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Towards Fourth-Generation Science Museums: Changing Goals, Changing Roles

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Abstract Once dominated by a focus on collecting and preserving, and later communicating science through hands-on experiences, science museums are slowly reshaping their identities and purposes to explicitly include and promote active citizenship, social responsibility, engagement with complex science and technology issues, and agency. Informed by progressive views of scientific literacy and dialogic and participatory models of communication, science museums are beginning to re-imagine their spaces and practices to embrace broader goals. This theoretical paper explores and discusses the changing roles and identities of these institutions through the emergence of what we identify as *fourth-generation science museums* and their six defining drivers (Pedretti & Navas Iannini, 2020). We argue science museums can become places that (1) embrace change and transformation; (2) promote productive struggle; (3) develop allyship; (4) foster empathy; (5) support epistemic democracy; and (6) act as a hybrid third space.

Résumé Autrefois axés essentiellement sur la collecte et la préservation, puis sur la communication de la science par le biais d'expériences pratiques, les musées scientifiques remodèlent lentement leurs identités et leurs objectifs pour inclure et promouvoir explicitement la citoyenneté active, la responsabilité sociale, l'engagement dans des questions scientifiques et technologiques complexes et l'agentivité. Éclairés par une vision progressiste de la culture scientifique et des modèles dialogiques et participatifs de communication, les musées scientifiques commencent à réimaginer leurs espaces et leurs pratiques pour adopter des objectifs plus larges. Cet article théorique explore et discute les rôles et identités changeants de ces institutions à travers l'émergence de ce que nous identifions comme des musées des sciences de quatrième génération et leurs six moteurs déterminants (Pedretti & Navas Iannini, 2020). Nous soutenons que les musées scientifiques peuvent devenir des lieux qui : 1) accueillent le changement et la transformation ; 2) promeuvent l'effort productif ; 3) établissent d'alliances ; 4) favorisent l'empathie ; 5) soutiennent la démocratie épistémique ; et 6) agissent comme un troisième espace hybride.

Keywords Science museums · Exhibitions · Scientific literacy · Science communication · Citizenship · Social responsibility

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Introduction

Science museums continue to ask, "who are we", "who do we serve", and "how do we serve"? These are important questions, and central to the larger narrative of museum practices and goals, particularly in these "troubled times" (Janes & Sandell, 2019) of environmental degradation, food security issues, digital revolutions, fake news, pandemics, and competing political discourses. This theoretical paper explores and discusses the changing roles and identities of these institutions through the emergence of *fourth-generation science museums*—a trend committed to criticality, social responsibility, and civic agency.

Science museums have been with us for centuries and have been visited by millions worldwide. They are places in which different publics come to explore, play, observe, discover, and perhaps learn some science along the way. Over time, science museums have reinvented themselves, shifting and/or expanding their purposes and functions, and moving through different generations (see Amodio, 2013; Friedman, 2010; McManus, 1992). Once dominated by a focus on collecting and preserving, and later communicating science through hands-on experiences (Bradbourne, 1998), science museums are slowly reshaping their identities and social goals to explicitly include and promote active citizenship, social responsibility, engagement with complex science and technology issues, and agency (Achiam & Sølberg, 2017; Barrett & Sutter, 2006; Cameron, 2005; Hine & Medvecky, 2015; Janes, 2009; Koster, 1999; Pedretti & Navas Iannini, 2018; Quistgaard & Kahr-Højland, 2010; Stocklmayer et al., 2010). Interestingly, this reshaping of science museums echoes similar calls for reforms in formal science education settings (e.g., Bencze, 2017; Hodson, 2011; Roth & Barton, 2004).

In a time when science museums are questioning (and being questioned about) their relevance and purpose (see, for example, Dawson, 2014b; Feinstein, 2017; Janes & Sandell, 2019), it seems appropriate to revisit the landscape, and ask: What are the roles of science museums in contemporary societies? How (if at all) are they reframing themselves? What kinds of visitor experiences are being created to address changing roles and goals? And to what end? In this article, we focus specifically on the changing landscape and the development of what we identify as *fourth-generation science museums* (Pedretti & Navas Iannini, 2020). We subsequently describe six key drivers that characterize and scaffold this generation, and illustrate how institutional practices from around the world reflect these emerging ideas.

Context and Background

Our contribution to the *generations of science museums* framework (discussed in the writings of Amodio, 2013; Friedman, 2010; McManus, 1992) emerges from a research project dedicated to exploring the work of science museums, particularly, as they engaged with complex socio-scientific subject matter, criticality, and controversy (see, Pedretti & Navas Iannini, 2020).

