Science & Education
https://doi.org/10.1007/s11191-025-00708-2

ARTICLE

The Intersection Between Social-Institutional Aspects of Nature of Science and Social Justice in Natural History Museum Exhibitions

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Received: 16 February 2025 / Revised: 11 October 2025 / Accepted: 16 October 2025

Abstract
Natural history museums (NHMs), once seen as elitist and colonial institutions, are now redefining their roles as agents for change and transformation in society. Many are committed to social justice, equity, and community engagement, which establishes them as significant cultural and educational entities. These museums often serve as hubs for scientific research and provide a uniquely authentic environment that promotes public engagement in scientific inquiry and exploration. Through their various initiatives, NHMs not only enhance the public's understanding of scientific principles but also act as vital spaces for addressing broader societal issues, such as Social Justice (SJ). This study focused on the ways in which the intersection between Nature of Science (NOS) and SJ is presented in NHMs exhibitions, and in particular "The Changing Face of Science" series at The Field Museum in Chicago, USA. We collected data from museum signages and conducted a content analysis of four exhibitions presented in the museum. Our analysis was framed through the lens of NOS, and centered on the intersection of social-institutional aspects and SJ. The findings serve to develop a 7-category framework that characterizes this intersection and show how museum exhibitions can convey the relationships between science and societal issues. This framework contributes to the discourse on informal science education by demonstrating how NHMs integrate NOS and SJ, thereby promoting a more comprehensive and socially conscious understanding of science.

Keywords Nature of Science · Social Justice · Natural History Museums · Informal Science Education · Public Understanding of Science · Public Engagement with Science

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Published online: 10 December 2025

1 Introduction

Natural history museums (NHMs) are valuable cultural resources and key hubs for scientific research. These museums constitute an authentic, unique environment and house diverse collections, often featuring artifacts of significant cultural importance (Gutwill & Allen, 2012; Paris & Hapgood, 2002). Their rich biological, geological, and anthropological collections serve as resources for global biodiversity and conservation research. Today, many NHMs operate specialized scientific departments and play an active role in academic research and often implement their scientific initiatives within their institutional missions. Public exhibitions aim to make this work accessible to wider audiences (Helmuth, 2024). However, throughout history, NHMs have often been perceived as elitist institutions that reflect colonial ideologies and social inequities (Cameron, 1971; Pedretti & Navas Iannini, 2020b). Like many other museums, NHMs have faced growing calls to critically re-examine their narratives, reduce colonial biases, and highlight previously marginalized cultural perspectives (American Alliance of Museums, 2018; Ash, 2022; Betsch Cole et al., 2019; Frank & Sotto, 2022; Gonzales, 2019; Sandell & Nightingale, 2013). While recent efforts show that NHMs have made efforts to promote greater inclusivity and historical responsibility by transforming their narratives (Brenner, 2020; Dorfman, 2018; Graham & Murphy, 2010; Heller, 2023), there is still a considerable amount of work to be done (Carter, 2019; Das & Lowe, 2018; Datnow et al., 2023).

NHMs offer diverse experiences and information, thus contributing to visitors' knowledge construction (Bamberger & Tal, 2008). Through their activities, NHMs support public engagement with science and aim to enhance visitors' comprehension of scientific principles and methods (Achiam et al., 2019). By engaging visitors in real scientific settings, these institutions foster diversity, equity, and inclusion (Dorfman, 2018). The interactions between visitors and exhibitions can foster a better understanding of how culture, gender, and politics influence scientific endeavors (Piqueras et al., 2022). These activities support a deeper understanding of Nature of Science (NOS) and also introduce broader historical, social, and political contexts that influence scientific knowledge. In doing so, they have the potential to prompt visitor questions that resonate with concerns related to Social Justice (SJ) (Dagher, 2020).

NOS is a multidimensional concept in science education encompassing epistemic-cognitive aspects such as scientific methods, evidence-based reasoning, and theory change, and social-institutional aspects such as the ethical norms, cultural values, political influences, and organizational structures that shape scientific work (Erduran & Dagher, 2014a). Traditional science education often emphasized the epistemic-cognitive aspects. Recent scholarship, however, has underscored the importance of the social-institutional aspects, in particular for understanding science as a human and value-laden enterprise (Allchin, 2020a, b; Erduran & Dagher, 2014b). Concentrating on social-institutional aspects makes it possible to critically analyze the interactions between science and wider societal structures and power dynamics. This perspective is especially crucial when addressing equity, representation, and inclusion in formal and informal science education, such as in NHMs.

The concept of SJ in education broadly refers to the intentional effort to challenge and disrupt the power structures and inequities rooted in oppression, discrimination, and prejudice (Marshall et al., 2020) to create equitable learning environments that remove systemic barriers related to race, class, gender, and other identity markers (Kretchmar, 2023). In science education, SJ translates into promoting inclusive curricula, countering stereotypes about scientists, amplifying underrepresented voices, and empowering learners to

use scientific knowledge for civic and environmental action (Levinson, 2023; Yacoubian & Hansson, 2020). In informal education settings such as NHMs, SJ transcends the traditional roles of preservation and display by emphasizing the importance of transforming museums into active institutions with social responsibility. This includes addressing sensitive and controversial social issues, promoting inclusion and broad participation from diverse audiences, building partnerships with marginalized communities, fostering empathy, and respecting diverse knowledge and perspectives. The goal is to position museums as catalysts for social change and broader public well-being (American Alliance of Museums, 2018; Pedretti & Navas Iannini, 2020b; Prôa & Donini, 2019).

Although the intersections between NOS and SJ have been explored in formal educational settings, in particular, how a NOS-informed pedagogy can support SJ goals (Allchin, 2020a; Ballard et al., 2023; Levinson, 2023), less attention has been paid to how these intersections are made visible in informal education settings such as NHMs. Expanding on our previous research that explored the integration of NOS in these settings (Pshenichny-Mamo & Tsybulsky, 2024, 2025), the current study explored the social-institutional aspects of NOS and their intersections with SJ in an exhibition series entitled "The Changing Face of Science" at the Field Museum in Chicago. This study examined the social-institutional aspects of NOS (Dagher, 2020; Erduran & Dagher, 2014a, b) by delving into the cultural and social objectives of science. This exhibition series highlights the stories and accomplishments of women and people of color in science, groups that are historically underrepresented in scientific domains (Mensah, 2011). The series presents the contributions and personal experiences of individual scientists and challenges traditional perceptions of who can be a scientist to inspire a more diverse audience to engage with science (The Field Museum, n.d.a). Therefore, this exhibition series provides a valuable opportunity for studying the intersection of NOS and SJ in NHMs due to its focus on diversity, its challenges to existing stereotypes about scientists, and the paths it paves toward investigating the interplay between science and society.

2 Theoretical Background

This section reviews two bodies of literature that frame the current study: SJ and NOS. SJ is discussed first in terms of education and NHMs, followed by the concept of NOS, NOS in education, and NOS in NHMs. These topics tend to be examined separately; one of our goals is to show how NOS and SJ intersect.

2.1 Social Justice

SJ is a multifaceted concept that promotes fairness, equality, equity, rights, and opportunities across numerous sectors (Killen et al., 2021), including economics, the workforce, and education, while encompassing a range of cultural perspectives, emphasizing group identity, moral reasoning, and equitable treatment. SJ examines existing social systems and acknowledges historical and ongoing injustices contributing to inequality (Francis et al., 2017; Killen et al., 2021). According to Rawls (1999), achieving *justice as fairness* involves prioritizing individual freedoms within social institutions while balancing these rights with the collective good. This conceptual framework emphasizes the importance of representation, recognition, and equitable outcomes (McArthur, 2023), notably in informal educational settings such as museums.

2.1.1 SJ in Science Education

In education, the primary goal of SJ can be seen as the distribution of resources and opportunities, particularly to support historically marginalized groups (Francis et al., 2017). In science education, SJ seeks to establish an equitable learning environment where all students, regardless of background, can access inclusive curricula, resources, and teaching practices. It underscores the importance of recognizing and addressing cultural, socioeconomic, and gender diversity to foster meaningful and representative science learning experiences (Ladson-Billings, 1995). The goal is to empower learners with the tools and knowledge to use science as a means for social change, advance democratic values, and address social injustices. SJ in science education challenges existing perceptions of science and scientists by urging a critical examination of the social, political, and economic structures that shape scientific endeavors (Yacoubian & Hansson, 2020).

2.1.2 SJ in NHMs

NHMs, as a science learning environment, can provide scientific learning to different sectors of society while addressing issues of SJ. The effort to promote SJ in NHMs involves critically examining the colonial and racist legacies of these institutions and actively working to create more inclusive and equitable practices (Das & Lowe, 2018). This critical self-reflection aligns with the broader transformation of NHMs as they evolve from traditional institutions devolved to collecting and communicating natural history knowledge to dynamic spaces that engage with contemporary societal issues. As Pedretti and Navas Iannini (2020a, b) noted, NHMs are increasingly becoming centers for active citizenship, social responsibility, and education. This shift heralds the emergence of what is known as "fourth-generation" NHMs, which is characterized by several key features: (1) NHMs are curently seen as agents of change and transformation that advocate for social, environmental, and political action alongside traditional educational goals; (2) They serve as spaces for productive struggle, by encouraging visitors to engage critically with controversial and complex topics while promoting deeper learning through emotional and cognitive challenges (Achiam & Sølberg, 2017; Pedretti & Navas Iannini, 2020a); (3) NHMs are becoming sites of allyship that recognize historical exclusions and work towards inclusivity and equity through partnerships with marginalized communities (Dawson, 2014a, b), while providing empathy-building spaces, helping visitors understand diverse perspectives, and encouraging social change (Koster, 2016); (4) These institutions act as epistemological spaces, challenging the traditional view of science as purely objective, and incorporating multiple knowledge systems (Dawson, 2014b; Feinstein, 2017); (5) NHMs are increasingly serving as hybrid third spaces, where visitors' everyday experiences intersect with scientific knowledge to foster dialogue, co-creation, and participation (Black, 2012). This shift thus positions NHMs as key players in promoting equity, diversity, and a broader understanding of NOS in informal science education.

For instance, by engaging with subaltern narratives and historically disadvantaged populations, museums can challenge normative hierarchies through dialogical practices of collecting, preserving, exhibiting, and interpreting (Coffee, 2022). This approach underscores the importance of social justice-oriented exhibitions and emphasizes the role of curators in inspiring action and building solidarity (Gonzales, 2019). Efforts involve reinterpreting collections to acknowledge their colonial origins and the contributions of Indigenous

peoples. This requires a fundamental shift in how museums present their exhibitions, which means moving from a Eurocentric perspective to one that recognizes the diverse histories and cultures associated with the specimens (Das & Lowe, 2018).

Visitors come to NHMs for various leisure-related goals, including education, entertainment, and social interaction (Falk, 2016). As discussed in Gonzales (2019), museums should ensure that the language and tone of their texts are welcoming to all audiences, provide thick descriptions utilizing diverse materials, and relate to contemporary concerns while connecting historical lessons. She also suggested that stories of specific individuals or local stories can spark visitors' interest. For example, it is crucial to include diverse stories on the society and stories of those whose communities were affected by colonialism. Thus, modern NHMs should strive to be inclusive spaces that engage with diverse publics while establishing educational programs and initiatives involving citizens. These programs can help demystify science by making it more approachable and relevant to people's everyday lives while fostering a sense of ownership and connection to the natural world (Prôa & Donini, 2019). Such initiatives can rectify past wrongs and enrich visitors' scientific and cultural understanding by creating a more comprehensive and truthful representation of natural history.

