On the Politics and Aesthetics of Museum Mathematics:

The Dissensual Curriculum of US Mathematics Exhibitions in the Early 21st Century

Molly L. Kelton[1] and Ricardo Nemirovsky[2]

[1] Washington State University

[2] Manchester Metropolitan University

Address correspondence to:

Molly L. Kelton, Department of Teaching and Learning, Washington State University, Pullman, WA, 99164-2132

Email: molly.kelton@wsu.edu

Dr. Molly L. Kelton is an Assistant Professor of Mathematics Education in Washington State University's College of Education, in Pullman, WA, USA.

Dr. Ricardo Nemirovsky is a Professor in Manchester Metropolitan University's Education & Social Research Institute, in Manchester, UK.

Abstract

Museum-based mathematics exhibitions are increasingly prominent but under-theorized learning environments. In this study we analyze the curriculum of United States mathematics exhibitions developed in the early 21st century in terms of their complex suggestions about the nature of mathematics and mathematical sense-making. We apply Rancière's notions of politics and aesthetics to explore what we describe as dissensus present in the texts, images, and multi-sensory exhibits of several major mathematics exhibitions. Our analysis characterizes this dissensus as a paradoxical mix of alternative and familiar mathematical aesthetics. On the one hand, we identify an alternative aesthetics emphasizing everyday ubiquity, sensuality, and informal sense-making. At the same time, we identify a countervailing emphasis on dominant notions of mathematics as esoteric, immaterial, and formal-symbolic. Museum mathematics efforts sometimes describe themselves as expanding how the public views and defines mathematics. A close examination of the exhibitions in this study reveals a complex picture, in which dominant and alternative forms of mathematics are co-present. The analysis suggests that museum-based mathematics researchers and practitioners view their work as containing political and aesthetic dimensions that can disrupt or reify what society counts as mathematics.

Keywords: museum, mathematics, politics, aesthetics, informal

This research was supported in part by the Math Core project funded by the National Science Foundation through Grant DRL-0840320 and the Informal Mathematics Collaborative project funded by the National Science Foundation through Grant DRL-1323587. All opinions and analysis expressed herein are those of the authors and do not necessarily represent the position or policies of the Foundation.

The authors have no conflict of interest to disclose.

Introduction

Museum-based mathematics exhibitions are increasingly prominent but under-theorized learning environments that educational research is just beginning to explore. While some research investigates whether and how these exhibitions promote targeted content learning, scholars have so-far rarely attended to the ways in which these spaces construct and enact alternative definitions and images of mathematics and mathematical sense-making. Studying these potentially more provocative aspects of mathematics exhibitions is essential in order to tap their full educational potential, particularly in light of efforts to promote and critically examine more expansive, inclusive, and equitable definitions of what counts as mathematics (Esmonde, 2013; Gutiérrez, 2017; Nemirovsky, Kelton, & Civil, 2017; Stevens, 2013).

In what follows, we briefly discuss research and public discourse on contemporary mathematics exhibitions. Then, inspired by new museological work on the politics and aesthetics of exhibitions, we articulate a theoretical orientation based on Rancière's (2000, 2010) philosophy of politics and aesthetics. We draw on Rancière's notion of politics as a distributed movement to affirm the equality of groups and practices that social consensus views as having no significance – hence deprived of the right to be seen or heard. As such, politics engenders *dissensus* that opens up a gap, an opening populated by persons and practices that, until then, had been invisible in the prevalent *consensus*. From this perspective, politics always involves challenging a prevalent aesthetics, a shift in the *distribution of the sensible*, conferring rights to be seen and to be equals relative to that which is affirmed by the prior consensual distribution of the sensible.

With this framing, we examine US mathematics exhibitions in the early 21st century in terms of the often-alternative images and experiences of mathematics they suggest, which might be understood as part of the curriculum of these spaces. We argue that the design aesthetics of many contemporary mathematics exhibitions express an emerging politics of mathematical thinking and learning. This politics affirms (always provisionally, tenuously, and complexly) an egalitarianism (i.e., dissensus) across longstanding hierarchical divides, privileged in the predominant consensus, that identify mathematics with the mental, immaterial, impersonal, rational, academic, and formal-symbolic against that which is embodied, material, personal, emotional, and everyday. We show, however, how a dominant consensual mathematics continues to intermix with these more alternative images, resulting in paradoxes. Thus, because we conceptualize politics as inherently tenuous and paradoxical, our analysis of the politics and aesthetics of mathematics exhibitions centers around a collection of interrelated aspects of dissensus we see present in these spaces.

Our study contributes to curriculum studies literature that takes an expansive view of curriculum to include public spaces and discourses such as memorial sites (Friedrich, 2011), shopping malls (Crowley & Matthews, 2006), popular and mass culture (Appelbaum & Clark, 2001), and museums (Furo, 2011; Harper, 2013; Nespor, 2000; Trofanenko, 2006; Wood & Latham, 2011). For example, writing about an art exhibition, Harper (2013) argues that every piece of art "is its own individual curriculum, as is the exhibition as a whole" (p. 247). Critical analyses of the pedagogies of such spaces can help us identify ways of "hacking" (Beery et al., 2013) or expansively leveraging them, reveal tensions or struggles related to epistemological authority and representation, and deconstruct contradictory constructions of specific disciplines such as science (Appelbaum & Clark, 2001). For example, Appelbaum and Clark's (2001) investigations of discourses of "fun" across diverse popular and museum-based science education resources show how "curriculum materials in the USA construct a contradiction between the instrumental view of science as cultural capital (get a job, increase the US position in a global market, etc.), and the means proposed to reach it (fun)" (p. 585). We consider an analysis of the politics and aesthetics of mathematics exhibitions to have significance not only due to their increasing prominence in the field but also due to their public self-positioning as key educational sites that extend – and provide counterpoint to – school mathematics curriculum.

Background: Research and Public Discourse on US Mathematics Exhibitions

Exhibitions about mathematics have proliferated across United States museums and science centers, growing in number and visibility within popular educational discourse (e.g., Adams, 2013; Anderson, 2001; Cooper, 2011; Nemirovsky et al., 2017). Due, in part, to science centers' increased investment in mathematics exhibitions and programs beginning in the 2000s (Anderson, 2001; Mokros, 2006; Nemirovsky & Gyllenhaal, 2006; Sutterfield, 2006), visitors to mathematics exhibitions across the US can now access technology-rich environments designed for learning about topics such as geometry, calculus, pattern, number, algebra, ratio and proportion, and mathematical applications. These exhibitions (and associated literature) include:

- The Exploratorium's Geometry Playground (Dancstep, Gutwill, & Sindorf, 2015; Dancu, Gutwill, & Hido, 2011; Dancu, Gutwill, & Sindorf, 2009)
- Flip It Fold It Figure It Out at the North Carolina Museum of Life and Science
- Handling Calculus at the Science Museum of Minnesota (Gyllenhaal, 2006; Nemirovsky & Gyllenhaal, 2006)
- Design Zone and Moneyville by the Oregon Museum of Science and Industry (Nemirovsky, Kelton, & Rhodehamel, 2012, 2013; Pattison, Ewing, & Frey, 2012)
- Pattern Wizzardry at the Brooklyn Children's Museum

- Secrets of Circles at the Children's Discovery Museum of San Jose
- Beyond Numbers at the Maryland Science Center
- Cyberchase: The Chase is On! at the Children's Museum of Houston
- Go Figure at the Minnesota Children's Museum
- Math Alive! developed by Raytheon
- Taping Shape at the Fleet Science Center in San Diego (Kelton et al., 2018; Kelton & Ma, 2020)
- Math Moves! at the Science Museum of Minnesota, the Boston Museum of Science, North Carolina's Museum of Life and Science, and New Mexico's Explora (Kelton, 2015, 2021; Wright & Parkes, 2015)

The widely publicized opening of the New York City Museum of Mathematics (MoMath) in 2012 further testifies to the increased visibility of museum-based mathematics education in the US. Although the future development of mathematics exhibitions is uncertain within shifting US economic and political climates – as well as in the wake of the COVID-19 crisis – they are nonetheless currently a widespread and under-researched type of learning environment.

While research on visitor learning in mathematics exhibitions has lagged considerably behind their development, a small body of literature is beginning to emerge on cognition and learning in these spaces. So far, this research has tended to focus on targeted learning behaviors (e.g., length of engagement) and pre-delineated content learning outcomes (e.g., improved spatial reasoning) (e.g., Dancu, Gutwill, & Hido, 2011; Guberman, Flexer, Flexer, & Topping, 1999; Gyllenhaal, 2006; Pattison, Ewing, & Frey, 2012). Other research has attended to teacher and learner interactional strategies for connecting the exhibition to school mathematics curriculum in the context of school fieldtrips (Kelton, 2021). Another strand of research utilizes mathematics exhibitions as field sites for developing foundational theory about the role of embodied interaction in mathematics learning (Nemirovsky et al., 2012, 2013; Kelton et al., 2018; Kelton & Ma, 2020).

However, missing from the literature is more explicit attention to the cultural politics of these spaces and the subtle, tacit messaging they may convey about the nature of the discipline. Mathematics exhibitions include hands-on, multi-sensory, and play-based technologies that differ from many school mathematics curricula. Moreover, in public discourse, mathematics exhibitions have been looked to as environments that might broaden and improve public perceptions of a discipline that is often conceptualized narrowly. For example, in a CBS interview, one of MoMath's founders explained that they hoped the museum would help more people to see that, "In fact, math is this extremely, very beautiful landscape" (http://www.cbsnews.com/news/a-new-museum-devoted-to-math/). To understand the curriculum of these spaces more fully, it is crucial to investigate how mathematics exhibitions might be seen as proposing new genres of mathematics. In this study, then, we analyze mathematics exhibitions in terms of this more provocative intent, asking how specific design features proffer boundary-pushing images, practices, and experiences as part of a provisionally expansive definition of mathematics, always in ways that are tenuous and messy. In the terms elaborated below, then, this is a study of the politics and aesthetics of contemporary mathematics exhibition designs as a form of public curriculum.