To deepen our understandings about the social purposes and changing roles of these institutions, we conducted, over the past six years, several case studies of exhibitions positioned at the intersection of science, technology, society, environment, ethics, and politics (e.g., *Mental Health: Mind Matters*—St Paul, U.S.A., *Our World: BMO Sustainability Gallery*—Vancouver, Canada, and *Preventing Youth Pregnancy*—São Paulo, Brazil). At the core of the case studies were interviews with over 40 museum professionals from Brazil, Canada, Italy, Finland, U.S.A., and Zimbabwe, including directors, CEOs, curators, coordinators, educators, and facilitators. Additionally, while on site, we observed and interviewed hundreds of visitors engaged with these exhibitions. Alongside interviewing different museum communities, professionals, and visiting publics, we gathered documents and artefacts about displays and programs; took images and field notes; and collected exit comment cards and accounts written by audiences while attending the science museum. Empirical data and findings from these multiple case studies have been published elsewhere (see, for example, Navas Iannini & Pedretti, 2017; Pedretti & Navas Iannini, 2018, 2020; Pedretti, Navas Iannini & Atkinson, 2019; Pedretti, Navas Iannini & Nazir, 2018) and have informed our theorizing in this work.

Our data analyses involved iterative interactions with theory situated in the fields of scientific literacy (Bencze, 2017; Hodson, 2011), science communication (Bucchi, 2008; Bucchi & Trench, 2014; Davies & Horst, 2016), science museum studies (Aguirre, 2014; Cameron, 2005), and controversy (Macdonald, 1998; Meyer, 2009). This back and forth movement allowed us to map out the evolution of science museums leading to a *fourth generation* and its six key drivers (Pedretti & Navas Iannini, 2020)—the foci of this paper.

Generations of Science Museums: from Natural History to Interactive Science Centres

Through their long and rich history, science museums have functioned as mediators of relationships between the esoteric world of science and the everyday world of society. Borrowing from Amodio (2013), Friedman (2010), and McManus (1992), we built upon the notion of *successive generations* of science museums as a way to understand the historical evolution of these institutions and their roles and social purposes.

Traditionally, science museums emphasized cultural heritage through objects of intrinsic value (Caulton, 2006; Friedman, 2010; McManus, 1992; Rennie & McClafferty, 1996). The "curiosity cabinets" of the Renaissance period were essentially small and crowded galleries equipped with copious invertebrate and vertebrate collections, skulls, shells, plant taxonomies, rocks, fossils, and esoteric objects. Those spaces, often recreated in houses of men of wealth, were used to display private collections of all kinds of "rarities" (Friedman, 2010) and symbolized social status. These early first-generation science museums contained displays and collections reflecting Cameron's (1971) metaphor of the museum as "temple", places where objects are exhibited and visitors observe quietly, passively, and reverently.

This first generation also encompasses the proliferation of natural history museums during the seventeenth, eighteenth, and nineteenth centuries. Designed to educate what was then viewed as lay audiences, the primary goal of these institutions (and their exhibitions) was to contribute to scientific knowledge by creating object-rich exhibits, with pieces selected by curators from the research collection and the consequent inclusion of "authoritative information" about them (McManus, 1992, p. 160). The displays tended to showcase collections of specimens (often organized by taxonomic groups), artefacts such as instruments used in scientific research and, later, stunning dioramas (see, for example, the dioramas of the American Museum of Natural History). Amodio (2013) describes this first generation as one based on the principle of look-but-don't-touch, a principle still in use today by science museums around the world (see Figs. 1 and 2).

By the twentieth century, the goals of science museums began to shift from displaying specimens and collections, to (1) showcasing objects representing scientific and technological "progress" and (2) disseminating accessible information about these objects to visiting publics (McManus, 1992). These new developments prompted other educational functions of these institutions to come to the fore while their research function, although still very vigorous, slipped further out of public view. For McManus (1992), the second generation refers to science museums as "fully functional public institutions" (p. 160). Under this category, we include the establishment of applied science, technology, and industry museums.

Bucchi (2008) describes this second generation of science museums as a euphoric period of technical progress, with the aim of presenting and celebrating human achievements (see Fig. 3) and the positive contributions of science to the production of industrial objects. The corollary to this was the sub-text that these new machines and industrial objects would enhance our well-being and our future. The close association between science and technology was clinched, and with that, the idea that our lives would be better through machines and technological progress.

Third-generation science museums move away from the more traditional object-based approaches (McManus, 1992) and are typically concerned with presenting universal abstract laws, principles, and phenomena that transcend time and place (Macdonald, 1998; Quistgaard & Kahr-Højland, 2010). They tend to offer "a decontextualized scattering of interactive exhibits, which can be thought of as exploring stations

Fig. 1 Replica of a *Cabinet of Curiosities*, Ontario Science Centre, Canada. Courtesy of Ana Maria Navas Iannini

of ideas" (McManus, 1992, p. 164). Their origin, often linked to Oppenheimer's conceptualization of the Exploratorium museum of science (Amodio, 2013; Schiele, 2014), involves the possibility of providing first-hand experiences with scientific phenomena, generating opportunities for freedom and exploration of the space, and engaging with new ways of teaching and learning about science. In short, their primary goal is to present scientific concepts and experiences through hands-on displays (primarily addressed to children and youth) and to enhance public understanding of science (Friedman, 2010).

