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Building capacity for inclusive informal STEM learning opportunities for autistic learners



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Abstract

Background Research is needed to better understand the specific challenges for autistic learners in informal STEM learning settings. This study aimed to increase inclusion in STEM museums, with a larger goal of increasing the impact (i.e., learning and application of knowledge during and after visits) of informal STEM learning settings for autistic youth. We conducted an online parent attitudes survey with 93 parents of autistic adolescents and 53 parents of adolescents in the general population to better understand the experiences of autistic adolescents when visiting STEM-related museums. Parent responses informed professional development training for museum staff at four partner museums, which taught strategies to better support autistic learners. Then, autistic adolescents ($n=20$) and their parents were randomly assigned to visit one partner and one control museum. They were asked to report their experiences through an online survey and semi-structured interviews.

Results Participants who completed the parent attitudes survey indicated significantly lower inclusion, engagement, and general impact of STEM museum visits among autistic adolescents compared to the general population comparison group. Parents of adolescents who visited partner and control museums reported higher STEM impact during visits to partner museums; however, parent-reported inclusion, engagement, and general impact did not differ significantly between partner and control museums. Qualitative analysis identified four themes (*Spectrum of Museum Impact*; *Adolescent-Environment Fit*; *Barriers to Engagement*, and *Barrier Breakers*), providing context for quantitative findings.

Conclusions Findings underscore the need for increased inclusion for autistic individuals in informal STEM learning environments like museums. This project demonstrated feasibility of professional development training of forward-facing staff and identified several themes that should inform future efforts to improve inclusion in informal STEM learning settings.

Keywords Informal learning settings, Museums, Autism spectrum disorder, Neurodiverse learners, Inclusion, Inclusive practices, Professional development training, Mixed-methods

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Introduction

Autism Spectrum Disorder (ASD) is a lifelong neurodevelopmental condition that involves persistent challenges with social communication and restricted, repetitive patterns of behavior (American Psychiatric Association, 2022). Approximately 1 in 36 8-year-old children in the US are diagnosed with ASD (Maenner et al., 2023) and there is significant heterogeneity within the autism spectrum. Autistic individuals demonstrate a diversity of strengths, which are often overshadowed by challenges introduced by environments that are not inclusive of neurodiversity (Pellicano et al., 2022). For a large proportion of the autistic population, challenges associated with ASD are linked to limited independence, difficulties with social relationships, and/or low employment rates (Forbes et al., 2023) alongside challenges with finding and maintaining jobs (Newman et al., 2011).

Research suggests that autistic individuals may have more proclivity for STEM (Science, Technology, Engineering, and Mathematics) disciplines than their non-autistic peers (Wei et al., 2012). Autistic individuals are also theorized to share characteristics that may predispose them to succeed with tasks relevant to a career in STEM (Baron-Cohen & Lombardo, 2017). Specifically, Baron-Cohen and colleagues propose that autistic individuals are more likely than non-autistic individuals to be dominant in “systemizing”; or a drive to identify, analyze, and make systems (Greenberg et al., 2018; Pan et al., 2022; Wakabayashi et al., 2006). However, only 44% of autistic adults pursue post-secondary education (Newman et al., 2011). There is an increasing demand for STEM professionals in the workforce (Olson & Riordan, 2012), and the strengths and talents of autistic individuals are a potentially underutilized resource.

Building science capital

Social capital, including perceived support from parents and positive attitudes regarding employment among parents and peers, is associated with higher employment rates for autistic individuals (Holwerda et al., 2013). Similarly, an individual’s science capital has the capacity to affect their attitudes towards STEM education and employment (Archer et al., 2015). Science capital is a theoretical lens that includes key factors that make some individuals more likely than others to identify and engage with STEM and pursue related careers (e.g., scientific literacy, science media consumption, participation in out-of-school science learning contexts, family science knowledge). Students in the general population with greater science capital are more likely to have high self-efficacy regarding their STEM coursework and be more inclined toward higher education in STEM or STEM careers (Archer et al., 2015; Christidou et al., 2021).

