to deal with as they facilitated and performed infrastructuring at the exhibit. Thus, infrastructuring and facilitation practices occurring as part of the data collection may not be subject to the same institutional constraints that existed outside of data collection.
Finally, research that strives for equity and social justice requires attending to the potential inequities present at the research site. In this case, who visits or works at the science centre is impacted by its location, accessibility, transit options, cost, etc. Museum staff members noted that the typical visitors to this exhibit were young families, often white, from middle-class or affluent backgrounds, something that has been noted as a trend across the literature (Dawson, 2019). A key factor in attendance demographics may have been cost of attending the museum (at the time of writing, $26/adult or $19/child per day, or $268/year for a family membership), even though the museum did occasionally run special events or had other pricing discounts. Transit options were not ideal, requiring a roughly 1km walk from the nearest train station, and on-site parking costs were $7/day (or free with membership). Beyond the cost, researchers have noted that science museums are more frequently attended by those with the time to do so, lowering accessibility for families with longer working hours. Finally, individuals with identities who have been historically marginalized in science or museums may feel that the museum is “not for them” and they therefore do not attend (Dawson, 2019). The demographics of visitors may impact the everyday practices of facilitators and the design of exhibits, such as signage and code comments being written only in English. Therefore, the infrastructuring and exhibit design practices reported in this dissertation may not be adequate for visitors of different racial, linguistic, or SES backgrounds.

Future Work

This dissertation work provides a starting point for future conceptualizations and implementations of co-design between educational researchers, museum facilitators, and visitors to science museums within RPPs. While previous studies involving RPPs with museums have
relied on visitor observations or surveys to determine the impact of designed interventions, this work will explicitly position museum visitors as *partners* in co-design of museum objects and practices. Specifically, ensuring that individuals who have been traditionally marginalized in science and science museums are not just consulted, but lead the process of designing and implementing new exhibits and educational programming can connect with their cultural, linguistic, and personal experiences. This is particularly important as these individuals may view science (and science museums) as being “not for them.” Engaging in this design work allows for more expansive notions of what “counts” within science and who can take part.

Relatedly, future work can deepen understandings of *participatory* design research – that is, design research where co-designers articulate the research questions and methods and carry out analysis and interpretation on top of the educational design work; this is something that is largely missing in current museum-based RPPs. Power dynamics are embedded in design prototypes, discussions, and decision-making processes. When a diverse group of people in different roles (e.g., visitors, museum floor staff, museum management, educational researchers) work together to co-design a new exhibit or educational program, tensions and conflicts will assuredly exist due to differing goals, perspectives, and experiences. For example, innovative designs may be constrained by institutional budgets, or managers may be wary of turning over full control of a gallery to visitors (reinforcing hegemonic power structures). I believe that turning this critical lens upon actions, discussions, designs, and decisions in co-design projects responds to recent calls to examine power and privilege in educational research and provides the opportunity to create new theories and methodologies within RPPs.
Conclusion

The goal of this thesis is to investigate how the power, positioning, and labour of museum facilitators contribute to their participation in design-based research, and what implications this has for the design of a computational science exhibit and the methodology of DBR overall. In Chapter 2, a critical review of the science museum facilitator literature showcased the ways in which facilitators held high importance yet low status/power in their institutions, that their work was often compared to school science literature in ways that lose sight of the unique affordances and constraints of informal science spaces, and that their frequent deficit positioning led to few studies that made their expertise visible and valued to educational researchers. Chapter 3 detailed the ways in which museum facilitator infrastructuring, a process that emerged and changed over time from within the facilitator community, was crucial to the success of a computational science exhibit. This infrastructuring was not visible to the researchers until they had spent time in the field building relationships and witnessing the impact of institutional constraints on the facilitators’ daily work – something that required reflection on power dynamics and facilitator positioning both in their institutions and the research project as a whole. Finally, Chapter 4 zoomed out to show how attending to epistemology and axiology within this DBR project required paying attention to the power, positioning, and labour of the museum facilitators. Productive shifts in the design, as well as theory-building for learning in informal spaces, emerged as researchers and practitioners navigated these tensions together. Most importantly, it was only after breaking away from traditional device-centred notions of DBR that we were able to see and act on these shifts and new theories together.
The biggest take-away of this research is that regardless of the context in which DBR is being conducted, we cannot ignore the ways in which epistemology and axiology are bound up in methodology. Ideas of what counts as learning and what counts as disciplinary engagement are central to the design of new educational interventions, regardless of whether they take the form of a new exhibit, an educational program, or something else. Researchers must not assume that their epistemologies are the same as the visitors in informal learning spaces, nor of the educators and facilitators who bring these educational interventions to life. This is especially true in computing, a discipline that has undergone shifts over the years but is still perceived as masculine, abstract, and exclusionary for many learners (Ensmenger, 2015) – creating new educational opportunities to challenge hegemony in the discipline is important, but difficult, and we must be prepared to productively navigate tensions and disagreements. Additionally, asking crucial questions of who gets to take part in DBR, how, and why can create opportunities for labour to be uncovered and valued. This labour may lead to new design ideas and educational theory, but more importantly, once visible, we can strive for new forms of partnerships so that researchers and practitioners can work together in more equitable and justice-oriented ways.
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