By the 1960s and 1970s, the interactive science centre, marked by its specialized hands-on galleries, was in full force and proliferating rapidly, particularly in countries such as Canada, U.S.A., and the U.K. The *Exploratorium* in San Francisco and the *Ontario Science Centre* in Toronto were two of the earliest examples of classic science centres dedicated to exploring scientific principles through hands-on exhibits. Today, there are interactive science centres all over the world.

Amodio (2013) observes that these latter science centres have focused on displaying "science 'in action'" (p. 30), while emphasizing emotion, wonder, and experiential content. New information and communication technologies (such as augmented reality) constitute the main interface between the exhibition and the visitor interaction. In this third-generation science museum, visitors tend to engage with exhibits by a combination of manipulating, reading, hearing, pushing, pulling, and generally using their senses (see Fig. 4). Information is carefully structured through engaging, interactive displays that respond to the visitor's

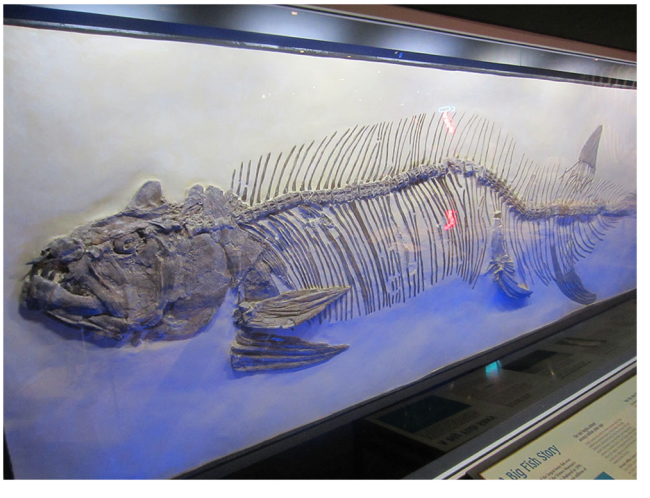

Fig. 2 *Fossil Specimen*, Science Museum of Minnesota, U.S.A. Courtesy of Ana Maria Navas Iannini

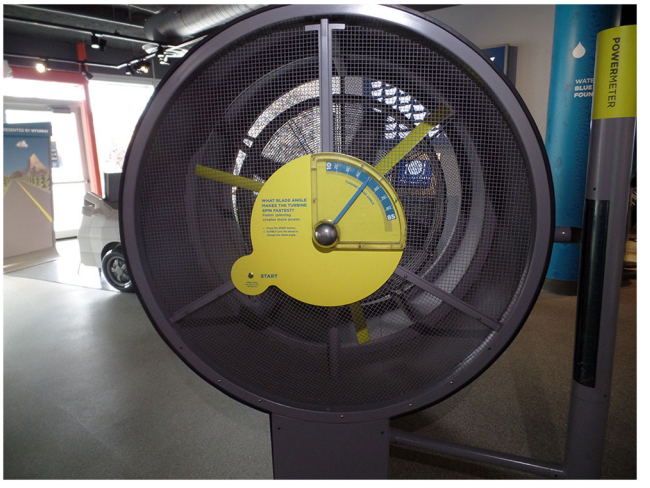

Fig. 3 *Turbine*, Science World, Canada. "… What blade angle makes the turbine spin fastest? Faster spinning creates more power". Courtesy of Ana Maria Navas Iannini

action and invite further response, as well as through hands-on exhibits that do not offer feedback to the visitor (Rennie & McClafferty, 1996).

This now brings us to more recent times and the advent of what we call the *fourth-generation* science museum (Pedretti & Navas Iannini, 2020). The following section discusses their evolution and why this shift is occurring.

Looking Forward: Fourth-Generation Science Museums

Described as a "a powerful paradigm shift" (Koster, 1999, p. 287), science museums began to see themselves as important players in a number of external scientific, social, cultural, and political contexts. In 2002, Pedretti noted the inclusion of criticality, the raising of social and environmental consciousness, and attention to socio-scientific issues—primarily through exhibitionary practices—as yet another major paradigm shift in the science museum world. The repurposing of science museums, their relevance, and mandates led us to identify a *fourth generation* (Pedretti & Navas Iannini, 2020). Informed by progressive views of scientific literacy, models of science communication that engage visitors in different ways, and the empirical work we conducted over the years, we argue that fourth-generation science museums are slowly

Fig. 4 Explora, Il Museo dei Bambini di Roma, Italy. Courtesy of Erminia Pedretti

emerging in different countries, in both private and public spheres, generating opportunities for re-imagining their spaces and practices while embracing broader goals and social roles.