Despite efforts by NHMs to promote inclusivity, visitors from communities of color often report feeling a lack of belonging in these spaces (Dawson, 2014b; Garibay, 2009, 2011). This sense of alienation is deeply rooted in the colonial histories that many museums fail to adequately address in their narratives, thus perpetuating structural inequities and reinforcing systemic racism (Das & Lowe, 2018). In response to ongoing discussions, there is an increasing demand for museums to transform their practices (Ash, 2022; Ash & Lombana, 2013) and create exhibitions that emphasize SJ (Gonzales, 2019). The American Alliance of Museums (2018) initiated a professional dialogue on SJ in museums, highlighting the need to tackle issues related to diversity, equity, accessibility, and inclusion. Museums, including NHMs, are urged to reflect the diversity of their communities to maintain relevance and earn public trust and support. The American Alliance of Museums (2018) pointed out historical inequities in the field that are visible in the underrepresentation of non-white individuals within museum staff, leadership, and audiences compared to their numbers in the general population. To combat perceptions of elitism and promote genuine equity and inclusion, the report stressed the critical necessity for structural inclusion. This means removing obstacles and ensuring meaningful access for all community members. Such initiatives require significant institutional change rather than mere superficial reforms which call for a fundamental shift in how museums operate, who they serve, and whose voices are included in exhibitions and decision-making processes. Although museums acknowledge these challenges, their responses often lean towards surface-level fixes at the staff level rather than pursuing comprehensive institutional reforms. Attaining genuine change demands a systemic transformation that affects all layers of museum structures (Ash, 2022).

2.2 Nature of Science

The concept of NOS captures fundamental issues about the nature of scientific knowledge and practices. Over the years, various frameworks have been put forward to conceptualize NOS in science education, ranging from the Consensus View (McComas, 2020), which focuses on a set of agreed-upon characteristics of science, to models such as Whole Science (Allchin, 2011) and the Nature of Scientific Knowledge framework (Lederman &

Lederman, 2020). However, recent scholarly discussions have increasingly converged around the Family Resemblance Approach (FRA), which is considered the most comprehensive and integrative framework to date (Erduran & Dagher, 2014a). FRA, which was originally developed by Irzik and Nola (2011) and adapted for science education by Erduran and Dagher, (2014a), portrays science as a network of interrelated features that different scientific disciplines share, rather than a uniform enterprise defined by fixed criteria. This approach allows for the inclusion of epistemic-cognitive aspects such as the role of theory, evidence, and methodological plurality, as well as social-institutional aspects, including the ethical norms, cultural values, political structures, and organizational dynamics that influence scientific work (Erduran & Dagher, 2014a). While traditional approaches to NOS have often emphasized the epistemic-cognitive aspects, contemporary perspectives underscore the importance of recognizing science as a socially embedded and value-laden endeavor (Allchin, 2020a, b; Erduran & Dagher, 2014b). Understanding these social-institutional aspects is crucial to examining the relationship between science and society, and to critically analyzing issues such as representation, authority, and power structures in scientific practice. A comprehensive understanding of NOS is a fundamental element in the development of learners' scientific literacy, as well as their capacity to apply scientific knowledge meaningfully to comprehend natural phenomena, analyze socio-scientific issues, and make informed decisions in personal and civic contexts (Allchin, 2014; Holbrook & Rannikmae, 2007). Scholars emphasize that science education incorporating NOS fosters a critical understanding of how scientific knowledge is produced, its limitations, and its entanglement with societal, political, and cultural contexts (Erduran & Dagher, 2014a; McComas, 2020). Recent research on NOS has primarily focused on formal education settings (Cheung & Erduran, 2023; McComas, 2020). Studies have examined various approaches to NOS instruction (Clough, 2006; Edmondson et al., 2020; Khishfe & Abd-El-Khalick, 2002; McComas & Clough, 2020; Tsybulsky, 2018; Witucki et al., 2023). This includes pedagogical approaches to NOS (Allchin et al., 2014; Hansson et al., 2019; Kapsala & Mavrikaki, 2020; Nouri & McComas, 2021; Tsybulsky, 2019; Tsybulsky et al., 2018a, 2018b; Williams & Rudge, 2019), teacher education on NOS (Beeghly et al., 2025; Mesci & Schwartz, 2017), how NOS is represented in science curricula and textbooks across countries (Caramaschi et al., 2022; Kaya & Erduran, 2016; McDonald & Abd-El-Khalick, 2017; Mork et al., 2022), and the perspectives of students and teachers on NOS (Abd-El-Khalick & Akerson, 2004; Akgun & Kaya, 2020; Bugingo et al., 2024; Lederman & Lederman, 2014). Works have explored how the public engages with NOS on digital platforms such as Twitter (Bichara et al., 2022). However, little is known about engagement with NOS in informal education settings such as NHMs (Holliday & Lederman, 2014; Lederman & Holliday, 2017; Pshenichny-Mamo et al., 2025; Pshenichny-Mamo & Tsybulsky, 2024, 2025; Reiss & McComas, 2020). This disparity highlights the need to expand NOS research into the NHM context, where science is communicated to broad audiences in diverse and often more accessible ways.

2.2.1 NOS in NHMs

NHMs are vital institutions for documenting and preserving biological diversity and engaging the public with science (Dorfman, 2018). Although traditionally centered on public *understanding of science*, recent NHMs have promoted *public engagement with science* by adopting a socio-cultural approach to make science more accessible and interactive for a diverse audience (Bevan & Xanthoudaki, 2008). Museums are making attempts

to place greater importance on inclusive practices to tackle educational inequalities and foster wider public engagement, transforming what were once exclusive environments into platforms for experiential learning and addressing systemic injustices (Feinstein, 2017). This transition reflects the broader understanding of science as a socially and culturally embedded practice that situates science within its social context. It underscores the importance of addressing both the epistemic-cognitive and the social-institutional aspects of NOS (Erduran & Dagher, 2014a, b). Recent studies have explored the integration of NOS in NHMs. Studies on museum educators' conceptions of NOS integration in guided tours indicate that this integration is often implicit and occurs spontaneously during tours rather than being systematically planned or embedded in the programs (Pshenichny-Mamo & Tsybulsky, 2025). Another study examined guides' views on integrating NOS in terms of visitors' experiences. The findings revealed that guides focus primarily on the cognitive aspects of visitors' experiences by forefronting the epistemic-cognitive aspects of NOS (Pshenichny-Mamo & Tsybulsky, 2024). A recent study explored the educational potential of climate change exhibitions at NHMs (Pshenichny-Mamo et al., 2025). The findings revealed that one of the educational goals of the museum staff was grounding knowledge in NOS. Furthermore, the analysis of climate change exhibitions indicated that both cognitive-epistemic and social-institutional aspects of NOS were integrated into the content of the exhibitions, although they were emphasized differently. A study involving visitors showed that hands-on activities allowed visitors to engage directly with epistemic-cognitive NOS aspects by analyzing objects as scientific evidence (Achiam et al., 2016, 2019). Piqueras et al. (2022) demonstrated that NHMs are not free of cultural and social biases. Their findings indicated that students visiting an exhibition on human evolution identified gender stereotypes and questioned the scientific reliability of the exhibition, and grasped that social norms had shaped it so that it did not necessarily represent historical reality objectively. However, while the students engaged in critical thinking about the limitations of scientific knowledge, including gender-related issues, they did not critically examine the racial and ethnic representations in the exhibition. They accepted the linear narrative of human evolution *out of Africa* as scientific fact without questioning the cultural and social biases underpinning this narrative. However, discussions with museum educators on the limitations of scientific knowledge and gender aspects allowed the students to integrate some aspects of NOS into their meaning-making. Nevertheless, the exhibition's failure to critically address the broader socio-cultural biases embedded in its narrative, such as racial and gendered stereotypes, points to a missed opportunity to engage with the social-institutional aspects of NOS, and the need for deeper and more explicit integration of these features. In general, the scholarly discourse on integrating the social-institutional aspects of NOS in NHMs is still underdeveloped despite its importance for fostering a more comprehensive understanding of the interconnectedness between science, society, and culture.

Further efforts to integrate the social-institutional aspects of NOS can be seen in attempts by NHMs to acknowledge and incorporate Indigenous knowledge systems and contributions that have been historically marginalized or omitted from museum narratives (Sullivan, n.d.). These efforts aim to explore the political power structure by promoting the understanding that science has historically been linked to governments and has advanced colonial interests (Erduran & Dagher, 2014b). For example, many collections in NHMs worldwide originated from Indigenous individuals or enslaved persons who contributed crucial local expertise during European expeditions. Despite this, the role of these contributors often remains unacknowledged due to inadequate labeling and anecdotal documentation, thus underscoring a gap in equitable representation (Sullivan, n.d.). While it is critical to acknowledge historical injustices such as the colonial acquisition of museum

collections, it is equally important to critically examine how these histories are communicated or downplayed in museum spaces (Bennett, 2013; Lonetree, 2012). The ways in which narratives are curated, framed, and made accessible to visitors play a central role in challenging or perpetuating dominant historical accounts (Hall, 1997). Simply noting that contributions from Indigenous or enslaved individuals are underacknowledged does not go far enough; there must also be explicit engagement with the mechanisms of omission and selective storytelling that shape public understanding (Harrison, 2012; Tythacott, 2010). Problematizing these representational practices enriched the theoretical framing of this study by situating NOS within its broader socio-historical and institutional contexts (Harding, 1998; Harrison, 2012), and by aligning with a SJ perspective that calls for transparency, reflexivity, and equity in the communication of scientific histories (Andreotti, 2011; Medin & Bang, 2014).

Thus overall, from temples of knowledge to dynamic spaces for dialogue and co-production, NHMs are evolving to present a more inclusive and multifaceted view of science. By integrating diverse narratives, NHMs have made attempts to enhance their capacity to promote diversity, equity, and inclusion (Dorfman et al., 2018) while addressing NOS. This transformation positions NHMs as platforms for fostering a deeper understanding of both NOS and SJ.

2.3 The Intersection of NOS and SJ

In recent years, the intersection between NOS and SJ has garnered increasing attention in science education research (Yacoubian & Hansson, 2020). While traditionally treated as distinct domains, there is growing recognition of their conceptual and pedagogical convergence (Erduran et al., 2020; Hansson & Yacoubian, 2020). Erduran et al. (2020), for example, put forward an important conceptual synthesis linking the social-institutional aspects of NOS with political theories of justice, such as those put forward by Rawls (1985) and Miller (2001), to explore how NOS instruction can serve SJ aims. Although their discussion focused on formal education, it provides a valuable theoretical foundation that inspired the current study's exploration of NOS and SJ intersections in informal learning settings such as NHMs. Studies have highlighted the potential of NOS to serve as a critical framework for addressing sociopolitical issues in science education by raising key questions about what knowledge, skills, and attitudes are necessary to promote equity and justice (Kampourakis, 2020).

Crucially, recognizing science as a social enterprise, an argument advanced by thinkers such as Popper (2003) and Galamba and Matthews (2021), further reinforces the need to examine how scientific knowledge is shaped within particular cultural and ideological contexts. Rather than existing in a vacuum, science is produced by individuals embedded in social systems, and as such, is susceptible to personal biases, institutional norms, and dominant worldviews. Popper (2003) emphasized that scientific practice is not immune to irrationality or partisanship, and noted the "passionate tenacity" with which some scientists defend their intellectual offspring. Similarly, Kuhn (1970), theorized scientific communities' reluctance to accept ideas leading to paradigm shifts and related this to the normative and political dimensions of knowledge production. These insights are central to justice-oriented NOS frameworks, which seek to expose how authority, privilege, and historical inequities shape what knowledge is legitimized and whose perspectives are marginalized. NOS and SJ share core concerns, including fairness, diversity, representation, and identity that directly challenge the longstanding assumption of science as a neutral and objective

endeavor (Allchin, 2020a; Hansson, 2020). A justice-oriented approach to NOS must encourage the examination of science as a culturally, socially, and politically embedded enterprise (Erduran & Dagher, 2014a; Zacharia & Barton, 2004). Asking questions such as whose science? and which version of NOS is represented? serves to interrogate dominant Positivist frameworks that continue to underpin much of mainstream science education (Hansson, 2018; Proper et al., 1988).