Theoretical Framing: An Approach to Politics and Aesthetics from Rancière

Analyzing the politics and aesthetics of exhibitions has an established scholarship in museum studies and related fields (e.g., Lidchi, 1997; Macdonald, 2011). Broadly, work in this area includes unpacking and critiquing the 'behind-the-scenes' practices of exhibition design as well as the ways in which exhibitionary styles and representational strategies produce and mobilize certain forms of knowledge and power over others. In the case of science museums, this scholarship questions official institutional narratives of authority, objectivity, and neutrality, while bringing to light the representational strategies — and lacunae — by which science exhibitions varyingly reproduce, transform, or contest images of scientific knowledge as objective, uncontroversial, and unchanging (Macdonald, 1998b). For example, studies in this vein have detailed how socio-political pressures have historically led to the exclusion of controversial content (such as Darwinism or the atomic bomb) in science museums (Conn, 2011); how educational materials from the Smithsonian Institute worked to legitimize research conducted at the institute as ‘real’ science (Allison-Bunnell, 1998); how science exhibitions position visitors as consumers of technology and scientific knowledge (Macdonald, 1995, 1998a); or how the advent of interactivity in science museums like the Exploratorium represents a troubled attempt to democratize science (Barry, 1998).

New museological scholarship on the politics of museum display has centered around ethnographic, science, and art exhibitions but has not focused on mathematics exhibitions. A central contribution of this article, then, is to begin to unpack these under-researched learning environments in terms of the complex stories and messages their various design elements might be suggesting about the nature of mathematics and mathematical sense making. Educational research and the learning sciences increasingly emphasize the importance of making visible, questioning, re-imagining, and pluralizing assumptions about what can, might, or should count as mathematics or science across various contexts (e.g., Bang et al., 2012; McDermott, 2013; McDermott & Webber, 1998; Stevens, 2013). As Stevens (2013) notes, “across society math is no unitary thing” (p. 6). We suggest that new museological orientations may have much to contribute to this endeavor, particularly with respect to critically examining representations of disciplinary knowledge in museum settings.

While new museological scholars take up ‘politics’ and ‘aesthetics’ (or, sometimes, ‘poetics’) in variable ways, in this study, we draw on philosopher Jacques Rancière’s (2000, 2010) notion of the distribution of the sensible to frame our analyses of mathematics exhibition design. Sometimes translated as “the partition,” “division,” or “sharing” of the sensible, Rancière (2000) describes the distribution of the sensible as a set of tacit boundaries that form an implicit “system of self-evident facts of perception based on the set horizons and modalities of what is visible and audible as well as what can be said, thought, made, or done” (p. 12). Simultaneously a matter of both politics and aesthetics, the distribution of the sensible is the “cutting up of the perceptual world,” that produces boundaries between “what is visible and what is not, of what can be heard and what cannot, of what is noise and what is speech” (Rancière, 2004, p. 225). For example, a distribution of the sensible may delineate spaces, times, and forms of activity along hierarchical arrangements, such as treating crafts as lesser forms of art. A distribution of the sensible may also regulate who or what counts within a social process. Children, for instance, do not vote to elect representatives, and in that sense, they are not counted in electoral results. Distributions of the sensible discriminate between signal and noise, such as when a composer’s music score is rejected as mere racket or a young child’s speech is regarded as nonsensical (Bingham & Biesta, 2010).

While the term “sensible” can connote “common sense,” here it also includes a more literal or sensual interpretation as that which can be apprehended, detected, or perceived. As de Freitas and Sinclair (2014) explain in their application of Rancière’s work to the study of mathematics classrooms, from this perspective, “any particular drawing of the boundary between what makes mathematical sense and what does not entails a particular kind of consensus about the valuing and regulating of the senses" (p. 172). The sensuality of our interpretation of this construct is, in part, what we feel makes Rancière's approach to politics particularly fitting for an analysis of the kind of multi-sensory, interactive exhibitions examined in this study.

Distributions of the sensible are not static or pre-determined arrangements, nor are they solely created by an individual or single authority. Instead, multiple groups, individuals, and processes at a variety of scales actively produce and maintain distributions of the sensible. Artists, art museums, curatorial norms, critics, and so on all play a role in sorting out what counts as art, often in ways that shift over time (Rancière, 2009). Similarly, school curriculum developers, testing companies, accountability policies, popular media etc. continually produce and reproduce a prevalent sense of what matters for mathematics education.

From time to time, rather unusually according to Rancière, a gap opens within a distribution of the sensible, creating a space for something which had previously been invisible and mute – something that arises embedded in claims of rights and equality. Rancière refers to this as dissensus. For Rancière, politics, then, is the struggle to affirm and confirm claims of equality that trouble – rather than maintain – established regimes of distributions of the sensible. Dissensual claims of equality may pertain to groups of people as well as, interrelatedly, to things, materials, places, or forms of activities. Consensus is not a state of agreement or harmony but, rather, lies in "the nullification of surplus subjects" (Rancière, 2010, p. 42) Similarly, dissensus does not refer to "a confrontation between interests or opinions" but is, rather, "the demonstration (manifestation) of a gap in the sensible itself" (Rancière, 2010, p. 38).

To clarify this notion of dissensus we refer to the *Fountain* – the famous ready-made urinal contributed in 1917 by Marcel Duchamp to the art exhibition at The Grand Central

Palace in New York. The controversial issues raised by the *Fountain* were not about, say, the composition of colors, the symmetry of form, the enigmatic style, or any of the issues that were prominently perceived and discussed at the time in the art world, all of them being part of its distribution of the sensible. In whatever room the *Fountain* was located, it opened a space for that which was not – not art, not creation, not serious, and so on. In this specific sense, exhibiting the *Fountain* was a dissensual act. Dissensual acts may occur in science, art, philosophy, popular culture, education, or any other field, and are, for Rancière, constitutive of politics. The claim that the *Fountain* was a piece of art, equal as such to other pieces of art routinely exhibited, was not something to be demonstrated empirically or by a chain of syllogisms. Just the fact that it had been included indicated that the curators acted on the basis that it was, as ridiculous as that presumption might have been seen by others.

This is a general thesis articulated by Rancière: an equality claim is never an empirical verification or a rational theorem but, rather, a presupposition to follow and verify through its practice. Efforts to "study" whether that which is unequal should be equal systematically postpone politics in order to preserve an established regime. The achievement of women's right to vote, for instance, arose from affirming equality in life and in the streets and then acting on that basis. In this way, dissensus can be seen as what Sonderegger (2012) describes as "affirmative critique." At the same time, any political process involves paradox, in which a newly affirmed equality overlaps with an actual inequality, such as affirming the equality of civil rights while social life denies them. Because of this, dissensus often encompasses a wide multitude of uncertainties, ambiguities, and shifting commitments.

What emerge from and contribute to dissensus are also nascent aesthetics – broadly sensed and openly configured sets of images, feelings, practices, and styles regulating what counts as meaningful and real versus that which is disorderly, noisy, or meaningless. These nascent aesthetics can introduce new objects and ideas cutting across cultural boundaries. A political claim to equality precipitously implicates a transformative and overarching aesthetics for what counts as worthwhile, desirable, and inspiring. Conversely, aesthetics are necessarily political because of their role in configuring distributions of the sensible. For this reason, de Freitas and Sinclair (2014) argue that “the mathematical aesthetic must be analysed as a form of cultural politics” (p. 172). From this perspective, then, the aesthetics of mathematics exhibitions have political import in that particular styles, images, and design features take part in a provisional delineation of what makes mathematical sense.

A widely held distribution of the sensible regarding mathematics is not difficult to recognize. Within this dominant distribution, mathematics is sensed to be more abstract than dance or plastic arts, those who excel in mathematics demonstrate a high degree of innate intelligence, mathematics is understood as a result of mental efforts, mathematics manifests itself in exotic symbolic forms, and so forth. Given this consensus, germinal claims of equality can be recognized across a wide variety of communities, maintaining that mathematics is no more abstract than dance, that mathematics involves just as much bodily activity and tangibility as the crafts do, that specialized symbolisms are no more relevant in mathematics than they are in music or sport, or that being “smart” in mathematics is multifarious and not rooted in innate luck. Note that, according to Rancière, the force of these claims is not based on empirical evidence demonstrating that, say, mathematicians are as intelligent as lawyers or that generally theorems are as abstract as medical diagnoses, but on the embryonic practice of their presupposition. The following analysis discusses ways in which contemporary mathematics exhibitions introduce dissensus with respect to traditional distributions of the sensible concerning mathematics.

Politics and Aesthetics of Contemporary Mathematics Exhibitions

Methodological Considerations and Overview

We turn now to interrogate the designs of contemporary mathematics exhibitions, offering an interpretation of their politics and aesthetics. Drawing on the above framing, we provide an analysis of the built environments, including objects, images, texts, and material arrangements. Here we treat the exhibitions themselves as data, much as, for example, educational researchers have treated textual materials as data in analyses of the aesthetics of school mathematics curriculum (e.g., Dietiker, 2015). We include three exhibitions, chosen for what we perceive as their representativeness of a distinct era of US exhibition development during the early 21st century: Handling Calculus, a calculus exhibition at the Science Museum of Minnesota; Geometry Playground, a traveling geometry exhibition developed by the Exploratorium; and Math Moves!, a ratio-and-proportion exhibition collaboratively developed and installed at the Science Museum of Minnesota, the Boston Museum of Science, North Carolina's Museum of Life + Science, and New Mexico's Explora.