Central to this fourth generation of science museums is a commitment to more progressive views of scientific literacy oriented to promoting responsible citizenship, critique, and agency. These kinds of commitments can be traced to a cluster of ideas that emerged in the science education research literature, often in the context of school science curriculum, including the following: nature of science perspectives; science, technology, society, and environment relationships; socio-scientific issues; and socially acute questions. These ideas are slowly finding their way into the museum world in direct response to the long-established practice of exhibiting uncontested facts and truths of science (Hine & Medvecky, 2015). For example, in international science education conferences, strands related to informal science education have emerged (e.g., The *Science Learning in Informal Context Strand*, within the National Association for Research in Science Teaching) allowing for interesting connections and academic discussions between museum professionals and science education researchers. Additionally, we note the rise of informal science education journals where conversations about formal and informal science education are taking place (consider the *International Journal of Science Education Part B*, originating from the *International Journal of Science Education*, or the special issue dedicated to *Informal Learning in Science* [2006] in the *Canadian Journal of Science, Mathematics and Technology Education*).

Furthermore, school and out-of-school science education communities have begun to collaborate in creative and complementary ways (Bevan et al., 2010). The Fiocruz Museum of Life (Brazil), for example, hosts weekly professional development opportunities for school teachers and administrators, with the scope of planning meaningful and relevant school visits and productive connections across both landscapes.

Science museums are also being recognized as places that can potentially establish two-way communication approaches (Storksdieck & Falk, 2004) and challenge long-standing deficit perspectives (Feinstein, 2017). Today, these institutions are engaging in the promotion of dialogue and participation among visitors (Mazda, 2004); embracing socio-scientific issues as part of their exhibition practices (Kollmann et al., 2013); creating more equitable relationships between visitors and museum professionals (Aguirre, 2014); and fostering scientific citizenship (Hine & Medvecky, 2015). Science museums that employ a range of science communication and public engagement models open up possibilities for creating spaces and practices that are critical and agential in both form and function.

Located in Paris, the Cité des Sciences is a good example of a fourth-generation science museum. Through a series of public colloquiums, the creation of blogs, and the development of innovative formats, visitors are invited to participate in conversations (and often debates) around topical issues such as global warming and the societal impact of emerging technologies. These strategies and approaches illustrate how science museums can potentially transform their spaces and practices to include deliberative forums where visitors can converse, participate, and engage in decision-making. Again, we hear echoes of Cameron's (1971) analysis that science museums must be more than temples.

The *Coalition of museums for climate justice: Building museums' capacity to promote awareness, mitigation & resilience in the face of climate change* (Coalition of Museums for Climate Justice, n.d.) is an outstanding example of the fourth-generation trend. This coalition reaches across Canadian museum workers and organizations and illustrates the kind of work that is being done externally—across institutions—for socio-eco justice and transformative practices. Among its guiding principles, it is argued that the Coalition should serve "as a trustworthy broker to facilitate healthy and respectful dialogue among different points of view on issues confronting museums and their communities as they address climate change" (Coalition of Museums for Climate Justice, n.d., para. 6).

Along similar lines, science museums have recently become online forums for difficult conversations around, for example, racism, climate change, and pandemics. During COVID-19, we witnessed an expansion of mandates and actions based on social responsibility. Some science museums are engaging in complicated conversations about the pandemic with their publics. For example, the Exploratorium in San Francisco (U.S.A.) has been hosting monthly *COVID Conversations* online events, where the audience can

dialogue with experts and share their doubts and concerns regarding the pandemic. The Museum of Science in Boston created the exhibit "Ask a virtual Expert" in which the audience can ask questions about the coronavirus directly to a leading public health specialist. Additionally, this museum hosted a community-wide town-hall online forum about the COVID-19 coronavirus. Focusing on this event the museum wrote:

> This important public conversation was for anyone interested in learning about making informed decisions for themselves and their families; the science behind this outbreak; local and state resiliency planning; and community support resources and organizing […] The Museum is proud to have hosted this critical, timely conversation […] Attendees asked questions and learned more about the 2019 Novel Coronavirus and the implications it has on an individual and community level. (Museum of Science, 2020, para. 1)

Taking a different tact, the Museum of London is collaborating with audiences by collecting their oral testimonies and objects of significant value during the pandemic, and sharing them online. According to the museum's website, this initiative will allow "future generations of Londoners … to learn about and understand this extraordinary period" (Museum of London, 2020, para 1).

And, of course, there are the exhibitions themselves—the staple of science museums. Here, we turn to the possibilities that exist in and through exhibition practices. Consider, for example, *Klimax* and *Heureka Goes Crazy* (one about climate change, the other about mental health, both at Heureka The Finnish Science Centre, Finland) and *Sex: A Tell All* (an exhibition about sex, sexuality, and sexual practices, located at the Montreal Science Centre, Canada). Such exhibitions provide hints as to how visitors can be encouraged to actively participate, debate, critique, and engage deeply with issues that are important to contemporary society and that cut across science and society (see Fig. 5). As Butler and Lehrer (2016) advocate, public institutions must experiment with "inclusive, critical, democratic, participatory, reflexive, multi-vocal, and socially relevant exhibition design" (p. 5).