This critical perspective is particularly crucial when considering historical instances where scientific authority has been weaponized to legitimize oppressive ideologies. Examples such as race science, eugenics, and phrenology demonstrate how claims to scientific legitimacy have been used to promote racism, exclusion, and inequality (Lodge, 2021). These cases reveal the ways in which science has often been co-opted to serve prevailing sociopolitical interests by reinforcing existing power structures under the guise of objectivity. Recognizing such histories highlights the entanglement between science and injustice and reinforces the need to prepare learners to critically evaluate the socio-ethical dimensions of scientific knowledge (Galamba & Matthews, 2021). Feminist and postcolonial perspectives have advanced particularly powerful critiques of traditional NOS frameworks by exposing entrenched forms of epistemic injustice that are often overlooked in science education. These perspectives highlight how women, Indigenous communities, and other marginalized groups have been systematically excluded not only from participation in science but also from the recognition and legitimization of their contributions (Bleichmar, 2011; Moura et al., 2020; Terrall, 2011). This exclusion is visible in formal curricula and in public institutions such as NHMs, where the practices that have shaped modern science, such as collecting, cataloguing, illustrating, are frequently hidden or presented without a historical or cultural context (Das & Lowe, 2018; Sullivan, n.d.). Consequently, NHMs may unintentionally perpetuate a Eurocentric, male-dominated narrative of science unless their interpretive frameworks are critically re-evaluated and actively diversified.

Overcoming these exclusions requires a reconceptualization of NOS that embraces epistemic plurality both internally and externally. Internal plurality acknowledges diverse scientific practices and ways of knowing within the scientific community, while external plurality calls for the recognition of alternative epistemologies that lie outside dominant Western paradigms. Santos (2010) argued that SJ on a global scale is unattainable without epistemic diversity. This does not simply involve adding marginalized knowledge to existing frameworks but rather engaging critically with the structures that have historically delegitimized them. Peripheral, Indigenous, and local knowledges must be legitimized on an equal footing with Western scientific epistemologies (Bazzul, 2020; Santos & Meneses, 2010). In response, holistic NOS frameworks such as the FRA offer a more inclusive and critically reflective model. FRA emphasizes the epistemic, cognitive, institutional, and social dimensions of science by encouraging learners to consider how science is shaped by and shapes broader sociopolitical realities (Dagher, 2020; Erduran & Dagher, 2014a). By contrast, traditional or narrow epistemic models focus predominantly on abstract scientific reasoning and processes, but in so doing, neglect the sociohistorical and ethical dimensions of scientific practice. As a result, they fail to equip learners with the tools needed to interrogate issues of bias, exclusion, and trust in science (Allchin, 2020a; Mueller, 2011). This broader conceptualization of NOS has significant implications for informal science education, particularly within NHMs (Pshenichny-Mamo et al., 2025; Pshenichny-Mamo & Tsybulsky, 2024, 2025**).** NHMs, due to their perceived objectivity and cultural authority, can move beyond presenting science as a neutral and universal enterprise. Instead, they can serve as transformative spaces that critically engage with the issues of representation, authority, and power. By interrogating whose knowledge is displayed, how science is

constructed, and what values underpin scientific narratives, NHMs can disrupt dominant paradigms and foster more inclusive understandings of science (Andreotti, 2011; Harding, 1998). When interpreted through a justice-oriented NOS lens, these institutions can actively amplify marginalized voices and make visible the sociohistorical processes that shape scientific knowledge. They can thus become key sites for epistemic transformation and public engagement with the politics of knowledge production.

Building on these theoretical considerations, the current study explored how the intersection of the social-institutional aspects of NOS and SJ are reflected in the exhibition's narrative, and what possibilities for integration they offer in NHMs. It focused on "The Changing Face of Science" exhibition series at the Field Museum in Chicago. These exhibitions highlight the contributions and experiences of women and people of color in science, thereby making visible the social-institutional dimensions of scientific practice. Through a content analysis of the narratives, we propose a theoretical framework that highlights how the social-institutional aspects of NOS intersect with SJ in NHM exhibitions.

3 The Research Site

"The Changing Face of Science" exhibition series at the Field Museum in Chicago, USA, presents the challenges faced by individuals with marginalized identities in the scientific community, in particular women and minorities, and questions traditional notions of what it means to be a scientist (The Field Museum, n.d.a). The exhibitions examined in this study showcased the female scientists and educators Lynika Strozier, Jingmai O'Connor, Janet Voight, and Ylanda Wilhite (Appendix 1), through displays of their life stories and contributions to scientific research and education. The exhibitions present stories about their scientific journeys, along with pictures of their personal and professional lives. The exhibitions feature personal items associated with their hobbies or families, as well as objects representing their scientific work. Each item and picture is accompanied by signage providing information in both English and Spanish. The exhibitions also include video presentations of the scientists discussing their work. The exhibitions are the outcome of a close-knit collaboration between the exhibition development team at the Field Museum and the featured scientists and educators. In Lynika's case, the exhibition was developed in collaboration with Lynika's family, friends, and colleagues. Appendix 1 provides links to the museum's official website, which offers pictures and virtual tours of the exhibitions analyzed in this study. This exhibition series was supported in part by an Institute of Museum and Library Services grant award (The Field Museum, n.d.a).

4 Methodology

This qualitative study centered on "The Changing Face of Science" exhibitions. This series of exhibitions lends itself well to a study on the intersection of NOS and SJ in NHMs given its emphasis on diversity, its questioning of preconceived notions about scientists, and the avenues it facilitates to explore the intersectionality of science and society. Ethical approval for this study was obtained from the university Ethics Committee.

The data collection process included photographing the exhibition materials. Data were gathered on-site in March 2023 and also obtained from museum staff from March 2023 to

April 2024. The analysis focused on the texts displayed on the exhibition signages. The findings specify the source of each quote and indicate the related exhibition.

The qualitative data were subjected to deductive and inductive content analysis that yielded a structured and in-depth exploration of the exhibitions' content and meanings. Studies show that this combined methodology provides a better understanding of qualitative data by leveraging the strengths of both inductive and deductive reasoning. It allows for deeper insights into a phenomenon while improving the accuracy and transparency of qualitative data analysis (Yuwono & Rachmawati, 2023).

The first cycle of the analysis followed a deductive, concept-driven approach (Kuckartz, 2019; Rimmel & Cordazzo, 2021) focused on identifying excerpts in the exhibition signage that illustrated the social-institutional aspects of NOS and SJ. For the purposes of this study, an excerpt was defined as a single signage text or a specific section within a signage that conveyed or illustrated a theme related to the social-institutional aspects of NOS and SJ. The analysis specifically focused on the social-institutional aspects of NOS to meet the study's emphasis on the cultural, historical, and societal structures that shape scientific practice and participation. The codes thus pertained to the social, cultural, and human dimensions of science, guided by the Erduran and Dagher (2014a) framework related to the institutional-social aspects of NOS, as well as the theoretical frameworks related to SJ put forward by Crenshaw (1997), Miller (2001), and Rawls (1985). This analysis cycle was also inspired by Erduran et al. (2020), who suggested a theoretical conceptualization of the intersection between NOS and SJ in science education. For the analysis, the authors examined the exhibition content by thoroughly reading and re-reading the texts, and identifying excerpts that highlighted the social-institutional aspects of NOS and SJ.

For example, the signage in the Lynika Strozier exhibition was assessed in the first cycle as follows:

> 3 lessons Lynika taught me" by one of Lynika's friends and teachers:
> 1. "Give people a chance. No matter what they look like, where they came from. What they wear- don't just judge them on their grades or abilities, but also consider their enthusiasm, their interest, their willingness to work hard."
> 2. "Give people the support to learn in their own way. Let's use science to teach people how to solve problems in their own lives and for a better world."
> 3. "Let's help people fight their demons. We all have hidden fears and worries…we don't like to acknowledge them, but doing so can actually help us move forward."

This excerpt illustrates the social-institutional aspects of NOS by portraying science as a human and socially embedded endeavor that values collaboration, personal resilience, and diverse ways of knowing. From an SJ perspective, the quotes call for equitable opportunities, recognition of learners' individual contexts, and inclusive educational practices.

After identifying the social-institutional aspects of NOS and SJ in the excerpts and their documentation, they were categorized as relevant excerpts for the research question. Initial impressions and thoughts about the excerpt were also recorded (Bingham, 2023). The first analysis cycle concluded when the authors finished classifying and highlighting the exhibition signages that emphasized the social-institutional aspects of NOS and SJ.

The second cycle of the analysis commenced with an inductive, data-driven analysis (Kuckartz, 2019; Rimmel & Cordazzo, 2021) employing a "conventional content analysis" method (Hsieh & Shannon, 2005, p. 1279). The analysis focused on identifying emergent ideas from the signage that illustrated the intersection between the social-institutional aspects of NOS and SJ in the NHMs exhibitions, which to date have received scant attention in theoretical frameworks. This cycle consisted of two stages (Bingham, 2023). The

first stage involved understanding the data. The authors identified emergent ideas from the excerpts related to the research question, defined codes derived from the data, developed initial categories and their definitions, and tracked evidence by documenting their thoughts and explanations. This stage comprised reading the data from the first cycle multiple times while exploring the context of the text and the illustrations of the social-institutional aspects of NOS and SJ presented in this context. The second stage entailed identifying the data patterns found in the excerpts that were initially categorized. The authors examined the context of the excerpts and their content compared to the initial definitions of the categories and each other. The authors developed definitions for each finalized category, identified representative and exemplary content to illustrate each category (Coffey & Atkinson, 1996; Patton, 2002), and recorded their analytical decisions, thus solidifying the development of the final categories. By the end of this stage, the authors had constructed a seven-category framework describing the intersection between the social-institutional aspects of NOS and SJ. The categories, coding methods, and indicators are presented in Appendix 2.

For example, the signage in the Lynika Strozier exhibition was assessed in the second cycle as follows. During the inductive analysis, the authors immersed themselves in the exhibition content and identified emergent ideas that captured the intersection between the social-institutional aspects of NOS and SJ. In this stage, the quote above stood out for its three content statements: the call to give people a chance regardless of background, support for diverse learning styles, and helping individuals confront their personal challenges, which all show how inclusivity, personal development, and empathy are important to the practice of science. These can be seen as the ethical commitments, communal values, and cultural responsibilities of science. It was initially assigned to the scientific ethos category because of its emphasis on values such as respect, openness, and support for individual growth. However, during the second phase, by cross-referencing the excerpts and their context, this excerpt was ultimately assigned to the category *Freedom to Belong in Science*. This category emphasizes freedom of expression, equitable participation, and respect for those engaged in scientific work. It reflects a moral vision of science as a human endeavor that must be inclusive, accessible, and strongly connected to personal and societal transformation.

To minimize the potential overlap between categories, each author conducted an independent content analysis and proposed a set of categories. After completing their respective analyses, the authors convened to finalize those categories that illustrated the intersection of the social-institutional aspects of NOS and SJ in these exhibitions. The final set of seven categories was constructed after in-depth discussions resulting in consensus. The disagreements were resolved during the analysis by exploring the contexts of the texts in the signages. Once the final categories had been confirmed, an independent researcher analyzed 30% of the data. The agreement was high, at 95%.

Several steps were taken to ensure the reliability of this study. We included a comprehensive description of the study setting. The chain of evidence was meticulously maintained, including transparent and systematic documentation of all analytical steps implemented throughout the study. This included preserving the original signage texts, tracking coding decisions, linking each excerpt to its corresponding category, and maintaining a clear audit trail of how the categories were developed and refined. This transparent record thus allows others to follow the research process and confirm the logic and consistency of the analytical procedures. The categories were presented with detailed descriptions followed by exhibition examples to enhance credibility and transferability. Careful consideration was given to the context of exhibition statements to ensure alignment with the intended meanings. This thorough approach supported the validity of the findings and contributed to

Table 1 The seven categories and the number of mentions that present the intersection of the social-institutional aspects of NOS and SJ in "The Changing Face of Science" exhibition series

Category	Excerpts
1. Multifaceted realities	9
2. Representation	5
3. Recognition	6
4. Equity barriers	4
5. Collaboration	5
6. Freedom to belong in science	5
7. Identity inspiration	18
Total	**52**

the study's reliability (Lincoln & Guba, 1985; Shenton, 2004). This method helped make sure the findings were grounded in the content of the exhibition and could be harnessed to provide a comprehensive understanding of how NOS and SJ are integrated into NHM.