These exhibitions were all part of a wave of exhibition development projects funded by the US National Science Foundation (NSF) during this time. This period of federal funding is, in part, what demarcates and distinguishes this wave of exhibitions. Beginning in the mid-1990s, and accelerating in the early 2000s, NSF funded the development and dissemination of numerous mathematics exhibitions across the US. Most of the exhibitions listed above were supported by NSF during this time. Due to changes in federal funding priorities this period of funding largely attenuated in the late 2010s. These projects took part in drawing historically unprecedented public attention and funding to museum-based mathematics education in the US. Although further developments have unfolded since this time, these exhibitions – and others in their historical cohort – remain very relevant today both because many of them are still installed or in circulation as traveling exhibitions (as are all three exhibitions in this study) and because many of their elements, styles, technologies, and designs have been taken up in more recent exhibition projects. We touch on more recent and forward-looking considerations for museum-based mathematics in the concluding section of this article, but remain focused in the majority of our analysis on the early-21st-century era given its influence and sustained prominence in the field. To provide some historical perspective, below we also include brief attention to Mathematica, an earlier and foundational exhibition developed in the 1960s.

In describing Rancière's politics as affirmative critique, Sonderegger (2012) describes Rancière's approach to politics as practices that "retrieve forgotten, hidden or invisible acts of critique and movements of resistance" (p. 254). For us, this means turning our attention to seemingly small details or design elements that we interpret to provisionally affirm the equality of practices, places, and materials that are typically held outside of or below a dominant mathematics. Hence, our analytic approach attunes to and amplifies "acts, however minor, that criticise or subvert" (Sonderegger, 2012, p. 255) dominant regimes of mathematical sensemaking. This includes, inter alia, choices of displayed images, texts, and inscriptions such as equations as well as specific ways of visitor sensing and moving implicated in exhibit technologies. At the same time, because politics does not ignore the dominant regime but, rather, intervenes on it in ways that can produce precarious moments of paradox, our analysis necessarily includes attention to design elements that might be seen as partially upholding more dominant images of mathematics and the potential paradoxes that ensue. Rather than attempting to "resolve" these paradoxes in some way, our analysis centers them in order to sustain our attention to these aspects of dissensus.

We bring to this analysis a hybrid positionality; we have varyingly intersected with the exhibitions we analyze as casual visitors, videographic researchers, participant observers, and collaborating designers. Because of this, the overall data corpus we have developed in this work is diverse and includes: photographs taken during our own visits to these exhibitions, publicly available imagery and language provided by museums and developers, published educator materials accompanying the exhibitions, numerous conversations with designers, and, in the case of Math Moves!, video and audio recordings of visits and fieldtrips. While we had some design input into some of these projects, our goal in this paper is not to ascertain or center designers' intentions. The literature and debates about "authorial intent" fall outside the scope of this paper, but we think that: (a) authors or designers are not necessarily conscious of intentions that can be retrospectively discerned, (b) authorship engages active forces and intuitions that are socially disseminated rather than possessions of individuals, and (c) dissensus is not necessarily proclaimed by authors, but taken up by readers and visitors in diverse ways. For these reasons, the data we primarily focus on for this study, center around visual imagery, physical design, and text panels within the exhibitions, and our analysis is inherently interpretive.

In what follows we first further situate contemporary mathematics exhibition design within some historical context. We then describe and exemplify three cross-cutting themes in the form of three aspects of dissensus that characterize what we describe as an aesthetics disturbing an existing consensus. We developed these themes inductively, using a qualitative approach similar to what grounded theorists describe as open and axial coding (Corbin & Strauss, 2014), beginning with broad attention to all exhibition design elements relevant to the initial research question of what kinds of subtle messaging about the nature of mathematics these exhibitions might be conveying. Drawing on our reading of Rancière, we looked, in particular, for ways in which the exhibit materials might be delineating spaces, times, and forms of activity as part of a distribution of the mathematically sensible. As our analysis proceeded, the emerging complexities and contradictions inspired us to refine our research question and theoretical framing to explicitly focus our attention on forms of dissensus that appeared to recur across many of the exhibit materials.

Two additional considerations shaped the direction of our analysis. First, our choice of these modes of dissensus is embedded within and informed by the historical trajectory of mathematics exhibition development, as described below in our discussion of the 1960s exhibition, *Mathematica*. Second, a separate ethnographic research study on children's experiences of *Math Moves!* – one of this study's focal exhibitions – also attuned our attentions to aspects of the exhibition that children described as unexpected or surprising (Author). We elaborate on this further in the discussion. Our analysis ultimately focuses on three modes of dissensus: at-times paradoxical and complex treatments of (a) mathematics and everyday life, (b) mathematics and the body, and (c) mathematical formalisms. In what follows we first describe some relevant historical context for 21st-century mathematics exhibitions and our analysis of them. We then share our analysis of each of these three modes of dissensus.

Contemporary Mathematics Exhibition Design in Historical Context

The design of contemporary mathematics exhibitions is embedded in several broader cultural-historical trends in the museum profession in the US and abroad. First, the number of museums in the US dramatically increased in the latter part of the 20th century, with 11,000 of the estimated 16,000 museums in the US established between the 1980s and early 2000s (Alexander & Alexander, 2008). This growth has been matched by a gradual shift in the public role of US (as well as Western-European) museums toward greater emphasis on their potential educational contributions. The waxing educational role of museums is manifested, inter alia, in institutional mission statements, more partnerships with K-12 schools and universities, and growing accountability and standards-alignment pressures (e.g., Alexander & Alexander, 2008; Falk & Dierking, 2000; Hein, 1998; Hooper-Greenhill, 2007; National Research Council, 2009). This contributes to mounting contradictory pressures on these institutions to serve simultaneously as alternatives and complements to formal schooling.

Contemporary mathematics exhibition design is further inflected by changes in the pedagogical philosophy of Western science centers beginning in the mid-to-late-20th-century, particularly following the post-World-War-II reconstruction of the Deutsches Museum in Munich in 1965 and the founding of the San Francisco Exploratorium in 1968 (Alexander & Alexander, 2008). During this time, science centers began to move away from hands-off visual display practices, such as presenting authentic technological artifacts or natural specimens in glass cases, in favor of a more hands-on, interactive design aesthetic, a trend that has continued into the 21st century. Scholars and practitioners, in turn, have further connected this shift in design aesthetic to a more democratized politics of audience reception. Thus, within museum discourse, the glass-encased object has generally come to connote a didacticism that privileges institutional interpretation, while the interactive exhibit betokens visitor participation and meaning making (e.g., Evans, Mull, & Poling, 2002).

One of the most well-known and influential exhibitions developed during the mid-century advent of science-center interactivity was *Mathematica: A World of Numbers…and Beyond*. Originally designed in the 1960s by modernists Charles and Ray Eames, the famous mathematics exhibition is considered iconic – “an artifact unto itself” (Tesler, 2001 – 2002) – within science museum communities. Due to its historic prominence and continued visibility in the museum world, it is an important part of the cultural-historical context in which the 21st-century exhibitions in this study were developed. The exhibition has remained on display at several US museums and has been kept alive not only through exhibition preservation efforts but also, periodically, by the development of additional programs and accompanying exhibits intended to be experienced in conversation with *Mathematica*. For example, in the early 2000s, the Exploratorium put a traveling version of *Mathematica* on display alongside newly developed exhibits and programs intended to extend and comment on the original exhibition (Tesler, 2001 – 2002).

The three aspects of dissensus we describe in the contemporary exhibitions in this study are informed and contextualized – but not neatly continuous with – what were considered news- and advertisement-worthy features of *Mathematica* when it was first developed, as well as some of the contradictions and paradoxes therein. While a full analysis of *Mathematica*'s politics and aesthetics is beyond our scope here, our understanding of the exhibition's history, messaging, and reception helped attune our analytic methodology and partly shaped the forms of dissensus on which we chose to focus. First, developers and commentators have argued that one of *Mathematica*'s central aims and contributions is to "strip away the mysteries" (Danilov, 1974, p. 86) of mathematics in ways that would make it "appealing and understandable to the public" (Danilov, 1974, p. 86). In the words of the Eames office, the exhibition shows "how mathematics shapes our world" (Eames Office, 2015 - 2021). One of the main strategies for achieving this is a pervasive emphasis on visual imagery and diagrams (see Figure 1 left) as opposed to symbolic formalisms (although the latter certainly are present). This claim to demystification through an embrace of the imagistic and diagrammatic partly informed our analysis of how 21st-century exhibitions treat relationships between mathematics and everyday life (Dissensus 1, see below) as well as the role of symbolic formalisms in mathematics (Dissensus 3). In addition, although *Mathematica* might be described as relatively traditional by current standards, when it was first developed, part of what was considered (and advertised) as distinctly “modern” about it was its emphasis on interactive and dynamic technologies, such as a large arrow whose traverse around a Möbius strip is initiated by a visitor pressing a button (see Figure 1, right). The exhibitions in the present study can be seen as continuing and further developing an interactive, “hands-on” design aesthetic that we attend to through our analysis of how these exhibitions treat the relationship between mathematics and the body (Dissensus 2).