In summary, fourth-generation science museums are those that (1) embrace progressive views of scientific literacy; (2) challenge ways of representing science and, therein, dominant cultural and (scientific) narratives; (3) articulate various disciplines; (4) recognize the complex relationships that co-exist between science, technology, society, and environment; (5) prompt reflection and critical questioning; (6) engage with controversy; (7) invite two-way communication approaches, civic participation, reflexivity, and engagement; and (8) work towards agency and social change (Pedretti & Navas Iannini, 2020). These fourth-generation science museums' commitments manifest as movements, practices, a range of exhibition and curatorial designs, coalitions, programs, forums, and community outreach.

Fig. 5 *Race: Are We so Different?* Science Museum of Minnesota, U.S.A. Courtesy of Daniel James Atkinson

Key Drivers of Fourth-Generation Science Museums

If science museums begin to embrace critical scientific literacy, democratic communication models, and socio-scientific (often controversial) subject matter, what might fourth-generation science museums be/become and/or embody? In this section, we extend our understandings of this fourth generation through six defining drivers that carry implications about institutional identities, long-standing practices, and research agendas for scholars and museum professionals. Although presented linearly, these key drivers are fluid, are overlapping, and inform one another theoretically and in praxis.

Science Museums as Hubs of Change/Transformation

Alongside traditional goals of collecting, conserving, and communicating ("finished" science, for example), fourth-generation science museums can be places for activism, reflecting more contemporary and forward-looking goals that speak to present-day museums' changing landscapes. Janes and Sandell (2019) write about "new and divergent expressions of the museum's inherent power as a force for good" (p. 1), as a catalyst for change. In a time of, for example, COVID-19, environmental degradation, advances in reproductive technologies, waste management issues, oil extraction, and global warming, science museums can become another player and voice for social, environmental, and political transformation (Janes, 2009; Ng et al., 2017).

We find the idea of museum mindfulness to be a useful construct. Janes (2010) describes mindfulness as being fully in the moment, and paying deliberate and explicit attention to things, people, or events that are happening around us both locally and globally—occurrences we might otherwise ignore. It is about understanding what we choose to do, and our reasons why. Museum mindfulness does not imply that we let go of traditions that have historically sustained and characterized science museums worldwide. Instead, we must also take on the mantle of mindfulness to address larger issues and rethink science museums' identities and roles in contemporary societies.

In the science museum world, we are beginning to see advocacy work and calls that reflect critical and agential (Pedretti & Navas Iannini, 2020) perspectives. For example, *The Toronto Declaration* (Science Centre World Congress, 2008), the *Tokyo Protocol* (Science Centre World Congress, 2017a), and the *Mechelen Declaration* (Science Centre World Congress, 2017b) speak to a larger global presence and to work that moves beyond the walls of science museums as coalitions and shared goals of agency and civic responsibility take hold.

If we think about exhibition practices, two examples come to mind. The first is *Ngoda: The Wealth Beneath our Feet* (Mutare Museum, Zimbabwe). This exhibit with its original focus on the illegal diamond trade and the accounts of villagers removed from extractions zones, translated to becoming a forum for public dialogue (Chipangura, 2017). Due to its contents, the exhibit quickly moved into controversial territory, leading to public discussions between government officials and the community. In so doing, this bold exhibition led to social change and some social justice for displaced families, and contributed to the reframing of the museum's and the villagers' communities' identities. The second exhibition to consider is *Race: Are we so different*? (Science Museum of Minnesota, U.S.A.). According to the Museum's website (Science Museum of Minnesota, n.d.), the exhibition: "helps visitors understand what race is and what it is not. It gives them the tools to recognize racial ideas and practices in contemporary American life" (para 4).

We cannot let this opportunity pass without acknowledging the horrific events that transpired in the U.S.A. (and Canada too), with the murder of George Floyd and the tragic loss of Regis Korchinski-Paquet. These events transpired as we wrote this paper, and we carry them with us. Systemic racism is deeply embedded within our culture, institutions societies, and practices. The sorrow, pain, and outrage felt throughout the world has mobilized a series of protests and actions denouncing recent events and calling for justice and change. At no other time has it been more apparent to us that science museums must also

serve as hubs of change and transformation. Institutions must move from their inward gaze to an outward one, from looking to the past to also looking to the present and future.

Science Museums as Places for Productive Struggle

The notion of productive struggle, at first glance, confronts images of science museums as places for amusement and entertainment. Ambiguity and dissonance are not what visitors necessarily expect when they come to a science museum and here an interesting paradox emerges: the public expects information, "conclusions" about certain topics, and enjoyable experiences to be provided and supported—while, at the same time, there is some agreement and interest (by staff and visitors alike) that science museums should also address controversy and complex issues (see Achiam & Sølberg, 2017; Cameron & Kelly, 2010; Navas Iannini & Pedretti, 2017; Pedretti & Navas Iannini, 2020).