5 Findings

There were 52 excerpts showcasing social-institutional aspects of NOS and SJ in the exhibitions. The presentation of the findings is structured around seven categories, as detailed in Table 1. In this section, we present the quotes from the texts and brief explanations.

5.1 Multifaced Realities

The data analysis revealed that nine of the 52 excerpts demonstrating NOS social-institutional aspects and SJ in the exhibitions reflected the multifaceted realities of the scientists' lives. This category illustrates how the lives of scientists are shaped by intersecting social structures. These excerpts emphasized that science is a human endeavor that is not practiced in a social vacuum but rather is embedded within complex human experiences. The excerpts from the exhibitions in this category highlight how gender, race, disability, and socio-economic status influence individuals' pathways into science and their experiences within it. This category covered the intersection of the social-institutional aspects of NOS, such as the social embeddedness of scientific work, the diversity of scientific practitioners, and the ways in which power and access shape participation in science, as they relate to with key dimensions of SJ, particularly the principle of intersectionality. Rather than portraying science as an objective pursuit, these excerpts expose how systemic inequities affect who becomes a scientist, whose knowledge is valued, and which voices are amplified or marginalized.

For example, in the exhibition on Lynika Strozier, the signage describes Lynika's personal and professional life:

> Lynika was a Field Museum Collections Associate, DNA researcher, and science educator. She was born on August 28, 1984, in Birmingham, Alabama, but moved to Chicago's Edgewater neighborhood to live with her grandmother ("Granny") when she was six years old. Her mother, who struggled with drug addiction, could no longer care for her, and her father was never a part of her life. […] She was eight

> years old when she was diagnosed with a learning disability. She struggled with math, but reading was even more of a challenge […]

An ideal scientist might be perceived as naturally gifted, neurotypical, and from a stable, privileged background, but this excerpt presents a different narrative. Lynika's challenges present to visitors with a different picture of scientists. Her narrative emphasizes that scientific careers are shaped not only by intellectual capability or interest but also by personal, familial, and structural conditions. Lynika's story highlights how early life experiences, poverty, parental absence, and a diagnosed learning disability can intertwine, thus aligning with the intersectionality framework in SJ. This narrative demonstrates the social embeddedness of science as a human endeavor shaped by individuals from diverse backgrounds, a social-institutional aspect of NOS.

Janet Voight's exhibition presented her family's geographic and educational background, but also a description of her family's own struggles when she was a child:

> No one—not her family, not herself—expected this girl to grow up to be a scientist. Her grandparents immigrated from Europe; her parents were working class. Janet grew up in land-locked Iowa in a family of modest means and conventional expectations. "Maybe if she works hard, she could be a teacher or a nurse," they said. Janet's parents valued education despite not having gone to college themselves. Her father taught himself trigonometry to become a sheet metal fabricator. Her mother, a housewife, hid the fact she didn't understand algebra for fear Janet would use that as an excuse not to understand it either.

Janet's story highlights both institutional and cultural barriers: class-based assumptions about suitable careers for women, the lack of direct educational support, and implicit gendered and classed expectations. In the context of social-institutional aspects of NOS, this example demonstrates that scientific knowledge and participation are not solely meritocratic but are instead influenced by social factors, norms, values, and familial contexts. In SJ terms, it reflects how class and gender intersect to limit aspirations and access, and how resisting these constraints can redefine who is seen as a scientist.

This category thus illustrates that scientists can come from various backgrounds and may have different disabilities, thus highlighting the intersectionality of their realities. Nevertheless, they all succeeded in playing a vibrant role in their scientific fields, thus demonstrating that science is a human endeavor shaped by cultural and social influences.

5.2 Representation

Five out of the 52 excerpts were about the representation of scientists from historically marginalized groups, which emphasized and aimed to ensure their visibility within the scientific community and broader public discourse. This category focused on how the scientists' professional contributions and their identities, such as race, gender, or appearance, were represented in the exhibitions. It illustrates how these forms of representation shape public perceptions of who scientists are and what they look like.

Lynika Strozier sadly passed away from complications resulting from COVID-19. The exhibition included quotes from her friends and colleagues about her. One colleague commented that:

> Science can't happen without representation […] She was the first black scientist I met outside of academia- It was like meeting Beyonce.

This quote emphasizes the importance of representation in science for inspiration and visibility.

Jingmai O'Connor addressed stereotypes and challenged assumptions about what a scientist looks like:

> After this exhibition opened, a lot of comments on social media suggested that someone who looks like me couldn't be a serious scientist. What? Let's break these assumptions. Here are just a few of my scientific publications!

This quote demonstrates the connection between visual appearance and public perceptions of what scientists look like, thus pointing to the need to challenge standard portrayals of scientists and the importance of and need for representation.

The Ylanda Wilhite exhibition shows her engagement with diverse communities and her work in different cultural settings:

> In 2011, I began interning in the Field Museum's Environment, Culture, and Conservation (ECCo) department. I worked with communities in Pilsen and the Southeast Asian community on Devon Ave. on sustainability and local gardening. It was my first time engaging with Chicago communities outside of my own.

This excerpt adds another layer to representation by showing the scientist not only as a knowledge producer but also as an active community participant, thereby expanding the role of science in society.

By forefronting the identities and lived experiences of scientists from historically marginalized groups, the exhibitions challenge prevailing stereotypes about who can be a scientist. These narratives reflect the social-institutional aspects of NOS, because they address the processes by which scientific credibility, authority, and recognition are granted within the scientific community and beyond. At the same time, they align with the principles of SJ by affirming the importance of inclusivity, equity, and epistemic diversity. Representing diverse scientists can thus help foster public engagement with science that is more inclusive and reflective of society's full spectrum.

5.3 Recognition

Six out of the 52 excerpts dealt with recognizing, acknowledging, and valuing the contributions of individuals from historically marginalized and underrepresented groups by depicting these scientists' achievements, work, and impact in their scientific fields. This recognition took the form of awards, public acknowledgments, and other forms of commendation. The recognition presented in the exhibition was explicitly or more indirectly expressed through references to public appreciation, community work, or early scientific involvement, as shown below.

Janet Voight is recognized for her work and impact on young people. Reproductions of letters she has received from the young generation show their gratitude, as indicated by the signage:

> Janet is especially proud of her work with young people. She tends to keep the thank you notes.

Jingmai O'Connor was recognized for her early contributions during her master's degree work and experiences in significant scientific endeavors:

> My first dino dig was in the Hell Creek region of Montana, helping the Los Angeles Museum of Natural History to excavate a T. rex named Thomas while I was an undergrad.

While not explicitly framed as formal recognition, these two excerpts convey respect and acknowledgment for the scientists' work and contributions. We viewed recognition as conveyed through more granular forms of appreciation that were included in the exhibition narrative.

The exhibition presenting Lynika Strozier ended with signage that directly appeals to visitors, inviting them to think about their recognition of scientists and acknowledging the effort needed to change perceptions and recognize diverse scientists:

> The face of science won't change by itself. The Field Museum had work to do in order to help people like Lynika find their way to science. The first part of that work is changing the way we think. Now that you've seen this exhibition, whose face will you see when you picture a scientist?

One excerpt out of six in this category explicitly recognizes Indigenous peoples' and communities' contributions to scientific research, the history of science, and the role of these communities in contemporary scientific collaborations through curation efforts or scientific research. Recognizing Indigenous communities within the context of NHMs points to the importance of diverse contributions to scientific knowledge in the past and present. It promotes a more inclusive and respectful approach to scientific inquiry that reflects the human dimensions of science and its reliance on collaborative efforts across different cultures and societies.

In the Ylanda Wilhite exhibition, a quote underscores this partnership:

> We were looking for evidence of Native American ancestral sites, and by extension their claim to this land.

The excerpts in this category acknowledge the diverse contributions of scientists by linking them to social certification and the dissemination of scientific knowledge, two of the social-institutional aspects of NOS. The lens of NOS also illustrates the social negotiation and institutional endorsement of credibility, authority, and inclusion in science. In particular, incorporating Indigenous perspectives reflects the broader understanding of science as socially and culturally embedded. This aligns with NOS by underscoring the importance of collaboration and inclusivity in advancing scientific knowledge, while also addressing epistemic justice by recognizing communities that have historically been excluded or misrepresented in scientific institutions. Acknowledging Indigenous knowledge systems in the exhibition context challenges dominant, colonial narratives of science and affirms the legitimacy of alternative epistemologies. These excerpts also emphasize the difference principle, one of the tenets of SJ, since they underscore the importance of valuing diverse contributions to enrich science as a human and cultural endeavor. Emphasizing recognition within exhibitions thus contributes not only to equity by acknowledging the contributions of individuals from marginalized groups, but also to reshaping the sociocultural boundaries of scientific legitimacy.

5.4 Equity Barriers

Four out of 52 excerpts in the exhibitions were related to presenting injustices, discrimination, and historical exclusion of people of color, women, and marginalized groups from science, while highlighting progress and efforts to improve the situation. Thus, this category stresses the importance of equal liberties and presents science as a human endeavor influenced by political and cultural power structures.

At the entrance to the Lynika Strozier exhibition, the first signage presents a stereotypical perception about the identity of a scientist and then provides empirical information on women and people of color in the scientific workforce, followed by quantitative data:

> When you think of a scientist, who do you picture? Someone in white lab coat? What are they doing? Who do they look like? Statistically speaking, they probably look like a white man. Based on data collected in 2019, women make up only about 30% of the scientific workforce. Meanwhile people of color are also outnumbered by white people in science by about 3:1 […] This exhibition aims to recognize the hundreds years of sexism, racism, and classism that cause these discrepancies, and raise up the diverse individuals that make science what it is.

The Janet Voight exhibition described the equity barriers that she has overcome as a woman:

> Janet was the fourth woman to be hired as a curator here at the Field Museum, and was the only female curator for her first several years.
> I do not think I was ever the only woman on a cruise, but the few women on board were always the junior members of the science party—until these last two cruises.—Janet Voight, 2023.
> A recent expedition explored new octopus habitat and behavior—an empowering experience as part of a mostly-female scientific team.

From a NOS perspective, these excerpts not only document individual experiences of exclusion and progression but also reveal how science operates within larger political and cultural power structures. They underscore that science is not immune to societal values and hierarchies. From a SJ perspective, they affirm the necessity of addressing historical inequalities to ensure equitable participation and representation while tracing the structural transformation toward equity in NHMs.

5.5 Collaboration

The exhibitions present examples of collaborations among scientists, with five out of 52 excerpts describing these partnerships during the featured scientists' scientific careers. Collaboration represents a fundamental component of the social-institutional aspects of NOS, where science is understood as a communal and coordinated effort. From a SJ perspective, collaboration is not inherently equitable. Therefore, this category focuses on forms of collaboration that actively promote inclusion, mutual respect, and equitable access to scientific opportunities and resources. These collaborations reflect ethical commitments and institutional practices that foster belonging, redistribute opportunity, and elevate voices from historically marginalized groups.

In the exhibition about Lynika Strozier, a signage read "Science is collaborative," to echo the statements of one of Lynika's close friends and colleagues:

> Science isn't conducted in isolation: it's all about sharing your work in the hopes of collaborating with fellow scientists. And Lynika was special because she was a scientist that could collaborate- and become friends- with anyone.

These statements present Lynika's ability to establish collaborations with colleagues to further scientific research.

The Jingmai O'Connor exhibition highlights the collaborative nature of fossil studies, where different teams work together in various locations to collect data:

> [...] There are museums with fossils to study in almost every country, as well as collaborative fieldwork projects and international scientific conferences.