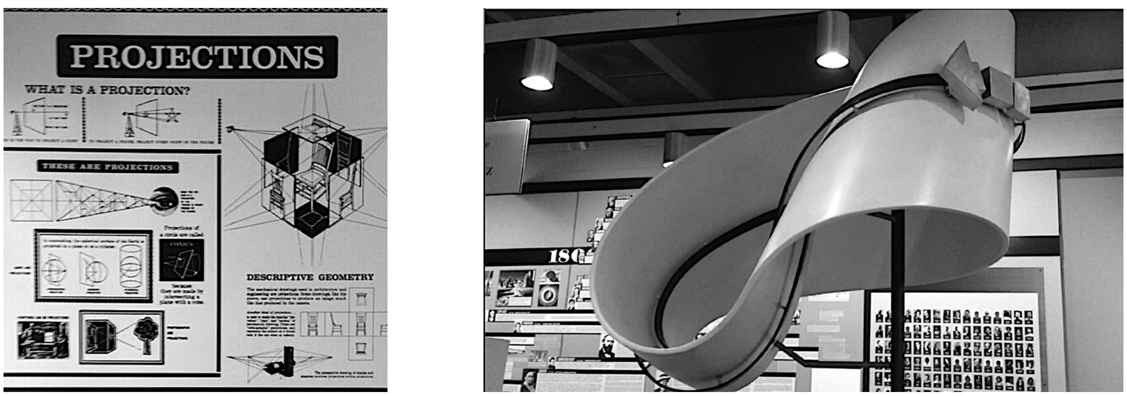

Figure 1. Mathematica exhibits. Photographs taken by the first author, February 2012 at the Boston Museum of Science. Top left image is taken from a much larger textual panel on the history of mathematics. Top right image is from a larger textual explanation of projections and projective geometry. Bottom image shows a kinetic Mobius strip sculpture activated by a push-button interface.

With this historical context in mind, we now further unpack the aesthetics of Handling Calculus, Geometry Playground, and Math Moves! by elaborating on three dissensual themes reflected in these spaces.

Dissensus 1: Mathematics and the Everyday

For Rancière (2004), a distribution of the sensible includes “a delimitation of *spaces and times*, of the visible and the invisible, of speech and noise, that simultaneously determines the *place and stakes* of politics” (p. 13, italics added). Mathematics exhibitions might contribute to dissensus through how they delineate spaces and times in which mathematical activity is seen as taking – or not taking – place. As out-of-school settings, the very establishment of mathematics exhibitions can be seen as inherently contesting dominant, schooled boundaries around where mathematics is considered to take place. And yet, this dissensual interruption into the spatio-temporal politics of mathematics is complex. For one, the disruption of schooled boundaries around what counts as mathematics isn't entirely democratizing; museums can be – and have been historically – elite spaces, sometimes struggling with the same issues of inequitable access as do schools. Second, it is not unusual for museums to undergo pressures to conform their programs and exhibitions to the curricular priorities and prevalent images of formal schooling, such as growing pressures for museums to align exhibitions and programs with K-12 school standards. However, despite these ambiguities, it is possible to identify, in the mathematics exhibitions we have examined, forms of dissensus over the presence and quality of mathematical activity across everyday spaces and times.

Within consensual aesthetics, mathematics can be found in the everyday world in terms of common applications, such as money transactions, measurement of recipe ingredients, or the design of practical mechanisms. But these are applications that people are supposed to have learned in school; mathematical knowledge is acquired in classrooms and then applied in the everyday world. Such asymmetry of mathematical activity – between the learning of general mathematical principles in school, on the one hand, and their worldly application, on the other – reflects a form of inequality making mathematics a possession of those who are properly schooled. It is not a coincidence that, historically, one of the most "surprising" results of research in mathematics education has been the discovery that unschooled children in Brazil who sold snacks and candy on the streets managed to properly handle monetary transactions with their customers (e.g., Carraher, Carraher, and Schliemann, 1985; Saxe, 1991). Examples have proliferated, such as studies of how nurses develop methods for administering correct dosages that make no use of the standard school algorithms to operate with fractions (Hoyles, Noss, & Pozzi, 2001). These studies already brought to bear dissensual claims into the field of mathematics education by challenging the inequality between school and everyday life, disputing the former as the sole cultural source of mathematical understandings.

We will describe aspects of the mathematical exhibitions that amplify and extend these dissensual claims, by asserting that not only is it the case that everyday problems are solved on the bases of understandings independent from school learning but, additionally, that the mathematics to be found in the everyday world is not limited to specific "practical applications." Mathematics can be present, for instance, in the act of making a summersault even though such an act may be one of free play and not of solving a utilitarian problem. This illustrates, we propose, the type of broadening of dissensual claims initiated by mathematical exhibitions.

Dissensual affirmations about the broader distribution of mathematics in out-of-school times and spaces pervade the texts and objects in the exhibits in this study. For example, Geometry Playground's title and overarching design concept hinge on reference to the setting of the playground, presumed (though not unproblematically) to be a familiar everyday place for most visitors. In the entryway text of Geometry Playground, Hans Freudenthal, a Dutch mathematician and mathematics educator, asserts through printed quotes, "Geometry is grasping space ... that space in which the child lives, breathes, and moves. The space that the child must learn to know, explore, conquer, in order to live, breathe, and move better in it." Elsewhere in the exhibition, a textual panel shows photographic images of youth climbing on playground structures and playing outdoors, along with text that asserts, "You experience geometry everywhere, and especially on playgrounds" (see Figure 2).

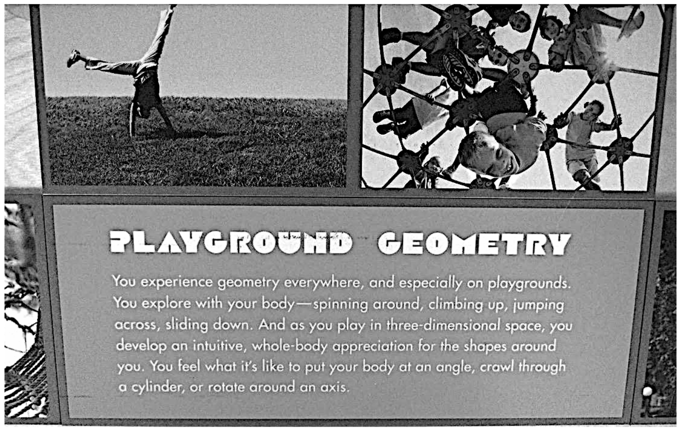

Figure 2. Panel from Geometry Playground. Text reads, “You experience geometry everywhere, and especially on playgrounds. You explore with your body — spinning around, climbing up, jumping across, sliding down. And as you play in three-dimensional space, you develop an intuitive, whole-body appreciation for the shapes around you. You feel what it’s like to put your body at an angle, crawl through a cylinder, or rotate around an axis.” Photograph taken by first author, November 2011 at the Reuben H. Fleet Science Center in San Diego, CA.

Math Moves! also includes numerous images connoting everyday activities and phenomena for the mathematics targeted by each exhibit. For instance, accompanying Shadow Fractions, a hands-on exhibit about the proportional relations involved in shadow projection, a suite of images showcasing the shadows of people as they walk down streets and public spaces intimates the mundane ubiquity of the exhibit’s subject (Figure 3).

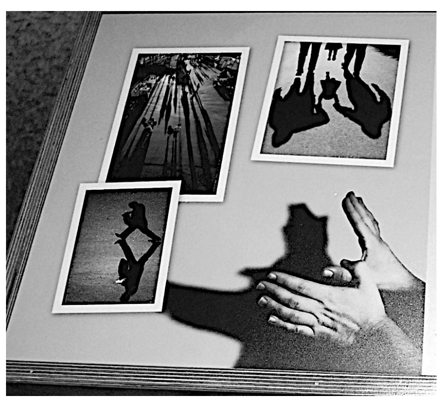

Figure 3. Panel from Math Moves!. Photograph taken by first author, October, 2012 at the Science Museum of Minnesota in St. Paul, MN.

Yet, the very impetus to portray this kind of mathematical everydayness is, paradoxically, partially necessitated by the specialized nature of the exhibits themselves. They are, after all, part of the museum’s proprietary offerings, inviting a highly designed palate of materials and technologies that one can't, in fact, encounter readily on the street. Thus, for instance, visitors to geometry playground don't climb on typical playground structures but, rather, on an immersive-scale gyroid or a constellation of tiled, stellated rhombic dodecahedra.

Moreover, amidst these multi-modal representations of the everyday, one can also find design elements that seem to exoticize mathematics rather than assert its ubiquity. Geometry Playground's Geometry Garden is perhaps the most vivid example of this (Figure 4). Alluding to early natural-history-museum display practices, Geometry Garden presents a "cabinet of geometric curiosities" (language used on exhibit texts and website) that includes a diverse assortment of natural specimens and sculptures. Arranged within a grid of glass encasements, spiraling seashells, crocheted hyperbolic surfaces, knitted Klein bottles, and woven polyhedra are assembled as an untouchable assortment of exotic mathematical oddities. Note that the cabinet of geometric curiosities prevents visitors from touching or manipulating the exhibited items, which is a tacit enactment of the "hands-off" visual pedagogy we referred to in the previous section.

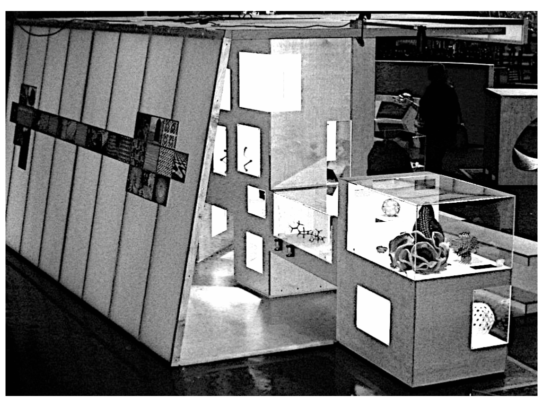

Figure 4. Geometry Playground's "cabinet of geometric curiosities." Photo found at https://pbs.twimg.com/media/Cmyb5GrUMAAuHR9.jpg, July 30, 2017.

Taking these examples together, mathematics is portrayed as both exotic and ubiquitous, curious and mundane, specialized and everyday. This paradoxical confluence, we suggest, attenuates the dissensual force of the claim that sources of mathematical understanding are equally distributed across formal and informal worlds.