In the context of science museums, productive struggle implies that visitors and museum professionals are engaged, think critically, and probably experience some emotional disequilibrium (D'Mello et al., 2012; Kapur, 2016). This can be problematic and uncomfortable as museum staff negotiate, for example, new exhibitions or other educational initiatives that approach controversial terrains (consider, for example, topics such as sex, race, or mental health). It can be equally disorienting and uncomfortable for visitors. What decisions should be made around content to be included/excluded? What knowledges are being privileged/not privileged, and why? How do institutions deal with issues imposed by sponsors and funders? And what about the public gaze? We argue that moments of productive struggle are necessary and provide opportunities for institutional growth, re-prioritizing of goals, and re-branding.

Science museums have embraced productive struggle in different ways. Opportunities for (positive) experiences with discomfort and struggle (both emotional and cognitive) can be fostered, for example, through exhibitions engaging with complex socio-scientific subject matter (e.g., Navas Iannini & Pedretti, 2017). These opportunities can also be promoted by other kinds of educational initiatives developed or supported by science museums. One outstanding example is the *Controversial Science Café*, periodically hosted by the museum Espaço do Conhecimento—UFMG (Knowledge Centre—Federal University of Minas Gerais) in Belo Horizonte, Brazil. The goal of this café is to engage visitors in contentious discussions about complex science issues with social implications (Espaço do Conhecimento, n.d.). In recent times, this space has broached topics such as the challenges of urban mobility, women in STEM fields, environmental disasters involving mining, and fake news. The informal, horizontal, and close exchange between experts and the audience and the nature of the topics chosen open up a space for conversations that are difficult and inclusive.

Productive discomfort reminds us that struggles (be they with content, complexity, value systems, cultural mores, etc.) can be positive and in fact help us work through difficult ideas and conflicting beliefs in meaning-making and sense-making experiences.

Science Museums as Sites for Allyship

Ng et al. (2017) introduce the powerful notion of allyship in the (science) museum world, as a blueprint for attending to, and enacting, diversity and inclusive practices. The notion of allyship allows us to understand these institutions as contested sites, inclusive spaces, and again, as places for social well-being and transformation. In the context of science museums, allyship implies the following: understanding that it is not about themselves; practicing active listening, self-reflection, and learning; and a willingness/consciousness to be active and able to take direction (Ng et al., 2017). This is difficult work and includes a number of lived practices and experiences (Ng et al., 2017).

We know that, historically, science museums have excluded marginalized, disenfranchised, and disempowered populations (see Dawson, 2014a, b; Feinstein, 2017). For many, these institutions can be seen as alienating and inaccessible places where whiteness (and the status quo) is often privileged. These reflections

cause us to question how science museums can decolonize themselves and establish relationships with the communities in which they are immersed. Potential pathways for enacting social inclusion and equity in meaningful ways include establishing partnerships and networks with different organizations and social actors such as universities, community centres, local environmental initiatives, and schools. This implies consultation with communities, building cultural competencies, and fostering community participation and acceptance (Dawson, 2014a, b; Feinstein, 2017; Janes & Sandell, 2019). Clearly, we are beginning to see the emergence of equity frameworks for science museums based on infrastructure access, literacy, community acceptance (Dawson, 2014a, b), and creative practices that support cross-cultural learning opportunities (Aguirre, 2014). Similarly, we advocate building experiences and practices that are inclusive, relevant, and meaningful for all visitors.

Allyship with communities signifies a powerful way for fostering social and environmental transformation in/through the science museum landscape. Consider the Parque Explora in Medellin, Colombia (Aguirre, 2014). Through different initiatives, this museum has looked to engage low-income communities that are geographically located nearby. The museum offers admission subsidies for low income and school groups, promotes youth hubs for research, and fosters community projects. One remarkable effort of Parque Explora is the *Expanded territory—Lab of neighbourhood practices* project. This initiative seeks to "articulate communities based on social appropriation of knowledge, exchange of knowledge, reflection about the local and collaborative work, for the development of leadership capacities, research and communication of the youth of […] Medellin" (Parque Explora, n.d.). Framed around topics such as biodiversity and creative electronics, these projects depart from the community interests and the social dynamics of their territories and look to generate collaborative solutions for local problems (Parque Explora, n.d.).

In sum, at the heart of allyship are as follows: (1) equity—pursuing justice and fairness through institutional practices and exhibition content (Feinstein, 2017; Ng et al., 2017) and (2) community capacities—honouring and recognizing community knowledge and competencies, and repurposing through them, the work of science museums.

Science Museums as Spaces to Develop Empathy

Of late, there has been an increase in publications, research, and science museum practices that speak to these institutions as places that can and should promote empathy through different pathways (Gokcigdem, 2016; Janes & Sandell, 2019; Ng et al., 2017). Although museums may find the idea of empathy jarring at first, and indeed rarely consider empathy as an outcome (Koster, 2016), its time has arrived.