Jingmai also noted the importance of collaborative efforts in solving environmental issues and stated that diversity in collaboration fosters creativity and innovation:

> To solve the environmental issues we've created, we need a diverse cohort of future scientists. Did you know diversity has been shown to increase creativity and innovation? We need scientists from different backgrounds, working together to save the world.

The Ylanda Wilhite exhibition presents her initiatives to make environmental education more accessible in her community. Her endeavor describes collaboration not only among scientists but also among science educators to make science education more accessible:

> I started a non-profit: Chicago Environmental Educators (CEE). In 2019, Ayesha Qazi (a Chicago Public Schools high school teacher) and I formed CEE. We wanted to eliminate barriers that prevented Chicago teachers from obtaining environmental education resources. Usually if a teacher wants to collaborate with someplace like the Museum, they need to be part of a special program or pay a fee. So, we opened a network connecting educators together without needing to pay anything.

From a NOS lens, this category points to the importance of collaboration with individuals from diverse backgrounds in scientific endeavors. It shows how science, as a socially organized human enterprise, relies on diverse collaborations to achieve its goals. The findings also illustrate how collaboration extends to science education, where partnerships are essential for providing equitable access to resources and fostering inclusivity. From a SJ perspective, this category demonstrates how equitable and inclusive collaborations can contribute to broader SJ goals by challenging structural barriers, fostering professional solidarity, and enabling diverse communities to engage meaningfully in scientific work and education. In this way, collaboration becomes not only a mechanism for scientific progress but also a tool for social transformation, aligning with justice-oriented visions of science as a human endeavor.

5.6 Freedom to Belong in Science

Out of the 52 excerpts, five focused on how freedom of expression and inclusivity contribute to scientific progress. This category highlights the importance of intellectual freedom, personal expression, and a sense of belonging as foundational principles of scientific practice. The exhibition signages illustrate how the ability to express ideas freely, especially for

scientists from historically marginalized or underrepresented groups, contributes not only to individual flourishing but also to advances in science. By documenting personal stories of overcoming challenges, embracing cultural diversity, and thriving in nonjudgmental environments, this category underscores the social and ethical responsibilities of the scientific community to create inclusive spaces. These include fostering open professional discourse, ensuring community-based validation of scientific knowledge, and recognizing the emotional and cultural dimensions of being a scientist.

Ultimately, this category connects the ethos of science with social justice by advocating for equitable participation, valuing diverse ways of knowing, and challenging systemic barriers. It envisions science as a space where everyone can belong, contribute, and grow.

The Janet Voight exhibition describes her public outreach while detailing her scientific discoveries through meeting visitors and publishing both scientific and popular articles:

> […] talking to visitors, mentorship, publishing, book projects, and energetic kitties compete for her attention.[…] Janet has kept herself busy authoring 85 scientific publications and 42 popular publications. Recently, she teamed up with Field Museum artist-in-residence Peggy MacNamara to publish From the Seashore to the Seafloor.

Jingmai O'Connor is cited to emphasize the importance of a supportive and non-judgmental environment:

> […] I loved the freedom from judgment and consumer culture I felt in China (which helped me deal with my anxiety and depression), not to mention the delicious food, incredible fossils, generous funding in support of science, and amazing friendships with people from all over the world.

This quote suggests how working in a culturally diverse and non-judgmental setting enables scientists to focus on their research without the burden of external pressures or societal expectations. These excerpts also show how freedom and recognition of personal struggles are essential to fostering a vibrant scientific community that allows everyone to express their ideas to enrich scientific inquiry and innovation.

5.7 Identity Inspiration

This category covers the factors that inspired the women presented in the exhibition to pursue science. Eighteen out of the 52 exhibition excerpts deal with identity inspirations, including influences from family, mentors, and community leaders. This category covers the milestones, routes, and roots in scientists' lives that significantly influenced their engagement in scientific careers. The signages stress the diverse backgrounds and influential figures that shaped these scientists. The narratives demonstrate how personal and community activities and determination can inspire and shape scientific careers. The exhibition signage illustrates how science is not just a collection of objective facts but a dynamic, human endeavor enriched by the inclusion of diverse voices and experiences.

Jingmai O'Connor credits her mother's academic dedication as her main inspiration for deciding on a science career:

> I was lucky to find my passion thanks to my mom [...] My mom went back to school to get her PhD in Geology when I was 10. Despite having four kids to take care of, she finished in 3.5 years. While my mom was studying, she took us on field excursions and into the lab. We learned about hard work by watching her and helping around the house.

Her story illustrates the family's powerful role in shaping inspiration and underscores the importance of role models in fostering a passion for science.

Ylanda Wilhite was inspired by her grandmothers and parents, who were deeply involved in education and community activism:

> My Grandma Wilhite taught me to advocate for my community and myself. My parents were also teachers at the same school [...]

Her story shows how role models in education and activism can inspire a commitment to both science and social justice.

These narratives emphasize how personal and social influences shape the identities and careers of scientists. Diverse backgrounds and mentors play a crucial role in breaking down barriers and supporting underrepresented groups in science. Overall, "The Changing Face of Science" exhibition series makes the point that science is not just a collection of principles and concepts but a human endeavor shaped by diverse voices and experiences. Thus, it aligns with NOS by emphasizing the influence of social and cultural contexts on scientific practice.

6 Discussion

This study explored the intersection between the social-institutional aspects of NOS and SJ in NHMs in the "Changing Face of Science" exhibition series at the Field Museum in Chicago. Using a two-cycle content analysis, we developed a theoretical framework that sheds light on how these two realms overlap in the exhibition narratives. The first cycle followed a deductive approach guided by the FRA application to NOS (Erduran & Dagher, 2014a, b) and key SJ theories (Rawls, 1985; Crenshaw, 1997; Miller, 2001), whereas the second cycle employed an inductive strategy to generate seven emergent categories illustrating this intersection. The resulting framework presents a multi-layered and socially embedded understanding of science to show how science is constructed, practiced, and communicated within broader sociopolitical structures. The findings form a theoretical framework that highlights how the social-institutional aspects of NOS intersect with SJ in the context of NHM exhibitions. By foregrounding these intersections, this study sheds light on the potential of NHMs as spaces for critical engagement with societal issues, along with the engagement with knowledge about science. In doing so, it contributes to the broader discourse in science education by positioning informal learning environments as vital for fostering a more inclusive and socially responsive understanding of science. It also demonstrates how NHMs, given their cultural authority and wide public reach, are uniquely positioned to serve as platforms for advancing epistemic justice (Santos, 2010) and equity in science education. Through narratives about individual scientists, the exhibitions contextualize science within personal, cultural, and institutional histories, thereby disrupting the image of science as apolitical and universal (Harding, 1998).

Of the seven categories, Multifaceted Realities, Representation, and Equity Barriers make visible the social barriers and systemic exclusions that individuals face in scientific fields. Other categories, such as Recognition, Collaboration, Freedom to Belong in Science, and Identity Inspiration, highlight enabling conditions and relational practices that support inclusive participation and engagement in science. These categories illustrate how SJ principles such as access, representation, and belonging intersect with social-institutional aspects of NOS, including the organization of scientific communities, the role of

institutions, and the certification and dissemination of knowledge (Erduran & Dagher, 2014a, b).

This study contributes to the growing body of literature about the intersection of NOS and SJ in formal science education (Erduran et al., 2020; Hansson & Yacoubian, 2020) by expanding this intersection beyond formal contexts and demonstrating how SJ-oriented NOS frameworks can be applied in informal science education environments. In particular, the findings illustrate how NHMs as civic educators can foster reflection on who creates science, whose knowledge counts, and what values shape scientific inquiry (Andreotti, 2011; Medin & Bang, 2014).

Importantly, the uneven distribution of excerpts across the seven categories suggests a tension in how social-institutional aspects of NOS and SJ are emphasized. Categories such as Identity Inspiration and Multifaceted Realities were more frequently represented, reflecting a clear institutional effort to humanize science and make it relatable and accessible through personal stories. NHMs serve as academic and cultural platforms that provide valuable opportunities for visitors to engage with the individuals behind scientific discoveries and their contributions to science. "The Changing Face of Science" series exemplifies this potential. Each exhibition deals with a single scientist and underscores the importance of diverse backgrounds. This approach makes science more accessible and relatable to a broader audience by encouraging visitors to see themselves as part of the scientific narrative and emphasizing science as a human endeavor. These efforts can inspire a more diverse audience to engage with scientific topics (Kamel, 2019). However, categories critically engaging with structural power, such as Recognition and Equity Barriers, are less well-represented. This imbalance reflects a broader pattern in museum practice where diversity and representation are emphasized, but deeper critiques of colonialism, epistemic injustice, and institutional power are infrequent (Das & Lowe, 2018; Sullivan, n.d.; Harding, 1998). These categories should be recognized more as NHMs evolve towards fourth-generation institutions that reflect a broader commitment to social justice, equity, and community engagement, and redefine their role as agents of change and transformation in society (Pedretti & Navas Iannini, 2020b).

Thus, while the findings confirm that social-institutional aspects of NOS and SJ intersect in the exhibition narratives, they also reveal that this intersection is not always balanced. The framework made it possible to identify gaps where the socio-institutional aspects of NOS could more fully support SJ goals, particularly in areas related to historical accountability, decolonization, and power relations. As Santos (2010) suggested, cognitive justice requires not only recognition of marginalized individuals but also an interrogation of the dominant epistemologies and structural mechanisms that sustain inequality.

From a NOS perspective, the focus on personal identity highlights science as a human endeavor, but may underrepresent how scientific authority is constructed, how decisions about validity are made, and how institutions regulate participation. From an SJ lens, overemphasis on representation risks sidelining the need for structural transformation.

Despite the important contribution of the "Changing Face of Science" exhibition series to promoting diversity and inclusion in science and how it is portrayed in NHMs exhibitions, significant challenges remain. One notable issue is the limited integration of these narratives into permanent displays, as noted by Das and Lowe (2018). This raises critical questions about the long-term institutional commitment of NHMs to addressing structural inequities and historical exclusions in science. As Ash (2022) argued, museums must more comprehensively attend to community needs and societal change by shifting from representational gestures toward sustained, systemic engagement. In this context, a dual focus is needed that acknowledges past injustices while actively highlighting ongoing progress toward equity in

science and considering them when designing exhibitions (Gonzales, 2019). For example, recognizing the historical and cultural contributions of Indigenous communities to scientific research is crucial. This involves not only exhibiting these contributions, but also forming genuine collaborations, engaging in dialogue about ownership and curation of museum objects, and integrating Indigenous epistemologies as legitimate and valued ways of knowing. Such steps align with the social-institutional aspects of NOS that emphasize the social embeddedness, inclusivity, and collaborative dimensions of scientific practice (Erduran & Dagher, 2014a). They also resonate with calls for epistemic justice (Santos, 2010) by challenging dominant narratives and foregrounding other knowledge systems. NHMs thus hold the potential to move beyond representational inclusion and become active agents in reshaping how science is historically situated, socially validated, and publicly understood.

Despite these limitations, the "Changing Face of Science" series represents a promising shift in how science is portrayed in NHMs. Moving beyond a neutral, decontextualized presentation of science can pave the way for conversations about who participates in science, under what conditions, and with what consequences. As museums continue to evolve toward more participatory and justice-oriented models (Pedretti & Navas Iannini, 2020b), they must expand their engagement with NOS and SJ to include not only visible diversity but also critical reflections on science's historical and institutional dimensions.

Overall, this study offers a theoretical framework that highlights how social-institutional aspects of NOS and SJ intersect in informal science education. It contributes to a better understanding of the role of informal science education, especially in NMHs, in promoting citizen awareness of NOS and the influence of science on society, including critical issues related to SJ. It calls on NHMs to recognize their potential as agents of epistemic and social transformation and to design exhibitions that do more than inspire, but also interrogate, challenge, and educate.