Dissensus 2: Mathematics and the Body

A second, related component of these mathematics exhibitions' dissensual designs relates to long-standing conceptualizations of mathematics as an incorporeal and immaterial knowledge domain (for critiques see, e.g., de Freitas & Sinclair, 2014; Hall & Nemirovsky, 2012; Lakoff & Núñez, 2000; Stevens, 2011). Historically, we might say that bodily sensation itself has been excluded from a dominant distribution of the mathematically sensible for centuries. Here we argue that part of the politics of contemporary mathematics exhibitions is to contest – always tenuously – the cleaving and subordination of embodied experience and materiality to a transcendent, incorporeal, and immaterial mathematics. In the designs of these exhibitions, we identify an affirmation of the body and its material interactions as genuine and equal constituents of an expansive mathematics. Rather than the "noise" that might detract or distract us from the "real" mathematics, bodies that have historically been "missing" (Stevens, 2011) from accounts of mathematics learning are rendered visible in numerous ways by the exhibitions. For brevity, we exemplify a few select components of what we describe as an embodied aesthetics, including some of the more paradoxical aspects of that aesthetics.

Both Geometry Playground and Math Moves! are pervaded with photographs of grasping, crawling, climbing, dancing, cartwheeling, bicycling, and running bodies. A Geometry Playground graphical panel, for example, displays several photographic images of hands, feet, fingers, and whole bodies in action (see Figure 5).

Figure 5. Graphical panel from Geometry Playground. Text reads, "Many games rely on an understanding of space — knowing where to put your hands, feet, and fingers, or judging angles and distances." Photograph taken by first author, November 2011 at the Reuben H. Fleet Science Center in San Diego, CA.

At the center of the photographs, text defines understanding space as "knowing where to put your hands, feet, and fingers," lending epistemic import to the physical activities of climbing rocks, swaying on monkey bars, and playing cat's cradle or four square. At Math Moves!, an exhibit involving motion detection and position-time graphs displays bodies running, bicycling, swimming, and figure skating (see Figure 6).

Figure 6. Graphical panel from Math Moves!. Photograph taken by first author, October 2012 at the Science Museum of Minnesota in St. Paul, MN.

Looking beyond these textual and graphical narratives to the exhibit components themselves, we find an even more direct elevation of acting, sensing bodies with respect to mathematical knowing. Sometimes knowing bodies are elevated in a literal sense, as with some of the large, climbable structures found in Geometry Playground, such as the exhibition's signature piece, the Gyroid (see Figure 7). Towering at larger-than-human scales and built to withstand the abuses of gripping hands and kicking feet, this tangible, material object invites visitors to make sense of the gyroid's unusual geometry through touching, clambering atop, and crawling through it.

Figure 7. The Gyroid, a climbable structure from Geometry Playground. Image taken from exhibition's official website: https://www.exploratorium.edu/geometryplayground/. September, 2015.

And a label accompanying Stack of Stars, another climbable geometric structure, states, "Climbing over, under, and around these shapes gives you a sense of their features and proportions," further articulating an embodied epistemology of geometric objects.

Math Moves! exhibits also implicitly affirm an equality of embodied experience and mathematical knowing through technologies that emphasize physical action and multi-sensoriality. For example, an exhibit called Sensing Ratios pairs haptic manipulations of two knobs along x- and y-axes with a dynamic, digital visual representation of a corresponding curve in the x-y plane, as well as dual auditory output of two theremin-inspired sounds whose pitches move in correspondence with the x- and y-positions. Thus, the exhibit is designed to allow a user simultaneously to feel, see, and hear a parametrically decomposed curve in the x-y plane.

Yet, if these design elements affirm the relevance of bodily experience to mathematical thinking and learning, they do so with paradoxical persistence of more consensual mathematical aesthetics. For instance, alongside the Freudenthal quote (see Dissensus 1), the entryway to

Geometry Playground also includes a quote from the American mathematician Jean Pedersen: "Geometry is a skill of the eyes and the hands *as well as of* the mind" (italics added). And another piece of introductory text reads: "Here you'll play with shapes and spaces. And while you're using your body, *you'll also be* using your mind" (italics added). While these quotations intimate a counter-Cartesian epistemology, they do so partially and complexly because the texts' grammatical constructions mobilize an additive logic that combines mind and body while preserving the distinction between them, simultaneously disrupting and maintaining a dominant distribution of the sensible partitioning mind from body. Elsewhere in the exhibition, one can find more mentalist epistemologies of mathematics subtly woven through. For example, embedded amidst another photographic collection of bodies in action shots, there is a definition that collapses spatial reasoning to mental imagery: "Making a mental picture of a shape – a kind of thinking called spatial reasoning – is critical in geometry." And, while Sensing Ratios, in principle, allows the user to hear and feel a circle, it also includes vision-centered and conventional mathematical representations, such as numeric frequencies and a gridded x-y plane (see Dissensus 3).

A second aspect of the embodied aesthetics of contemporary mathematics exhibitions is the way in which immersive designs incorporate whole bodies into mathematical objects and processes. For instance, at Geometry Playground's Distorted Chair (see Figure 8), the visitor's body is positioned both as a locus of epistemic access to the geometry of anamorphosis as well as a mathematical object itself. By stretching awkwardly out along an elongated chair that has been distorted according to principles of mirror projection, a visitor can view their reflection in the chair through a large cylindrical mirror that renders the image "normal" again.

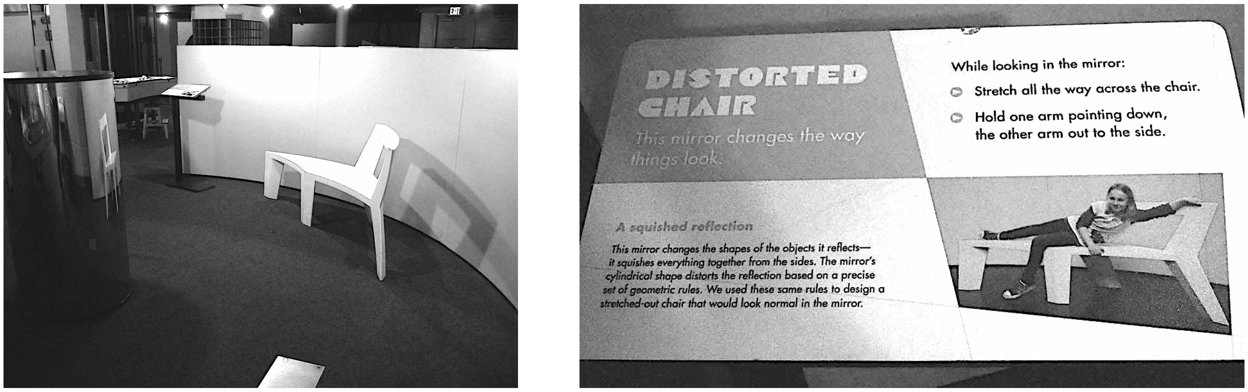

Figure 8. Distorted Chair and accompanying graphical panel from Geometry Playground. Text on top right reads: "While looking in the mirror: Stretch all the way across the chair. Hold one arm pointing down, the other arm out to the side." Photograph taken by first author, November 2011 at the Reuben H. Fleet Science Center in San Diego, CA.

Here, understanding the mathematics of anamorphic projection is designed as a combination of incommodious whole-body positioning and self-viewing. At the same time, in order to effect this arrangement, the body must become an object of mathematical transformation, forming part of the pre-image (or domain) of an anamorphic mapping while its reflection becomes part of the image (or range). Moreover, the combination of whole-body immersion and visual reflection at Distorted Chair provisionally topicalizes – or foregrounds – bodily experience and appearance by affording the incorporation of the visitor's body into part of the exhibit's public display. The Math Moves! exhibit, Comparing Forms, examined in a subsequent section, also has this quality.

Yet, as immersive aesthetics provisionally incorporate bodies into a corporeal ontology of mathematical objects, they sometimes do so in a way that sometimes appears more to code bodies with a more dominant, consensus mathematics. In other words, while embodied experience is in some ways being re-imagined as part of a more expansive mathematics, in other ways, a more orthodox mathematics is sometimes layered over the body. In some cases, for example, mathematics exhibits have a way of mathematizing bodies by rendering their forms and motions subject to calculating scrutiny and graphical analysis. This positioning of the body as an object of a more established form of mathematical inquiry is salient in the visual tableau presented by the Handling Calculus exhibit, Slope Rider (Figure 9).

Figure 9. Slope Rider from Handling Calculus. Image obtained by first author from exhibition development staff, July, 2015.

Here, a steel Cartesian grid labeled with x- and y-axes encases a sculpted, human-scale replica of a moving, sensing body, modeled after a child. Inviting a mathematical analysis of the body's movements, the exhibit layers a canonical mathematical representation over the child's physique. Thus, while embodied experience is sometimes designed to push against a mathematical consensus, at other times there seems to be a countervailing push of consensus mathematics back onto the body, a paradoxical set of dynamics that takes part in the dissensuality of body-based design aesthetics.

Dissensus 3: The Status of Mathematical Formalisms

In a consensual mathematical aesthetics, the paradigmatic expressions of mathematics are equations, chains of signs, geometric diagrams, graphs of different kinds, and many other representational formalisms. As it is with music scores or medical x-rays, these expressions are typically considered incomprehensible for the uninitiated, although recognizable as being "mathematical." They play an important role as alienating barriers for those who see themselves as "non-math" people and serve as a litmus test to identifying as encultured in at least some mathematical communities.

In the mathematics education literature, discussions of the development of understanding of symbolic and other representational conventions have historically included deficit characterizations of children as riddled with “cognitive obstacles” (Herscovics, 1988) and misconceptions (e.g., MacGregor & Stacey, 1997). An example is the problem of the “Students and Professors” which has been extensively studied (Clement et al, 1981). The problem is usually stated as follows:

> Write an equation using the variables S and P to represent the following statement: "There are six times as many students as professors at this university." Use S for the number of students and P for the number of professors.