Empathy is described as recognizing and sharing the feelings (including distress) of others to better understand their situations, even if we do not share those feelings and/or situations (Koster, 2016). The science museum exhibition *Heureka Goes Crazy* (Heureka The Finnish Science Centre) and the slightly customized American renamed version *Mental Health: Mind Matters* (Science Museum of Minnesota, U.S.A.) attend to complex and sensitive socio-scientific issues related to mental health. Their shared institutional goals include the following: raising awareness and demystifying social preconceptions about mental health and mental illness; engaging visitors with topics that have been historically considered taboo; destigmatizing mental health; and developing empathy (Rosenström, 2015; Science Museum of Minnesota, 2018). These are striking examples of two science museums' deliberate and explicit articulation to promote empathy, and by implication social change and transformation, through their exhibitionary practices. Both of these exhibits call on the visitor to engage critically, emotionally, and sometimes in the place of "other" to develop empathy, compassion, and understandings (in terms of both knowledge and feelings).

Looking beyond the production of exhibitions, recall the emergence of other practices that include coalitions, organizations, and spaces, all of which seem to share a common thread—advocating for empathy, social impact, and social action in museums today (Murawski, 2016). Interestingly, these practices and movements are often located in history and art museums. For example, the Center for Empathy and the Visual Arts within the Minneapolis Institute of Art (Center for Empathy and the Visual

Arts, n.d.) focuses on research and institutional practices (for staff and visitors alike) that foster and promote empathy and global awareness through the arts. In another example, the Empathy Museum (Empathy Museum, n.d.) includes traveling participatory art projects that focus on issues of prejudice, inequality, and conflict through the lens of empathy. Their primary goal is to help visitors "see" the world through others' perspectives and experiences. We argue that it is equally compelling and necessary to locate and foster empathy in the context of science museums (and broadly speaking, in the science education field) in part because of a dominant tradition of (re)presenting science as objective, and void of context (e.g., social, cultural, environmental, political, and ethical). Fourth-generation science museums can develop spaces and practices that invite visitors to take part, feel deeply, and better understand others.

Science Museums as Epistemological Spaces

We know and recognize that science museums have traditionally been in the business of portraying science as abstract, unproblematic, authoritarian, and conclusive. These long-established practices and commitments to presenting "truth" and the "facts" perpetuate the status of scientific knowledge and continue to privilege a knowledge system that has been primarily White and Western-oriented. These observations prompt questions about other voices, about knowledge and experiences being silenced, and about the privilege that certain epistemologies hold. We suggest that fourth-generation science museums can disrupt traditional (grand) science narratives, honour a diversity of voices, and begin to share "epistemic authority".

Feinstein (2017) states that "the science" of science museums is often developed "with a particular group of people in mind" (p. 534). This is powerful and dangerous. Although science museums are viewed worldwide as places for learning science, research and practices tell us that, typically, the way we create these learning experiences is based on a set of norms, conventions, and practices of particular groups of people (Dawson, 2014b; Feinstein, 2017). It can be more difficult and less rewarding for visitors engaging in cultural practices that are unfamiliar to them, or which contradict their own practices (Rogoff, 2003). According to Sjöström and Eilks (2017), the views we develop on scientific knowledge depend on (and are embedded in) our own culture (including values and worldviews). If we adhere to the notion of science museums as epistemological spaces, we can (and should) consider a range of science learning experiences that honour a diversity of perspectives and knowledge systems and that engage the learner in the co-production of knowledge.

One example of this kind of experience is provided by the permanent exhibition *A Question of Truth* located at the Ontario Science Centre, Canada. *A Question of Truth* examines and deconstructs the history and practice of science, viewing science as a human and social activity located in culture, politics, and predominant worldviews (Pedretti & Navas Iannini, 2020). It is one of the earliest exhibitions to challenge the status of scientific knowledge and epistemic authority. Different voices, ways of knowing, and knowledge systems are celebrated. Other displays interrogate episodes (such as slavery, eugenics, the Holocaust, and intelligence testing) in the history and practice of science. Intentionally designed to be "a provocative exhibition about bias, prejudice, and discrimination in science" (Livingstone, Pedretti, & Soren, 2001, p. 356), *A Question of Truth* examines largely uncontested territory about the nature of science and examines historical repercussions and legacies of scientific pursuits, decisions, and subsequent actions.

Our research over the years suggests that science museums are beginning to attend to "unsettled and unfinished science" (Hine & Medvecky, 2015) and to confront the epistemological status of scientific knowledge (which can be messy, complex, and often fraught with opposing and/or irreconcilable values and other differences). In so doing, the epistemological foundations of museums and science (as objective and authoritarian sources of knowledge) are interrogated and challenged (Macdonald, 1998).

Science Museum as a Hybrid Third Space

The notion of a hybrid third space (Barton & Tan, 2009; Moje et al., 2004), when applied to science museums (Stocklmayer et al., 2010), is particularly useful to our discussions of the fourth-generation trend.