However, no published research to our knowledge has examined science capital or STEM self-efficacy among autistic individuals. Increasing access to STEM learning opportunities may facilitate development of science capital and STEM self-efficacy in autistic learners, which, in turn, may lead to increased likelihood of pursuing STEM education and careers.

Informal learning environments

Several studies have examined the contributions of informal learning, or learning outside of a traditional classroom setting, to STEM outcomes in the general population. The National Research Council Committee on Learning Science in Informal Environments reports three categories of informal learning: everyday experiences (i.e., encounters with scientific phenomena in the natural world), designed settings (i.e., public spaces for learning, like museums), and programs for science learning (i.e., special interest science programs, like school chemistry club; Bell et al., 2009; Kotys-Schwartz et al., 2011). Informal learning is initiated by the individual and involves engaging in an activity related to the learning topic (Callanan et al., 2011), which, in turn, can provide a framework for a knowledge base that can help build meaningful connections with STEM professions (Denson et al., 2015).

Informal learning may also make a difference for neurodiverse learners. One study examined a “maker program” (i.e., hands-on project-based learning) that improved technology and engineering skills and interest among autistic participants (Martin et al., 2020). Similarly, a systematic review on informal learning in robotics found enhanced engagement and performance in learners with neurodevelopmental disorders across various robotics-related tasks and outcome measures (Pivetti et al., 2020). However, there remains a need for more studies that elucidate potential benefits and specific challenges for autistic learners in informal learning spaces.

Inclusion in informal learning environments

Although informal learning environments have significant potential to benefit autistic individuals, many may encounter barriers in public spaces. Parents of autistic individuals report feeling pressure to modify, manage, or even hide their child’s behavior to avoid being misunderstood in public (Farrugia, 2009; Ryan, 2010; Turnock et al., 2022). Autistic individuals report feeling overwhelmed by aversive sensory stimuli in public places, making it challenging to engage with the environment. This can also lead to avoidance of such spaces, consequently decreasing community engagement (Bagatell et al., 2022; Davidson, 2010). Parent reports of art museum experiences revealed neurotypical children were

three times more likely to participate in activities than autistic children, whereas parents of autistic children were three times more likely to experience negative emotions (e.g. feeling, nervous, angry, irritable, ashamed, and alone) about their visit than parents of neurotypical children (Antonetti & Fletcher, 2016). In a similar study, parents of autistic children reported unpredictable sensory stimuli and unpredictable child behavior as barriers to engagement (Langa et al., 2013).

Museum spaces with low inclusion may be rooted in a lack of understanding of autistic individuals' needs. Autistic individuals are incredibly diverse but share important characteristics (e.g., social communication challenges; difficulty with change; sensory sensitivities) which may broadly impact their museum experiences. To design inclusive informal learning environments, it is critical to identify factors that preclude and facilitate engagement for autistic individuals and their families. Crucially, efforts to increase inclusion have the potential to benefit the autism community and the general population. Increased inclusion and accessibility will facilitate a sense of belonging for autistic learners and their family members, as well as increased opportunities for the development of science capital and STEM self-efficacy. Although inclusive practices aim to increase engagement for individuals who might otherwise be excluded, they often improve engagement for everyone (Meyer et al., 2014). Simultaneously, including autistic individuals and their families in informal learning settings can enhance autism acceptance and understanding among staff, visitors, and the broader community, while also recognizing the valuable contributions autistic individuals make to society.

Current study

The current study was one component of the first phase of a larger project that focused on four museums in the Phoenix-metropolitan area in the US state of Arizona. Phase 2 of the project has begun and will extend efforts at facilitating inclusion in informal learning environments in three additional cities throughout the US. The overarching theory for the larger project posits that improving *inclusion* (i.e., the extent to which adolescents and parents perceive museum spaces to be welcoming and accessible) in STEM museums will lead to increased *engagement* (i.e., meaningful interaction with museum materials and staff around topics of interest to the adolescent). Increased engagement will result in increased *impact* (i.e., salient evidence that the adolescent engaged in learning and application of knowledge, including learning something new, connecting material to pre-existing knowledge, developing a new or existing interest, applying information learned at the museum, or learning

about careers related to the museum content) of STEM museum visits. Last, increased impact will build *science capital* and increase the likelihood of autistic individuals pursuing higher education and careers in STEM. In the context of current study's focus on building STEM capital and the reality that many STEM-related informal settings also include non-STEM content, impact was conceptualized as two categories: general impact (e.g., learning and application of any topic) and STEM impact, which is highly consistent with the STEM capital construct.