The typical error is that students write ‘6S = P’ instead of the correct equation ‘6P = S’. This error is reported to be “resistant to remediation” (Rosnick & Clement, 1980).

Over the past several decades, researchers have increasingly argued that these challenges may result, in part, from “symbols-first” instructional approaches that introduce symbolic formalisms too “early,” before learners have had the opportunity to develop conceptual meaning for them (e.g., Sherman, Walkington, & Howell, 2016). To address this, approaches such as “concreteness fading” (e.g., Nathan, 2012) and Realistic Mathematics Education (e.g., Gravemeijer & Doorman, 1999), while differing in details, share in common an emphasis on “contextual” sense-making familiar to learners, as a grounding phase for the development of symbolic formalisms through the processes of guided discovery and openness to non-standard formalisms invented by learners.

This approach can be illustrated by Figure 10 that emphasizes progressively “mathematizing” experientially real scenarios toward increasingly formal notation (https://rme.org.uk/what-is-rme/about-rme/). The figure depicts an iceberg with a mass of informal experiences underwater and a small tip overwater "distilling up" the amorphousness of those experiences into mathematical notations.

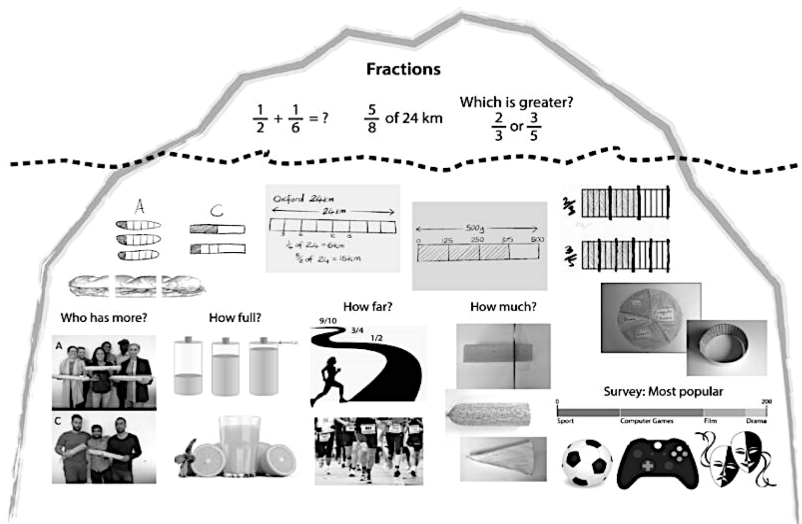

Figure 10. "Iceberg" Metaphor for the Topic of Fractions from Realistic Mathematics Education. From "How does RME do mathematics differently?" by Realistic Mathematics Education at Manchester Metropolitan University, 2021 (https://rme.org.uk/what-is-rme/about-rme/). Reprinted with permission.

We suggest that a form of dissensus potentially introduced by museums can be seen as tilting the iceberg on its side to produce a horizontal distribution of the mathematically sensible, dethroning formal notations as housing mathematics itself, and releasing them as components in a broader world of mathematical practices. The dissensual claim promoting inclusiveness is that the mastering of specialized mathematical vocabularies and notations, while useful and powerful, is only one aspect of mathematical understanding, not unlike reading music scores for a musician.

This dissensus manifests itself in the ambivalent presence of symbolic formalisms and mathematical terms within the exhibitions in this study. Furthermore, this aspect of dissensus includes ongoing debates about the degree to which a recognizable mathematics should be made explicit through labels, exhibition names, and other design choices (Gyllenhaal, 2006; Pattison et al., 2012). For example, while Geometry Playground, Math Moves!, and Handling Calculus all include conventional mathematical vocabulary, other exhibition titles, such as Design Zone, have eschewed explicit naming.

In all the mathematics exhibitions considered here, mathematically specialized notations have a sparse but definitive presence. For instance, at first approach, Geometry Playground's exhibit, Polyhedra (see Figure 11), invites a hands-on, symbol-free encounter with the mathematical objects for which it is named. The exhibit has a cylindrical architecture studded with polyhedra, including the Platonic solids as well as other stellated or truncated forms.

Figure 11. Polyhedra at Geometry Playground. Photograph taken by first author, November 2011 at the Reuben H. Fleet Science Center in San Diego, CA.

Built to last in colored metal, and freely rotatable along a vertical axis, the ineluctable materiality of the polyhedra invites a haptic exploration of their geometries. Viewed from the *outside* of the exhibit, the polyhedra are otherwise unadorned, embedded within graphics-free panels that line the exhibit's surface. Yet, quasi-hidden within the exhibit's cylindrical architecture is a complex layer of formal-symbolic exegesis. Standing *inside* Polyhedra, a visitor can see not only the metallic, manipulable geometric objects, but also an intricate web of inscription detailing their technical names, counting their faces and vertices, and charting their inter-relations (Figure 12).

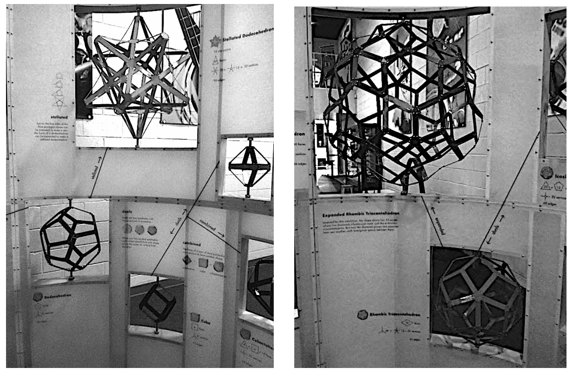

Figure 12. Inside Polyhedra. Photograph taken by first author, November 2011 at the Reuben H. Fleet Science Center in San Diego, CA.

And, to the left of a large, blue icosahedron, the exhibit displays Euler's polyhedral formula, F + V - E = 2, along with an explanation of the formula and a worked example for the case of a cube. It is not just the presence of these inscriptions in Polyhedra that interests us here, but rather their hidden-ness, the way in which they are halfway present. Tucked behind the exhibit's cylindrical walls – and, hence, available from only a very particular vantage – the equations, formulae, and technical nomenclature take on an ambivalent quality.

Math Moves! similarly includes a handful of graphical images labelled as "Math Moments," such as the equation-based statements of proportionality shown in a label accompanying one of the stations (see Figure 13).

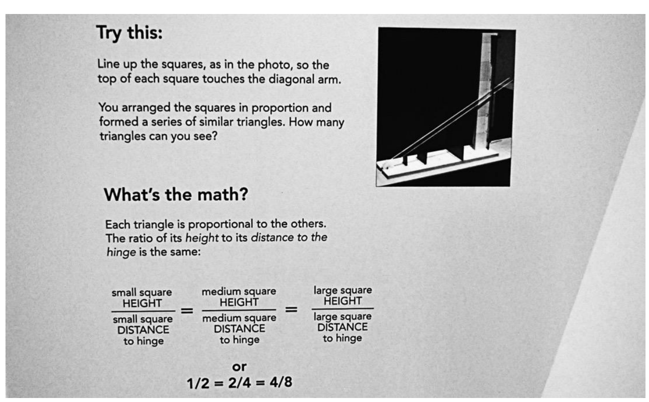

Figure 13. Label for a Math Moments station called "Triangle Math." Photograph taken by first author, October 2012 at the Science Museum of Minnesota in St. Paul, MN.

Situated within the sensual landscape of the exhibition's body-based and symbol-sparse technologies, this label explicitly locates mathematics ("What's the math?") through two sets of variable and numeric equations. Together, formal-symbolic text and its encompassing sensual, non-symbol-centered context create a kind of dissensual tableau, in which symbolic formalisms are noted but only in relatively marginal corners and small specialized spaces.

Discussion

When people enter an exhibition about calculus, geometry, or ratio and proportion, they encounter complex images, suggestions, and proposals for what counts as mathematics, where and when mathematics might take place, and who can be seen as practicing mathematics. Treating such spaces as alternative routes to "the same" mathematics (e.g., valued by traditional mathematics curriculum or dominant consensus) risks overlooking how mathematics exhibitions might contribute to a more expansive, creative, and inclusive mathematics education, as well as the challenges, contradictions, and paradoxes educators might face in charting an expansive agenda for museum-based mathematics education. In lieu of viewing mathematics exhibitions as neutral purveyors of fixed mathematical content, in this study we provided an interpretation of the curriculum of these spaces in terms of the complex, subtle, and often-tenuous suggestions they offer about the nature of mathematics and mathematical sense-making.

Through an analysis of these environments framed by Rancière's (2000, 2010) conceptualization of politics and aesthetics, we characterized early 21st century mathematics exhibitions as being in a state of dissensus. This dissensus includes a multi-dimensional and paradoxical mix of alternative and familiar mathematical aesthetics. We identified an aesthetics emphasizing everyday ubiquity, bodily activity and sensuality, and informal sense-making. At the same time, weaving through and sometimes interrupting this aesthetics, we argued, is a countervailing emphasis on more consensual notions of mathematics as esoteric, abstract and immaterial, and formal-symbolic. We note that the three aesthetic dimensions delineated here are deeply interrelated. For example, graphical evocations of everydayness intersect, to a large extent, with the foregrounding of bodies in action.

Our analysis briefly contextualized the exhibitions in this study within a general historical turn toward interactivity among science museums. However, the nature of "interactivity" across the four science museums in which Math Moves! is installed varies a great deal on close examination. The Science Museum of Minnesota, for instance, typically includes a mix of "hands-on" and "specimens-based" design styles while Explora is often considered a more radically interactive environment with a different set of institution-wide aesthetics. More nuanced attention to specific institutional contexts could further refine understandings of the politics and aesthetics of mathematics exhibitions.