In a hybrid third space, "everyday resources are integrated with disciplinary learning to construct new texts and new [scientific] literacy practices that merge the different aspects of knowledge and ways of knowing offered in a variety of spaces" (Moje et al., 2004, p. 44). Science museums as hybrid third spaces have potential to recognize the knowledge, wisdom, experiences, and learnings that visitors bring to their meaning-making in confluence with established theoretical foundations of science.

Preventing Youth Pregnancy (Catavento Museum, São Paulo, Brazil) is an example of an innovative and controversial exhibition created for youth to explore, in a safe and supportive environment, issues related to sexuality, sexual practices, teenage pregnancies, risks, and prevention. Recognizing a social need to confront stereotypes and generate awareness about reproductive rights and sexual practices, the exhibit recreates a playful environment—a party—with a labyrinth of choices, courses of actions, and outcomes (see Navas Iannini & Pedretti, 2017). Teenagers are invited to engage in the party, dance, enjoy, laugh, dramatize, and make "tough" decisions about issues that could actually confront them (such as having sex, choosing contraceptive options, getting pregnant, considering abortion, fearing a sexually transmitted disease). At the end of the party, with the support of a sexual educator, visitors share their impressions, feelings, decisions, doubts, and concerns.

The development of *Preventing Youth Pregnancy* is a living example of a science museum performing as a hybrid third space. Through this installation, everyday knowledge and experiences (related to sexuality and sexual practices) that are present in life, alongside interests and concerns of teenagers, are combined with disciplinary knowledge (present in the voices of educators and the exhibit contents). The dialogue opportunity that takes place at the end of the visit, and the sharing of understandings and lived experiences, allow for new literacies and narratives to emerge. In/through this exhibition, we see wisdom, different practices, experiences, and knowledge intersecting (potentially) beyond the science museum space.

Reconceptualizing the science museum as a hybrid third space strengthens the role of museums as civic and epistemic agents, where audiences are valued co-creators of knowledge. Prioritizing viewpoints and experiences over the "language" of the object (or of science itself) reflects a broader movement where institutions place visitors and their communities (and what they bring) at the centre of their function (Black, 2012). It also allows for a myriad of exhibition practices and spaces that open up powerful and creative opportunities for dialogue, participation, dissent/conflict, and agency.

Concluding Thoughts

The six defining drivers of fourth-generation science museums that we established bring relevance and renewed purpose to these institutions, push the status quo, and move us to more contemporary discussions about their social roles and goals. We believe that science museums can become places for change and transformation, productive struggle, allyship, empathy, and epistemic democracy, and can serve as hybrid third spaces. Re-imagining institutional goals, spaces, and practices is difficult (but necessary) work (Pedretti & Navas Iannini, 2020) and requires "a turn away from the self-referential museum functions of the past, towards a more complete externalisation of purpose" (Achiam & Sølberg, 2017, p. 18). In other words, it is not enough that science museums exist for their own sake; they must also embrace their active exchange and co-production of knowledge within the societies in which they exist.

The relevance and purpose of science museums seems to be an enduring and contentious subject of debate. In 1998, Bradburne suggested that science centres must undergo a dramatic transformation if they are to remain relevant and thrive. He cautioned about the demise of the science museum and argued (rightly) that science centres uncritically continue to be planned around clusters of hands-on displays about scientific principles and phenomena, and when public institutions try to put science and technology into its social context, the society, paradoxically, is left out. Janes (2009) through his suggestive book, entitled *Museums in a troubled world: Renewal, irrelevance or collapse*?, moves us to keep questioning the purpose of these institutions particularly in current times, when so many difficult socio-scientific issues need to be

considered and discussed in order to enact social and environmental transformation. Other recent writings (Butler & Lehrer, 2016; Janes & Sandell, 2019; Pedretti, 2002; Pedretti & Navas Iannini, 2020) make similar compelling arguments, pushing conversations and museum practices in new and provocative directions that emphasize criticality and agency.

Our analyses of science museums through the emergence of a fourth-generation, and their key drivers, suggest that institutions are evolving, revisiting, and repurposing themselves to become more than they have been historically. The fourth-generation science museum is, in our view, bold, innovative, and forward thinking, and carries possibilities for promoting civic engagement, activism, and change. We recognize that fourth-generation science museums, alongside their critical and agential practices (whether they be exhibitions or other curatorial displays, programs, forums, science cafés, outreach, coalitions, and community work), carry their own set of challenges and narratives, particularly when approaching controversy. However, the time for change has come.

As we wrote this paper, we were self-isolating and the world was in lock-down, followed by an international resurgence of, and support for, the *Black Lives Matter* movement. The world is experiencing unprecedented challenges—challenges that encompass science, technology, society, environment, ethics, geopolitics, economics, and well-being. How and what we do in science education, in both the formal and informal sectors, matter deeply.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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