The objective of Phase 1 was to build capacity for increased inclusion in informal STEM learning environments, with a larger goal of increasing the impact of museum visits for autistic youth. The current study was guided by two research questions (RQ):

RQ 1: Do autistic adolescents experience different levels of inclusion, engagement, and impact at STEM-related museums compared to non-autistic adolescents?

RQ 2: Do the experiences of autistic adolescents and their parents differ during visits to museums that receive and do not receive professional development training in inclusive practices?

Aim 1: Parent attitudes survey

To examine RQ1, we conducted an online attitudes survey with parents of autistic adolescents in Arizona to better understand their experiences when visiting STEM-related museums. Parent responses were reviewed and used to inform professional development training for museum staff, which aimed to teach inclusive practices to better support autistic learners. To contextualize the experiences of autistic adolescents, we conducted a similar survey with a comparison sample of parents visiting STEM-related museums with their adolescents who were presumed to be a general population sample. Specifically, we predicted that autistic adolescents would experience lower levels of inclusion, engagement, and impact during museum visits relative to a general population sample.

Aim 2: Perceived inclusion, engagement, and impact during visits to partner and control museums

To examine RQ2, we explored the effect of staff professional development training on autistic adolescents' museum visits using a quasi-experimental within-subject design. Specifically, we asked adolescent-parent dyads to report about their experiences at a partner museum (PM; i.e., staff received training) and a control museum (CM; i.e., staff did not receive training). We predicted that participants would report higher inclusion, engagement, and impact during PM visits relative to CM visits. We also analyzed semi-structured interviews to explore features of visits that affected participants' experiences, and whether these features differed between PMs and CMs.

Methodological limitations introduced by the COVID-19 pandemic

The first phase of the Building Capacity project was conducted from Fall 2020 to Summer 2023 but was designed prior to the COVID-19 pandemic. We initially planned to implement a pre-post design where autistic adolescents and their parents would report on their experiences at museums before and after staff received professional training in inclusive practices. To accommodate closures of public spaces during the first year of the project, we transitioned from the original pre-post design to a quasi-experimental within-subject design. Rather than visiting partner museums pre- and post- training, each family was assigned to visit one partner museum post-training and one control museum that did not receive any training. Further details on study design and related limitations are outlined in the Methods and Limitations sections.

Methods

Participants

Aim 1: Parent attitudes survey

Demographics for all participants are reported in Table 1. Participants included 93 parents of autistic adolescents (ages 10–18 years) who visited at least one museum with their adolescent between 2016 and 2019 (i.e., before the pandemic led to closures of public venues) and a community comparison sample of 53 parents of adolescents (ages 10–18 years) visiting a STEM-related museum who were presumed to be a general population sample. Parents of autistic adolescents were recruited from a database of families maintained by the autism center where this research was conducted. Study information was also shared on the autism center's social media platforms and those of other autism-related organizations. The community comparison sample was a convenience sample recruited before or after museum visits with their adolescents. Informed consent was obtained from parents before they completed the questionnaire.

Aim 2: Perceived inclusion, engagement, and impact during visits to partner and control museums

Participants included 20 adolescents ages 10–18 years with an ASD diagnosis and one parent of each child. Participants were recruited by emails to families in a database maintained by the non-profit autism center, social media posts, and word of mouth. The Autism Diagnostic Observation Schedule, Second Edition (ADOS-2; Lord et al., 2012) was used to confirm clinical ASD diagnoses and participants had a composite IQ score of 70 or above on the Kaufman Brief Intelligence Test, Second Edition

(KBIT-2; Kaufman & Kaufman, 2004). Informed consent and assent were obtained from all adolescent-parent dyads.