7 Limitations and Directions for Future Research

This study analyzed four exhibitions from "The Changing Face of Science" series at the Field Museum in Chicago. These exhibitions present the stories of women and people of color in science, offering inspiration for personal exploration and emphasizing how diverse perspectives, identities, and backgrounds contribute to scientific advancement (The Field Museum, n.d.a). This aim emphasizes themes related to SJ and the social-institutional aspects of NOS. Future research may investigate other contexts and exhibitions that address SJ and NOS from epistemic-cognitive and social-institutional perspectives, as Erduran and Dagher (2014a, b) suggested. Future studies could research this integration in other cultural and geographical contexts, including exploring permanent exhibitions and educational activities conducted within NHMs. Further research could explore the perspectives of exhibition curators, including their intentions, curatorial decisions, and the institutional constraints and opportunities that shape the content and form of displays. Investigating curatorship could reveal how values associated with the NOS and SJ are integrated into the exhibition development process. This type of study could also provide a better understanding of the complex institutional identities of NHMs. Additionally, research on guided tours and ongoing discussions between visitors and museum staff in these museums could provide further insights into the intersection of NOS and SJ in these institutions. Researchers might also examine visitors' experiences and perceptions during their visits to these exhibitions, particularly regarding the

intersection between NOS and SJ. Such investigations would provide a broader understanding of these exhibitions' impact on visitors' perspectives on the characteristics of scientific knowledge, science itself, and its accessibility and relevance to diverse audiences.

Appendix 1

Backgrounds of the scientists in the exhibitions

Scientist	Background
Lynika Strozier	An African American scientist, researcher, and educator. Strozier discovered her passion for science at Truman College and later contributed to significant research at the Field Museum's Pritzker DNA Lab, leading to the discovery of new species. She earned her B.Sc. from the Dominican University and a double M.Sc. in Biology and Science Education in 2018. Strozier also taught biology at Malcom X College and directed the science labs at the School of the Art Institute of Chicago. In 2020, she was awarded the honorary title of Collections Associate at the Field Museum. Sadly, she passed away from COVID-19 that same year at the age of 35 (Dixon, 2020; The Field Museum, n.d.a, n.d.b) Access to photos from the exhibition: https://www.fieldmuseum.org/changing-face-lynika-strozier
Jingmai O'Connor	A vertebrate paleontologist and the Field Museum's Curator of Fossil Reptiles. She earned her PhD at the University of Southern California, studying Mesozoic birds under Dr. Luis Chiappe. Before joining the Field Museum, O'Connor held the rank of professor at the Institute of Vertebrate Paleontology and Paleoanthropology in Beijing, where she spent over a decade. Her prolific research has resulted in over 150 publications, including descriptions of more than 45 new species. Her work focuses on the evolution of flight in dinosaurs, the dinosaur-bird transition, and early bird biology (The Field Museum, n.d.c) Access to a virtual tour of the exhibition: https://www.fieldmuseum.org/the-changing-face-of-science-jing-mai-o-connor
Janet Voight	An Associate Curator of Invertebrate Zoology, and a prominent researcher in cephalopod mollusks, specializing in octopi. With a global reputation for her contributions to deep-sea science, Dr. Voight has expanded her research beyond octopi to examine unique marine life such as wood-boring bivalves and their predators (The Field Museum, n.d.d). Known for her unexpected path into science, Voight leads and collaborates with predominantly female scientific teams, thus demonstrating her expertise and commitment to inclusive science practices. Through her work at the Field Museum, she aims to shed light on the largely unknown world of deep-sea organisms, thus bridging gaps in people's understanding of marine biodiversity (The Field Museum, n.d.a, n.d.d) Access to a virtual tour of the exhibition: https://www.fieldmuseum.org/the-changing-face-of-science-janet-voight

Scientist	Background
Ylanda Wilhite	The Senior Partnership Coordinator for the Keller Science Action Center's Chicago Region team at the Field Museum. She plays an essential role in building strong community connections to nature and promoting environmental stewardship through hands-on activities such as camping and kayaking along local rivers (The Field Museum, n.d.a). Professor Wilhite's work aims to inspire and train the next generation of conservation leaders, by empowering them to take meaningful environmental action within their communities. Through her efforts, she enhances the Field Museum's capacity to support future leaders across both formal and informal educational settings, thus impacting environmental education and advocacy (The Field Museum, n.d.e) Access to a virtual tour of the exhibition: https://www.fieldmuseum.org/the-changing-face-of-science-ylanda-wilhite

Appendix 2

Second cycle content analysis: categories, coding methods, and indicators in the texts

Category	Coding method	Indicators in the text
1. Multifaceted realities	Excerpts that highlight the complex and intersecting life circumstances of scientists (e.g., race, gender, disability, socio-economic status) and how these have shaped their path in science	References to personal or structural challenges (e.g., disability, poverty, single-parent households); descriptions of hardships or underprivileged backgrounds; references to systemic barriers or overcoming adversity
2. Representation	Excerpts that emphasize the visibility and portrayal of historically marginalized groups in science and how these representations can influence public perceptions of who "belongs" in science	References to appearance or identity and public reactions; showcasing diversity in science for inspiration and visibility; challenging stereotypes; portraying scientists as engaged community members or cultural ambassadors
3. Recognition	Excerpts that focus on recognizing, acknowledging, and valuing the contributions of individuals from historically marginalized and underrepresented groups and Indigenous people and communities, formally or informally, through awards, public appreciation, community recognition, or other acts of appreciation	References to honors, awards, thank you notes, or other means of appreciation; references to impactful work, together with references to the ancestral knowledge of Indigenous communities; partnerships with scientists; collaborative curatorial arrangements; declarations linking scientific investigations to land or cultural heritage
4. Equity barriers	Excerpts that present historical and ongoing injustices, exclusion, and discrimination affecting women and people of color in science, alongside progress and efforts toward inclusion	References to statistics or data on workforce gaps; narratives about exclusion or being the first or only one in scientific positions; institutional barriers, and breakthroughs

Category	Coding method	Indicators in the text
5. Collaboration	Excerpts that describe collaborations among scientists and educators emphasizing mutual respect and inclusive practices by fostering belonging, redistributing opportunity, and elevating voices from historically marginalized groups	References to scientific teamwork, fieldwork, or partnerships across countries or communities; inclusive nonprofit efforts
6. Freedom to belong in science	Excerpts that reflect equitable participation, respect for those engaged in scientific work, intellectual freedom, emotional well-being, and cultural belonging as preconditions for scientific contributions	References to cultural comfort, creativity, mental health, personal expression, and freedom of thought; descriptions of non-judgmental environments; emphasis on being oneself in scientific spaces
7. Identity inspiration	Excerpts that explore personal, familial, and community influences that have inspired scientists' career paths	References to family members, teachers, or community leaders as role models or mentors; early experiences shaping scientific interests and careers

Acknowledgements Anna Pshenichny-Mamo gratefully acknowledges the support of the Azrieli Foundation through the award of an Azrieli Fellowship. The authors extend their gratitude to the Exhibitions Development team at the Field Museum for their invaluable assistance and supportive guidance throughout the research process. We extend our gratitude to the three anonymous reviewers of this journal for their constructive feedback on a previous version of this article.

Author Contribution Anna Pshenichny-Mamo: conceptualization, data collection and analysis, investigation, project administration, writing—original draft preparation. Wilton Lodge: conceptualization, data analysis, investigation, writing—review and editing. Dina Tsybulsky: conceptualization, data analysis, investigation, project administration, writing—review and editing.

Funding Open access funding provided by Technion - Israel Institute of Technology.

Data Availability The exhibition texts analyzed in this study were publicly displayed at the Field Museum. Access to these texts is subject to the museum's policies. Researchers interested in obtaining the texts may contact the Field Museum directly for further information.

Declarations

Ethics Approval This study was approved by the University Ethics Committee. Although the research was based on publicly available exhibition content, ethical approval was obtained due to the study's engagement with socially sensitive themes such as equity, representation, and institutional responsibility. The study adhered to ethical guidelines, ensuring respectful handling of exhibit narratives and cultural representations.

Competing Interests The authors declare that they have no competing interests.

References

Abd-El-Khalick, F., & Akerson, V. L. (2004). Learning as conceptual change: Factors mediating the development of preservice elementary teachers' views of nature of science. *Science Education, 88*(5), 785–810. https://doi.org/10.1002/sce.10143

Achiam, M., Lindow, B. E. K., & Simony, L. (2019). Was Archaeopteryx able to fly? Authentic palaeontological practices in a museum programme. *Educação Matemática Pesquisa*, *21*, 112–126. https://doi.org/10.23925/1983-3156.2019v21i4p112-126

Achiam, M., Simony, L., & Lindow, B. E. K. (2016). Objects prompt authentic scientific activities among learners in a museum programme. *International Journal of Science Education, 38*(6), 1012–1035. https://doi.org/10.1080/09500693.2016.1178869

Achiam, M., & Sølberg, J. (2017). Nine meta-functions for science museums and science centres. *Museum Management and Curatorship, 32*(2), 123–143. https://doi.org/10.1080/09647775.2016.1266282

Akgun, S., & Kaya, E. (2020). How do university students perceive the nature of science? *Science & Education, 29*(2), 299–330. https://doi.org/10.1007/s11191-020-00105-x

Allchin, D. (2011). Evaluating knowledge of the nature of (whole) science. *Science Education, 95*(3), 518–542. https://doi.org/10.1002/sce.20432

Allchin, D. (2014). From science studies to scientific literacy: A view from the classroom. *Science and Education, 23*(9), 1911–1932. https://doi.org/10.1007/s11191-013-9672-8

Allchin, D. (2020a). From nature of science to social justice: The political power of epistemic lessons. In H. A. Yacoubian & L. Hansson (Eds.), *Nature of science for social justice* (pp. 23–39). Springer. https://doi.org/10.1007/978-3-030-47260-3_2

Allchin, D. (2020b). Historical inquiry cases for teaching nature of science analytical skills. In W. F. McComas (Ed.), *Nature of science in science instruction: Rationales and strategies* (pp. 595–607). Springer. https://doi.org/10.1007/978-3-030-57239-6_32

Allchin, D., Andersen, H. M., & Nielsen, K. (2014). Complementary approaches to teaching nature of science: Integrating student inquiry, historical cases, and contemporary cases in classroom practice. *Science Education, 98*(3), 461–486. https://doi.org/10.1002/sce.21111

American Alliance of Museums. (2018). *Facing change: Insights from the American Alliance of Museums' diversity, equity, accessibility, and inclusion working group*.

Andreotti, V. (2011). *Actionable postcolonial theory in education*. Springer. https://doi.org/10.1057/9780230337794

Ash, D. B. (2022). *Reculturing museums: Embrace conflict, create change*. Routledge. https://doi.org/10.4324/9781003261681

Ballard, H.L.,Calabrese Barton, A., & Upadhyay, B. (2023). Community-driven science and science education: Living in and navigating the edges of equity, justice, and science learning. *Journal of Research in Science Teaching, 60*(8), 1613–1626. https://doi.org/10.1002/tea.21880

Bamberger, Y., & Tal, T. (2008). Multiple outcomes of class visits to natural history museums: The students' view. *Journal of Science Education and Technology, 17*(3), 274–284. https://doi.org/10.1007/s10956-008-9097-3

Bazzul, J. (2020). Political entanglement and the changing nature of science. In H. A. Yacoubian & L. Hansson (Eds.), *Nature of science for social justice* (pp. 79–95). Springer. https://doi.org/10.1007/978-3-030-47260-3_5

Beeghly, K., Gao, S., & Kruse, J. (2025). Preservice secondary science teachers' nature of science views, rationales, and teaching during a NOS course guided by RFN: A multiple case study. In *Science & Education 34*, 3155–3196. https://doi.org/10.1007/s11191-024-00548-6

Bennett, T. (2013). *The birth of the museum: History, theory, politics*. Routledge. https://doi.org/10.4324/9781315002668

Betsch Cole, J., & Lott, L. L. (Eds.). (2019). *Diversity, equity, accessibility, and inclusion in museums* (1st ed.). Rowman & Littlefield.