Broadly, through this analysis we hoped to show how the aesthetics of mathematics exhibitions can also be seen as having political dimensions in that they contribute to distributions of the mathematically sensible in society. Museum mathematics efforts have often described themselves as expanding how the public views and defines mathematics. A close examination, however, of three major mathematics exhibitions reveals a more complex and contradictory picture, in which dominant and alternative forms of mathematics are co-present. Although our study represents a limited subset of recent and current mathematics exhibitions, the analysis suggests that they convey subtle messaging about the nature of mathematics.

Museum-based mathematics contains political and aesthetic dimensions that can disrupt or reify what society counts as mathematics. At the same time, we note that contradiction need not necessarily carry negative valence but, rather, have the potential to be generative for visitors to mathematics exhibitions. We wonder whether there might be value in instructional designs that leverage the dissensuality of mathematics exhibitions to make deliberate space for students to have a say in what can, should, or might count as mathematics. Echoing Trofanenko (2006), perhaps “an education in the museum needs to be an education *about* the museum” (p. 61, italics in original), an opportunity to critically notice and reflect on how an exhibition portrays its subject matter.

Indeed, our ethnographic studies of school field trips to Math Moves! suggest that the exhibition has the potential to engage children in generative forms of dissensus around what counts – or should count – as mathematics (Author). For example, during focus-group interviews, children commented that the exhibition had unexpected, unusual, or surprising features. When asked for general impressions from the trip, a 5th-grader commented that the exhibits were “oddball.” A 6th-grader stated, “I didn’t really think it would be like that.” When asked to elaborate, the student said, “I kinda thought it would be like show problems kind-of, and not have where you can s- like spin the wheel and you can walk and everything and all the shadows and stuff like - I didn’t think it would be that like hands-on and stuff.” Thus, although the exhibition was installed in a science center in which “hands-on” activities are arguably a norm, the emphasis on bodily engagement and diverse materials in a mathematics exhibition was still treated as unexpected. The students in this study also treated experiences of “fun” in the exhibition as unexpected or, in some cases, an aspect of the visit that didn’t fit with standard notions of what it means to do mathematics. For instance, one 5th-grade participant stated that “it was hard to tell that you were doing math because it was more fun.” Students brought up this contrast between mathematics and having fun on several occasions, raising for us important questions about the relatively more affective or emotional components of mathematical consensus and dissensus and how these might play out within mathematics exhibitions. Although a more complete analysis of this data is outside of the scope of the present study, we acknowledge that visitor voices like these are also an important part of understanding the politics and aesthetics of mathematics exhibitions and we hope to expand on this important issue in further related work.

Another important lacuna in our analysis is that we have not examined these designs with respect to issues of (dis)ability. We suggest that future work should examine the politics and aesthetics of mathematics exhibition design – such as multi-sensoriality and images of (a)typical bodies – with respect to evolving cultural constructions of mathematical (dis)ability. Our analysis has also disattended to constructions of race and gender in mathematics exhibitions, perhaps in the same ways that these spaces may tend to produce bodies as anonymous and universal. In future work we hope to attend to the ways in which "embodied designs" address – or deny – how bodies are gendered and racialized.

While our analysis has focused on mathematics, we suggest, by extension, that there is also value in curriculum studies that attend to the politics and aesthetics of exhibitions pertaining to other subjects and disciplines as well. In any discipline there are consensual and dissensual perspectives that can be traced or recognized in corresponding museum spaces. These kinds of museum dynamics have been studied in relation to topics that are politically volatile, such as race, migration, injustice, or human rights, but we hope for this paper to contribute a more encompassing, and perhaps dissensual viewpoint, according to which distributions of the sensible are, in every discipline, contested fields of political action sensitive to the nuances of ongoing historical events.

Finally, there have been several new developments in museum mathematics learning environments – both in the US and internationally – subsequent to the focus of analysis in this paper. For example, the Imaginary organization (Matt 2017), headquartered in Germany, has been promoting and supporting hundreds of mathematical exhibitions all over the world. The development of Mathina – an "Interactive storybook between mathematics and fantasy" (https://mathina-hub.netlify.app/) – is currently ongoing and available for formal and informal education settings. New mathematics museums have opened (e.g., Mathematics Museum of Catalunya, in Barcelona, Spain) or are in development (e.g., MathsCity in Leeds, UK). Mathemáticas en la Calle (Mathematics in the Streets) is an initiative advanced by the Spanish Federation of the Associations of Mathematics Teachers, sponsoring mathematics fairs in different Spanish cities (https://fespm.es/index.php/category/actividades/matematicas-en-la-calle/). Different styles of street mathematics are being explored, some of which are based on geolocation (https://momath.org/graph-the-grid/).

We wonder how expanding our attention internationally while following these newer developments might enrich our understanding of the forms of dissensus in the mathematics exhibitions analyzed in this article. Moreover, what kinds of new forms of mathematical dissensus might be emerging? And what forms of dissensus can we see if we expand our attention beyond museums to other designed out-of-school mathematics spaces such as the mathematical garden in Stockholm (https://www.tekniskamuseet.se/en/discover/exhibitions/the-mathematical-garden/) or the mathematics-in-the-streets movements in Spain, Finland, Hungary, New Zealand, and others? And how can these shifting dimensions of mathematical politics and aesthetics continue to inform our field's efforts to expand what counts as mathematics in ways that are more just, equitable, inclusive, and creative?

References

Adams, C. J. (2013). Museums open doors to informal math learning. *Education Week*. Retrieved from http://www.edweek.org/ew/articles/2013/06/05/33mathmuseum_ep.h32.html

Alexander, E. P., & Alexander, M. (2008). *Museums in motion: An introduction to the history and functions of museums*. Lanham, MD: AltaMira Press.

Allison-Bunnell, S. W. (1998). Making nature "real" again: natural history exhibits and public rhetorics of science a the Smithsonian Institution in the early 1960s. In S. Macdonald (Ed.), *The Politics of Display: Museums, Science, Culture* (pp. 77–97). London: Routledge.

Anderson, A. V. (2001). *Mathematics in science centers*. Washington, D. C.: Association of Science-Technology Centers.

Appelbaum, P., & Clark, S. (2001). Science! Fun? A critical analysis of design/content/evaluation. *Journal of Curriculum Stuies, 33*(5), 583 - 600.

Bang, M., Warren, B., Rosebery, A. S., & Medin, D. (2012). Desettling expectations in science education. *Human Development*, *55*, 302–318.

Barry, A. (1998). On interactivity: consumers, citizens, and culture. In S. Macdonald (Ed.), *The Politics of Display: Museums, Science, Culture* (pp. 98–117). London: Routledge.

Beery, T., Fischer, N., Greenberg, A., & Polendo, A. (2013). Occupy museums as public pedagogy and justice work. *Journal of Curriculum Theorizing, 29*(2), 230 - 239.

Bingham, C., & Biesta, G. (2010). The Figure of the Child in Jacques Rancière and Paulo Freire. In *Jacques Rancière: Education, Truth, Emancipation* (pp. 49–72). New York, NY: Continuum.

Carraher, T. N., D. W. Carraher, and A. D. Schliemann. (1985). Mathematics in the streets and in schools. *British Journal of Developmental Psychology*, *3*(1), 21–29.

Clement, J., Lockhead, J., & Monk, G. (1981). Translation difficulties in learning mathematics. *American Mathematical Monthly, 88*(4), 286-290.

Conn, S. (2011). Science museums and the culture wars. In S. Macdonald (Ed.), *A Companion to Museum Studies* (pp. 494–508). West Sussex: Wiley-Blackwell.

Cooper, S. (2011). An exploration of the potential for mathematical experiences in informal learning environments. *Visitor Studies*, *14*(1), 48–65.

Corbin, J., & Strauss, A. (2014). Basics of qualitative research: Techniques and procedures for developing grounded theory. Sage publications.

Crowley, V., & Matthews, J. (2006). Museum, memorial and mall: postcolonialism, pedagogies, racism and reconciliation. *Pedagogy, Culture & Society, 14*(3), 263 - 277.

Dancstep, T., Gutwill, J. P., & Sindorf, L. (2015). Comparing the Visitor Experience at Immersive and Tabletop Exhibits. *Curator: The Museum Journal*, *58*(4), 401–422. https://doi.org/10.1111/cura.12137

Dancu, T., Gutwill, J. P., & Hido, N. (2011). Using iterative design and evaluation to develop playful learning experiences. *Children, Youth and Environments*, *21*(2), 338–359.