Bevan, B., & Xanthoudaki, M. (2008). Professional development for museum educators: Unpinning the underpinnings. *The Journal of Museum Education, 33*(2), 107–119. https://doi.org/10.1080/10598650.2008.11510592

Bichara, D. B., Dagher, Z. R., & Fang, H. (2022). What do COVID-19 tweets reveal about public engagement with nature of science?. *Science and Education, 31*(2), 293–323. https://doi.org/10.1007/s11191-021-00233-y

Bingham, A. J. (2023). From data management to actionable findings: A five-phase process of qualitative data analysis. *International Journal of Qualitative Methods, 22*, 1–11. https://doi.org/10.1177/16094069231183620

Black, G. (2012). *Transforming museums in the twenty-first century*. Routledge. https://doi.org/10.4324/9780203150061

Bleichmar, D. (2011). The geography of observation: Distance and visibility in eighteenth-century botanical travel. In L. Daston & E. Lunbeck (Eds.), *Histories of scientific observation* (pp. 373–395). University of Chicago Press.

Brenner, S. E. (2020). *Decolonizing natural history museums through volunteer engagement*. University of Washington.

Bugingo, J. B., Yadav, L. L., Mugisha, I. S., & Mashood, K. K. (2024). Improving teachers' and students' views on nature of science through active instructional approaches: A review of the literature. *Science and Education, 33*, 29–71. https://doi.org/10.1007/s11191-022-00382-8

Cameron, D. F. (1971). The museum, a temple or the forum. *Curator: The Museum Journal, 14*(1), 11–24.

Caramaschi, M., Cullinane, A., Levrini, O., & Erduran, S. (2022). Mapping the nature of science in the Italian physics curriculum: From missing links to opportunities for reform. *International Journal of Science Education, 44*(1), 115–135. https://doi.org/10.1080/09500693.2021.2017061

Carter, J. (2019). Museums and justice. *Museum Management and Curatorship, 34*(6), 541–543. https://doi.org/10.1080/09647775.2019.1686241

Cheung, K. K. C., & Erduran, S. (2023). A systematic review of research on family resemblance approach to nature of science in science education. *Science and Education, 32*, 1637–1673. https://doi.org/10.1007/s11191-022-00379-3

Clough, M. P. (2006). Learners' responses to the demands of conceptual change: Considerations for effective nature of science instruction. *Science and Education, 15*(5), 463–494. https://doi.org/10.1007/s11191-005-4846-7

Coffee, K. (2022). *Museums and social responsibility*. Routledge. https://doi.org/10.4324/9781003222811

Coffey, A., & Atkinson, P. (1996). *Making sense of qualitative data: Complementary research strategies*. Sage.

Crenshaw, K. (1997). Demarginalizing the intersection of race and sex: A black feminist critique of antidiscrimination doctrine, feminist theory and antiracist policies. In K. Maschke (Ed.), *Feminist Legal Theories* (1st ed., pp. 23–51). Routledge.

Dagher, Z. R. (2020). Balancing the epistemic and social realms of science to promote nature of science for social justice. In H. A. Yacoubian & L. Hansson (Eds.), *Nature of science for social justice* (pp. 41–58). Springer. https://doi.org/10.1007/978-3-030-47260-3_3

Das, S., & Lowe, M. (2018). Nature read in black and white: Decolonial approaches to interpreting natural history collections. *Journal of Natural Science Collections, 6,* 4–14. http://www.natsca.org/article/2509

Datnow, A., Yoshisato, M., Macdonald, B., Trejos, J., & Kennedy, B. C. (2023). Bridging educational change and social justice: A call to the field. *Educational Researcher, 52*(1), 29–38. https://doi.org/10.3102/0013189X221138837

Dawson, E. (2014a). Equity in informal science education: Developing an access and equity framework for science museums and science centres. *Studies in Science Education, 50*(2), 209–247. https://doi.org/10.1080/03057267.2014.957558

Dawson, E. (2014b). "Not designed for us": How science museums and science centers socially exclude low-income, minority ethnic groups. *Science Education, 98*(6), 981–1008. https://doi.org/10.1002/sce.21133

Dixon, E. (2020). *Lynika Sharlice Strozier (1984–2020)*. BlackPast.Org. https://www.blackpast.org/african-american-history/people-african-american-history/lynika-sharlice-strozier-1984-2020/

Dorfman, E. (Ed.). (2018). *The future of natural history museums*. https://doi.org/10.4324/9781315531892-15

Dorfman, E., Landim, I., & Kamei, O. (2018). The future of natural history museums: General discussion. In E. Dorfman (Ed.), *The future of natural history museums* (pp. 229–242). Routledge.

Edmondson, E., Burgin, S., Tsybulsky, D., & Maeng, J. (2020). Learning aspects of nature of science through authentic research experiences. In W. F. McComas (Ed.), *Nature of science in science instruction* (pp. 659–673). Springer. https://doi.org/10.1007/978-3-030-57239-6_36

Erduran, S., & Dagher, Z. R. (2014a). *Reconceptualizing the nature of science for science education*. Springer. https://doi.org/10.1007/978-94-017-9057-4

Erduran, S., & Dagher, Z. R. (2014b). Science as a social-institutional system. In *Reconceptualizing the nature of science for science education* (pp. 137–162). Springer. https://doi.org/10.1007/978-94-017-9057-4_7

Erduran, S., Kaya, E., & Avraamidou, L. (2020). Does research on nature of science and social justice intersect? Exploring theoretical and practical convergence for science education. In H. A. Yacoubian & L. Hansson (Eds.), *Nature of science for social justice* (pp. 97–113). Springer. https://doi.org/10.1007/978-3-030-47260-3_6

Falk, J. (2016) Museum audiences: A visitor-centered perspective. *Loisir Et Societe, 39*(3), 357–370. https://doi.org/10.1080/07053436.2016.1243830

Feinstein, N. W. (2017). Equity and the meaning of science learning: A defining challenge for science museums. *Science Education, 101*(4), 533–538. https://doi.org/10.1002/sce.21287

Francis, B., Mills, M., & Lupton, R. (2017). Towards social justice in education: Contradictions and dilemmas. *Journal of Education Policy, 32*(4), 414–431. https://doi.org/10.1080/02680939.2016.1276218

Frank, P., & Sotto, T. (Eds.). (2022). *From small wins to sweeping change: Working together to foster equity, inclusion, and antiracism in museums*. Rowman & Littlefield.

Galamba, A., & Matthews, B. (2021). Science education against the rise of fascist and authoritarian movements: Towards the development of a pedagogy for democracy. *Cultural Studies of Science Education, 16*(2), 581–607. https://doi.org/10.1007/s11422-020-10002-y

Garibay, C. (2009). Latinos, leisure values, and decisions: Implications for informal science learning and engagement. *The Informal Learning Review, 94*(10), 13.

Garibay, C. (2011). *Responsive and accessible: How museums are using research to better engage diverse cultural communities*. ASTC Dimensions. https://www.astc.org/astc-dimensions/responsive-and-accessible-how-museums-are-using-research-to-better-engage-diverse-cultural-communities/

Gonzales, E. (2019). *Exhibitions for social justice*. Routledge. https://doi.org/10.4324/9781315232812

Graham, M., & Murphy, N. (2010). NAGPRA at 20: Museum collections and reconnections. *Museum Anthropology, 33*(2), 105–124. https://doi.org/10.1111/j.1548-1379.2010.01090.x

Gutwill, J. P., & Allen, S. (2012). Deepening students' scientific inquiry skills during a science museum field trip. *Journal of the Learning Sciences, 21*(1), 130–181. https://doi.org/10.1080/10508406.2011.555938

Hall, S. (Ed.). (1997). *Representation: Cultural representations and signifying practices*. Sage.

Hansson, L. (2018). Science education, indoctrination, and the hidden curriculum. In M. R. Matthews (Ed.), *History, philosophy and science teaching* (pp. 283–306). Springer. https://doi.org/10.1007/978-3-319-62616-1_11

Hansson, L. (2020). Teaching the limits of science with card sorting activities. In W. F. McComas (Ed.), *Nature of science in science instruction: Rationales and strategies* (pp. 627–639). Springer. https://doi.org/10.1007/978-3-030-57239-6_34

Hansson. L., Leden, L., & Pendrill, A. M. (2019). Contemporary science as context for teaching nature of science: Teachers' development of popular science articles as a teaching resource. *Physics Education, 54*(5). https://doi.org/10.1088/1361-6552/ab194e

Hansson, L., & Yacoubian, H. A. (2020). Nature of science for social justice: Why, what and how? In H. A. Yacoubian & L. Hansson (Eds.), *Nature of ⊓cience for social justice* (pp. 1–21). Springer. https://doi.org/10.1007/978-3-030-47260-3_1

Harding, S. (1998). *Is science multicultural?: Postcolonialisms, feminisms, and epistemologies.* Indiana University Press.

Harrison, R. (2012). *Heritage: Critical approaches*. Routledge. https://doi.org/10.4324/9780203108857

Heller, N. E. (2023). Perspective: Is re-interpretation enough? Dismantling violence in the natural history museum. *Curator, 66*(3), 483–491. https://doi.org/10.1111/cura.12559

Helmuth, T. (2024). The research museum–A place of integrated knowledge production. *Science Museum Group Journal*. https://doi.org/10.15180/242204

Holbrook, J., & Rannikmae, M. (2007). The nature of science education for enhancing scientific literacy. *International Journal of Science Education, 29*(11), 1347–1362. https://doi.org/10.1080/09500690601007549

Holliday, G. M., & Lederman, G. N. (2014). Informal science educators' views about nature of scientific knowledge. *International Journal of Science Education, Part B, 4*(2), 123–146. https://doi.org/10.1080/21548455.2013.788802

Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, *15*(9), 1277–1288. https://doi.org/10.1177/1049732305276687

Irzik, G., & Nola, R., (2011). A family resemblance approach to the nature of science for science education. *Science and Education 20*(7), 591–607. https://doi.org/10.1007/s11191-010-9293-4

Kamel, S. (2019). Diversifying Islam and the museum. *Material Religion, 15*(3), 374–375. https://doi.org/10.1080/17432200.2019.1572361

Kampourakis, K. (2020). Foreword. In H. A. Yacoubian & L. Hansson (Eds.), *Nature of science for social justice* (pp. v–vi).

Kapsala, N., & Mavrikaki, E. (2020). Storytelling as a pedagogical tool in nature of science instruction. In W. F. McComas (Ed.), *Nature of science in science instruction: Rationales and strategies* (pp. 485–512). Springer. https://doi.org/10.1007/978-3-030-57239-6_27

Kaya, E., & Erduran, S. (2016). From FRA to RFN, or how the family resemblance approach can be transformed for science curriculum analysis on nature of science. *Science and Education, 25*, 1115–1133. https://doi.org/10.1007/s11191-016-9861-3

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching, 39*(7), 551–578. https://doi.org/10.1002/tea.10036

Killen, M., Yee, K. M., & Ruck, M. D. (2021). Social and racial justice as fundamental goals for the field of human development. *Human Development, 65*(5–6), 257–269. https://doi.org/10.1159/000519698

Koster, E. (2016). Forward. In E. M. Gokcigdem (Ed.), *Fostering empathy through museums*. Rowman & Littlefield.

Kretchmar, J. (2023). *Social justice in education*. https://www.ebsco.com/research-starters/education/social-justice-education

Kuckartz, U. (2019). *Qualitative text analysis: A systematic approach*. 181–197. https://doi.org/10.1007/978-3-030-15636-7_8

Kuhn, T. S. (1970). The structure of scientific revolutions. University of Chicago Press.

Ladson-Billings, G. (1995). Toward a theory of culturally relevant pedagogy. *American Educational Research Journal, 32*(3), 465–491. https://doi.org/10.3102/00028312032003465

Lederman, J. S., & Holliday, G. M. (2017). Addressing nature of scientific knowledge in the preparation of informal educators. In P. G. Patrick (Ed.), *Preparing informal science educators: Perspectives from science communication and education* (pp. 509–525). Springer. https://doi.org/10.1007/978-3-319-50398-1_25

Lederman, N. G., & Lederman, J. S. (2014). Research on teaching and learning of nature of science. S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education II* (pp. 600–620). Routledge.

Lederman, N. G., & Lederman, J. (2020). Nature of scientific knowledge and scientific inquiry. In V. L. Akerson & G. A. Buck (Eds.), *Critical questions in STEM education* (pp. 3–20). Springer. https://doi.org/10.1007/978-3-030-57646-2_1

Levinson, R. (2023). Science education and social justice: A possible dream. In M. Weinstein, C. Pouliot, I. Martins, R. Levinson, L. Carter, L. Bencze, & A. Sharma (Eds.), *Science education towards social and ecological justice: Provocations and conversations* (pp. 95–121). Springer. https://doi.org/10.1007/978-3-031-39330-3_5

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Sage Publications.

Lodge, W. (2021). Confronting repressive ideologies with critical pedagogy in science classrooms. *Cultural Studies of Science Education, 16*(2), 609–620 https://doi.org/10.1007/s11422-021-10047-7

Lonetree, A. (2012). *Decolonizing museums: Representing Native America in national and tribal museums*. University of North Carolina Press.

Marshall, C., Gerstl-Pepin, C., & Johnson, M. (2020). *Educational politics for social justice*. Teachers College Press.

McArthur, J. (2023). Understanding social justice: Why it matters. *PRISM: Casting New Light on Learning, Theory and Practice, 5*(2), 1–8. https://openjournals.ljmu.ac.uk/prism/article/view/1835

McComas, W. F. (2020). *Nature of science in science instruction*. Springer. https://doi.org/10.1007/978-3-030-57239-6

McComas, W. F., & Clough, M. P. (2020). Nature of science in science instruction: Meaning, advocacy, rationales, and recommendations. In W. F. McComas (Ed.), *Nature of science in science instruction: Rationales and strategies* (pp. 3–22). Springer. https://doi.org/10.1007/978-3-030-57239-6_1

McDonald, C. V., & Abd-El-Khalick, F. (2017). Representations of nature of science in school science textbooks. In C. V. McDonald & F., Abd-El-Khalick (Eds.), *Representations of Nature of Science in School Science Textbooks: A Global Perspective* (1st ed., pp. 1–19). Routledge. https://doi.org/10.4324/9781315650524-1

Medin, D. L., & Bang, M. (2014). *Who's asking?: Native science, western science, and science education.* MIT Press.

Mensah, F. M. (2011). A case for culturally relevant teaching in science education and lessons learned for teacher education. *Journal of Negro Education, 80*(3), 296–309.
Mesci, G., & Schwartz, R. S. (2017). Changing preservice science teachers' views of nature of science: Why some conceptions may be more easily altered than others. *Research in Science Education, 47*(2), 329–351. https://doi.org/10.1007/s11165-015-9503-9
Miller, D. (2001). Principles of social justice. Harvard University Press.
Mork, S. M., Haug, B. S., Sørborg, Ø., Parameswaran Ruben, S., & Erduran, S. (2022). Humanising the nature of science: An analysis of the science curriculum in Norway. *International Journal of Science Education, 44*(10), 1601–1618. https://doi.org/10.1080/09500693.2022.2088876
Moura, C. B., Jager, I. T., & Guerra, A. (2020). Teaching about sciences in/for the global south: Lessons from a case study in a brazilian classroom. In H. A. Yacoubian & L. Hansson (Eds.), *Nature of science for social justice* (pp. 137–156). Springer. https://doi.org/10.1007/978-3-030-47260-3_8
Mueller, M. P. (2011). Ecojustice in science education: Leaving the classroom. *Cultural Studies of Science Education, 6*(2), 351–360. https://doi.org/10.1007/s11422-011-9333-7
Nouri, N., & McComas, W. F. (2021). History of science (HOS) as a vehicle to communicate aspects of nature of science (NOS): Multiple cases of HOS instructors' perspectives regarding NOS. *Research in Science Education, 51*, 289–305. https://doi.org/10.1007/s11165-019-09879-9
Paris, S. G., & Hapgood, S. E. (2002). Children learning with objects in informal learning environments. In S. G. Paris (Ed.), *Perspectives on object-centered learning in museums* (pp. 37–54). Lawrence Erlbaum Associates.
Patton, M. Q. (2002). *Qualitative research and evaluation methods*. Sage.
Pedretti, E., & Navas Iannini, A. M. (2020a). *Controversy in science museums: Re-imagining spaces and practice*. Routledge. https://doi.org/10.4324/9780429507588
Pedretti, E., & Navas Iannini, A. M. (2020b). Towards fourth-generation science museums: Changing goals, changing roles. *Canadian Journal of Science, Mathematics and Technology Education, 20*(4), 700–714. https://doi.org/10.1007/s42330-020-00128-0
Piqueras, J., Achiam, M., Edvall, S., & Ek, C. (2022). Ethnicity and gender in museum representations of human evolution: The unquestioned and the challenged in learners' meaning making. *Science & Education, 31,* 1517–1540. https://doi.org/10.1007/s11191-021-00314-y
Popper, K. (2003). *The open society and its enemies: Hegel and Marx*. Routledge.
Prôa, M., & Donini, A. (2019). Museums, nature, and society: The use of natural history collections for furthering public well-being, inclusion, and participation. *Theory and Practice: The Emerging Museum Professionals Journal, 2*, 1–18.
Proper, H., Wideen, M. F, & Ivany, G. (1988). World view projected by science teachers: A study of classroom dialogue. *Science Education, 72*(5), 547–560. https://doi.org/10.1002/sce.3730720502
Pshenichny-Mamo, A., Demarse, M., Howard Hunter, R., & Tsybulsky, D. (2025). Exploring the educational potential of climate change exhibitions in natural history museums. In O. Morin, C. Bruguière, & M. Hammann (Eds.), *Challenges of a changing world in biology education. Contributions from biology education research.* Springer. https://doi.org/10.1007/978-3-032-05346-6
Pshenichny-Mamo, A., & Tsybulsky, D. (2024). Museum guides' views on the integration of the nature of science while addressing visitors' experiences: The context of ecological and evolutionary issues. In K. Korfiatis, M. Grace, & M. Hammann (Eds.), *Shaping the future of biological education research. Contributions from biology education research* (pp. 79–91). Springer. https://doi.org/10.1007/978-3-031-44792-1_6
Pshenichny-Mamo, A., & Tsybulsky, D. (2025). Natural history museum guides' conceptions on the integration of the nature of science. *Science & Education, 34,* 511–529. https://doi.org/10.1007/s11191-023-00469-w
Rawls, J. (1985). Justice as fairness: Political not metaphysical. *Philosophy and Public Affairs, 14*(3), 223–251.
Rawls, J. (1999). *A theory of justice*. The Belknap Press of Harvard University. https://doi.org/10.1007/BF00136652
Reiss, M. J., & McComas, W. F. (2020). Informal learning sites and their role in communicating the nature of science. In W. F. McComas (Ed.), *Nature of science in science instruction: Rationales and strategies* (pp. 711–729). Springer. https://doi.org/10.1007/978-3-030-57239-6_39
Rimmel, G., & Cordazzo, M. (2021). Deductive versus inductive content analysis: A methodological research note to disclosures studies in intellectual capital research. In J. Dumay, C. Nielsen, M. Lund, M. Massao, & J. Guthrie (Eds.), *Research Handbook on Intellectual Capital and Business* (pp. 109–124). Edward Elgar Publishing. https://doi.org/10.4337/9781785365324.00013
Sandell, R., & Nightingale, E. (Eds.). (2013). *Museums, equality and social justice*. Routledge. https://doi.org/10.4324/9780203120057-23

Santos, B. S. (2010). Para além do pensamento abissal: Das linhas globais a uma ecologia de saberes. In B. S. Santos & M. P. Meneses (Eds.), *Epistemologias do Sul* (pp. 23–72). Almedina.

Santos, B. S., & Meneses, M. (2010). Introdução. In B. S. Santos & M. P. Meneses (Eds.), *Epistemologias do Sul* (pp. 9–20). Almedina.

Shenton, A. K. (2004). Strategies for ensuring trustworthiness in qualitative research projects. *Education for Information, 22*(2), 63–75. https://doi.org/10.3233/EFI-2004-22201

Sullivan, J. (n.d.). *Hidden figures: Forgotten contributions to natural history*. Natural History Museum, London. https://www.nhm.ac.uk/discover/hidden-figures-forgotten-contributions-to-natural-history.html

Terrall, M. (2011). Frogs in the mantelpiece: The practice of observation in daily life. In L. Datson spsampsps & E. Lunbeck (Eds.), *Histories of scientific observation* (pp. 185–205).

The Field Museum. (n.d.a). *Janet Voight*. Retrieved January 12, 2025, from https://www.fieldmuseum.org/about/staff/profile/janet-voight

The Field Museum. (n.d.b). *Jingmai O'Connor*. Retrieved January 12, 2025, from https://www.fieldmuseum.org/about/staff/profile/jingmai-o-connor

The Field Museum. (n.d.c). *Lynika Strozier*. Retrieved January 12, 2025, from https://www.fieldmuseum.org/changing-face-lynika-strozier

The Field Museum. (n.d.d). *The Changing Face of Science*. Retrieved January 12, 2025, from https://www.fieldmuseum.org/exhibition/the-changing-face-of-science

The Field Museum. (n.d.e). *Ylanda Wilhite*. Retrieved January 12, 2025, from https://www.fieldmuseum.org/about/staff/profile/ylanda-wilhite

Tsybulsky, D. (2018). Comparing the impact of two science-as-inquiry methods on the NOS understanding of high-school biology students. *Science and Education, 27*(7), 661–683. https://doi.org/10.1007/s11191-018-0001-0

Tsybulsky, D. (2019). Students meet authentic science: The valence and foci of experiences reported by high-school biology students regarding their participation in a science outreach programme. *International Journal of Science Education, 41*(5), 567–585. https://doi.org/10.1080/09500693.2019.1570380

Tsybulsky, D., Dodick, J., & Camhi, J. (2018a). High-school students in university research labs? Implementing an outreach model based on the 'science as inquiry' approach. *Journal of Biological Education, 52*(4), 415–428. https://doi.org/10.1080/00219266.2017.1403360

Tsybulsky, D., Dodick, J., & Camhi, J. (2018b). The effect of field trips to university research labs on Israeli high school students' NOS understanding. *Research in Science Education, 48*(6), 1247–1272. https://doi.org/10.1007/s11165-016-9601-3

Tythacott, L. (2010). Politics of representation in museums. In J. D. McDonald & M. Levine-Clark (Eds.), *Encyclopedia of library and information sciences* (3rd ed., pp. 4230–4241). CRC Press. https://doi.org/10.1081/E-ELIS3-120044117

Williams, C. T., & Rudge, D. W. (2019). Effects of historical story telling on student understanding of nature of science. *Science and Education, 28*(9–10), 1105–1133. https://doi.org/10.1007/s11191-019-00073-x

Witucki, A., Beane, W., Pleasants, B., Dai, P., & Rudge, D. W. (2023). An explicit and reflective approach to teaching nature of science in a course-based undergraduate research experience. *Science and Education, 33*(6), 1371–1399. https://doi.org/10.1007/s11191-023-00441-8

Yacoubian, H. A., & Hansson, L. (Eds.). (2020). *Nature of science for social justice*. Springer. https://doi.org/10.1007/978-3-030-47260-3

Yuwono, M. A., & Rachmawati, D. (2023). Combined methods. Can this solve the differences between deductive and inductive methods in qualitative research? *Moroccan Journal of Quantitative and Qualitative Research*, *5*(3). https://doi.org/10.48379/IMIST.PRSM/mjqr-v5i3.45541

Zacharia, Z., & Barton, A. C. (2004). Urban middle-school students' attitudes toward a defined science. *Science Education, 88*(2), 19710.1007/978-3-030-47260-3222. https://doi.org/10.1002/sce.10110