Dancu, T., Gutwill, J. P., & Sindorf, L. (2009). Geometry Playground Pathways Study. *Geometry Playground Pathways Study*. Retrieved from San Francisco Exploratorium Website: http://www.exploratorium.edu/partner/pdf/Geometry_Playground_Pathways.pdf

Danilov, V. J. (1974). Mathematica. *Museum International*, *26*(2), 86-98.

de Freitas, E., & Sinclair, N. (2014). *Mathematics and the Body: Material Entanglements in the Classroom*. New York, NY: Cambridge University Press.
Dietiker, L. (2015). What Mathematics Education Can Learn from Art: The Assumptions, Values, and Vision of Mathematics Education. *Journal of Education*, *195*(1).
Eames Office. (2015 – 2021). Mathematica: a World of Numbers…and Beyond. https://www.eamesoffice.com/the-work/mathematica/ (Accessed February 1, 2022).
Esmonde, I. (2013). What counts as mathematics when "we all use math everyday"? A look at NUMB3RS. In B. Bevan, P. Bell, R. Stevens, & A. Razfar (Eds.), *LOST Opportunities: Learning in Out-of-School Time* (pp. 49–63). New York, NY: Springer.
Evans, E. M., Mull, M. S., & Poling, D. A. (2002). The authentic object? A child's-eye view. In S. G. Paris (Ed.), *Perspectives on object-centered learning in museums* (pp. 55–77). Mahwah, NJ: Lawrence Erlbaum Associates.
Falk, J., & Dierking, L. D. (2000). *Learning from museums: Visitor experiences and the making of meaning*. Lanham, MD: Altamira Press. Retrieved from files/1177/Falk and Dierking - 2000 - Learning from museums Visitor experiences and the.html
Friedrich, D. (2011). The memoryscape in Buenos Aires: Representation, memory, and pedagogy. *Cultural Studies, 27*(3), 171 - 189.
Furo, A. (2011). What is in a voice? A pedagogy of voice for museums. *Journal of Curriculum Theorizing, 27*(1), 104 - 116.
Gravemeijer, K., & Doorman, M. (1999). Context problems in realistic mathematics education: A calculus course as an example. *Educational Studies in Mathematics, 39*(1), 111 - 129.
Guberman, S. R., Flexer, R. J., Flexer, A. S., & Topping, C. L. (1999). Project Math-Muse: Interactive mathematics exhibits for young children. *Curator*, *42*(4), 285–298.
Gutiérrez, R. (2017). Living mathematx: Towards a vision for the future. *Philosophy of Mathematics Education Journal, 32.*
Gyllenhaal, E. D. (2006). Memories of math: Visitors' experiences in an exhibition about calculus. *Curator*, *49*(3), 345–364.
Hall, R., & Nemirovsky, R. (2012). Introduction to the special issue: Modalities of body engagement in mathematical activity and learning. *Journal of the Learning Sciences*, *21*(2), 207–215.
Harper, R. L. S. (2013). Shape of the wound: Restorative justice in potential spaces: A review of "Opening the Black Box: The Charge is Torture" (Exhibition, Sullivan Galleries, The School of the Art Institute of Chicago, 2012). *Journal of Curriculum Theorizing, 29*(2), 244 - 253.
Hein, G. E. (1998). *Learning in the museum*. New York, NY: Routledge.
Herscovics, N. (1988). Cognitive obstacles encountered in the learning of algebra. In S. Wagner & C. Kieran (Eds.), *Research issues in the learning and teaching of algebra* (pp. 60-86). Reston, VA: National Council of Teachers of Mathematics.
Hoyles, C., Noss, R., & Pozzi, S. (2001). Proportional reasoning in nursing practice. *Journal for Research in Mathematics Education, 32*, 4 - 27.
Hooper-Greenhill, E. (2007). *Museums and education: Purpose, pedagogy, performance*. New York, NY: Routledge. Retrieved from files/1175/Hooper-Greenhill - 2007 - Museums and education purpose, pedagogy, performa.html
Kelton, M. L. (2015). *Math on the move: A video-based study of school field trips to a mathematics exhibition*. Dissertation, University of California, San Diego and San Diego State University.

Kelton, M. L. (2021). Mathematics learning pathways on a school fieldtrip: interactional practices linking school and museum activity. *Visitor Studies, 24*(2), 220 - 242.

Kelton, M. L., & Ma, J. Y. (2020). Assembling a torus: Family mobilities in an immersive mathematics exhibition. *Cognition and Instruction, 38*(3), 318 – 347.

Kelton, M. L., Ma, J. Y., Rawlings, C., Rhodehamel, B., Saraniero, P., & Nemirovsky, R. (2018). Family meshworks: Children's geographies and collective ambulatory sense-making in an immersive mathematics exhibition. *Children's Geographies, 16*(5), 543-557.

Lakoff, G., & Núñez, R. (2000). *Where mathematics comes from: How the embodied mind brings mathematics into being*. New York, NY: Basic Books.

Lidchi, H. (1997). The poetics and politics of exhibiting other cultures. In S. Hall (Ed.), *Representation: Cultural Representations and Signifying Practices* (pp. 151–222). London: Sage/Open University.

Macdonald, S. (1995). Consuming science: public knowledge and the dispersed politics of reception among museum visitors. *Media, Culture & Society*, *17*(1), 13–29.

Macdonald, S. (1998a). Supermarket science? Consumers and "the public understanding of science." In S. Macdonald (Ed.), *The Politics of Display: Museums, Science, Culture* (pp. 118–138). London: Routledge.

Macdonald, S. (Ed.). (1998b). *The Politics of Display: Museums, Science Culture*. London: Routledge.

Macdonald, S. (2011). Expanding museum studies: An introduction. In S. Macdonald (Ed.), *A Companion to Museum Studies* (pp. 1–12). West Sussex: Wiley-Blackwell.

MacGregor, M., & Stacey, K. Students' understanding of algebraic notation: 11-15. *Educational Studies in Mathematics, 33*(1), 1 - 19.

Matt, A.D. (2017). IMAGINARY - a how-to guide for math exhibitions. *Notices of the AMS, 64*(4), 368 - 374.

McDermott, R. P. (2013). When is mathematics, and who says so?: A commentary on Part I. In B. Bevan, P. Bell, R. Stevens, & A. Razfar (Eds.), *LOST Opportunities: Learning in Out-of-School Time* (pp. 85–91). New York, NY: Springer.

McDermott, R. P., & Webber, V. (1998). When is math or science. In J. G. Greeno & S. Goldman (Eds.), *Thinking practices in mathematics and science learning* (pp. 321–339). Mahwah, NJ: Lawrence Erlbaum.

Mokros, J. (2006). *Math momentum in science centers*. Cambridge, MA: TERC.

Nathan, M. J. (2012). Rethinking formalisms in formal education. *Educational Psychologist, 47*(2), 125-148.

National Research Council. (2009). *Learning science in informal environments: People, places, and pursuits*. Washington, DC: National Academy Press.

Nemirovsky, R., & Gyllenhaal, E. D. (2006). Handling Calculus: Graphing motion to understand math. *ASTC Dimensions*, *January/February*, 13–14.

Nemirovsky, R., Kelton, M. L., & Civil, M. (2017). Toward a vibrant and socially significant informal mathematics education. In J. Cai (Ed.), *Compendium for Research in Mathematics Education* (pp. 90–101). Reston, VA: National Council of Teachers of Mathematics.

Nemirovsky, R., Kelton, M. L., & Rhodehamel, B. (2012). Gesture and imagination: On the constitution and uses of phantasms. *Gesture*, *12*(2), 130–165.

Nemirovsky, R., Kelton, M. L., & Rhodehamel, B. (2013). Playing mathematical instruments: Emerging perceptuomotor integration with an interactive mathematics exhibit. *Journal for Research in Mathematics Education*, *44*(2), 372–415.

Nespor, J. (2000). School field trips and the curriculum of public spaces. *Journal of Curriculum Studies, 32*(1), 25 - 43.

Pattison, S. A., Ewing, S., & Frey, A. K. (2012). Testing the Impact of a Computer Guide on Visitor Learning Behaviors at an Interactive Exhibit. *Visitor Studies*, *15*(2), 171–185. https://doi.org/10.1080/10645578.2012.715010

Rancière, J. (2000). *The Politics of Aesthetics: The Distribution of the Sensible*. (G. Rockhill, Trans.). London: Bloomsbury.

Rancière, J. (2004). *The Philosopher and His Poor*. (A. Parker, Ed., J. Drury, C. Oster, & A. Parker, Trans.). Durham, NC: Duke University Press.

Rancière, J. (2009). *The Emancipated Spectator*. (G. Elliott, Trans.). London, UK: Verso.

Rancière, J. (2010). *Dissensus: On politics and aesthetics*. (S. Corcoran, Trans.). London, UK: Continuum Press.

Rosnick, P., & Clement, J. (1980). Learning without understanding: The effect of tutoring strategies on algebra misconceptions. *Journal of Mathematical Behavior, 3*(1), 3 - 28.

Saxe, G. B. *Culture and Cognitive Development: Studies in Mathematical Understanding.* Hillsdale, NJ: Lawrence Erlbaum Associates, 1991.

Sherman, M. F., Walkington, C., & Howell, E. (2016). A comparison of symbol-precedence view in investigative and conventional textbooks used in algebra courses. *Journal for Research in Mathematics Education, 47*(2), 134 - 146.

Sonderegger, R. (2012). Negative versus affirmative critique: on Pierre Bourdieu and Jacques Rancière. In *Conceptions of critique in modern and contemporary philosophy* (pp. 248-264). Palgrave Macmillan, London.

Stevens, R. (2011). The missing bodies of mathematical thinking and learning have been found. *Journal of the Learning Sciences*. https://doi.org/10.1080/10508406.2011.614326

Stevens, R. (2013). Introduction: What counts as math or science? In B. Bevan, P. Bell, R. Stevens, & A. Razfar (Eds.), *LOST Opportunities: Learning in Out-of-School Time* (pp. 3–6). New York, NY: Springer.

Sutterfield, C. (2006). Finding the Math: A Math Momentum sampler. *ASTC Dimensions*, *January/February*, 5–8.

Tesler, P. (2001 – 2002). Mathematica: a World of Numbers…and Beyond: A classic exhibition by Charles and Ray Eames. https://www.exploratorium.edu/mathematica/ (accessed February 1, 2022).

Trofanenko, B. (2006). Interrupting the gaze: On reconsidering authority in the museum. *Journal of Curriculum Sutdies, 38*(1), 49 - 65.

Wood, E., & Latham, K. F. (2011). The thickness of things: Exploring the curriculum of museums through phenomenological touch. *Journal of Curriculum Theorizing, 27*(2), 51 - 65.

Wright, T., & Parkes, A. (2015). Exploring connections between physical and mathematical knowledge in science museums. *Informal Learning Review*, *131*, 16–21.