Procedures

Aim 1: Parent attitudes survey

All study procedures were approved by the Heartland Institutional Review Board. Between February and December 2021, we collected information from parents who visited at least one STEM-related museum with their autistic adolescent between 2016 and 2019. We also collected information from parents in the general population comparison sample. Parents were asked to complete a questionnaire about their experiences at STEM-related museums to provide an understanding of perceived inclusion, engagement, and impact of museum visits. Additionally, open-ended questions were designed to identify strategies to improve the museum environment for autistic learners and their families.

Aim 2: Perceived inclusion, engagement, and impact during visits to partner and control museums

Professional development training Following review of questionnaire responses, adaptations were made to an existing inclusion training model that was already being delivered by the non-profit autism center to staff at various public venues (e.g., summer camps, schools) to better support autistic individuals. The original training model used Behavior Skills Training (BST), an evidence-based method for teaching new skills to staff (Reid, 2017) to teach competencies derived from the Kids Included Together Inclusion Checklist for Programs (Kids Included Together, 2017) and several other evidence-based practices promoting inclusion (e.g., Stahmer et al., 2011). BST methods teach skills systematically by providing instructions, modeling the skill, providing opportunities for rehearsal of the skill, and providing feedback (Reid, 2017). Primary adaptations to the existing model were based on parent questionnaire responses and focused on facilitating positive staff-initiated interactions with museum visitors, communicating available accommodations with all museum visitors, and providing interactive, hands-on activities. We began professional development training at four PMs in the Phoenix area from November 2021 to April 2022. Two Board-Certified Behavior Analysts (BCBA) employed by the non-profit autism center conducted training and consultation with museum staff. Both BCBA's had experience training parents in behavior intervention techniques and training staff in inclusive practices at other public venues.

The first phase of training involved a 90-min didactic on ASD and inclusion for all staff at each of the four PMs. The didactic was conducted through Zoom and

Table 1 Participant Demographics

	Parent Attitudes Survey			Museum Visit Sample
	Parents of Minimally Speaking Adolescents (n = 21) <i>M (SD) or %</i>	Parents of Adolescents with Fluent Speech (n = 72) <i>M (SD) or %</i>	Parents of General Population Comparison Sample (n = 53) <i>M (SD) or %</i>	Adolescent-Parent Dyads (n = 20) <i>M (SD) or %</i>
Adolescent age	13.95 (2.46)	13.40 (2.73)	12.92 (2.06)	14.10 (2.18)
Adolescent gender identity (%)				
Male	95.2%	73.6%	30.2%	65%
Female	4.8%	23.6%	62.3%	30%
Non-binary, Transgender, and Other	0%	2.8%	7.5%	5%
Adolescent race/ethnicity				
Asian/Asian American	4.8%	0.0%	5.7%	0%
Black/African American	0%	2.8%	5.7%	5%
Latinx/Hispanic/Latin American	19.0%	11.1%	34.0%	25%
Middle Eastern/Middle Eastern American	0%	1.4%	0.0%	0%
Multiracial or Biracial	14.3%	8.3%	5.7%	10%
Native American/American Indian/Alaskan Native	4.8%	0%	1.9%	0%
White	57.1%	75%	45.3%	60%
Prefer not to answer	0%	1.4%	1.9%	0%
Adolescent ADOS-2 Calibrated Severity Score	–	–	–	8.25 (1.57) ^a
Adolescent KBIT-2 Composite IQ	–	–	–	102.28 (15.94) ^b
Parent type (%)				
Mother	95.2%	95.8%	73.6%	100%
Father	4.8%	4.2%	17.0%	0%
Other	0%	0%	9.4%	0%
Parent Education				
Some high school	4.8%	1.4%	3.8%	0%
High school diploma or equivalent	0%	0%	17.0%	5%
Some college or 2-year degree	23.8%	25.0%	28.3%	10%
4-year college degree	47.6%	36.1%	28.3%	40%
Master's degree or advanced credential	19.0%	25.0%	17.0%	40%
Doctoral degree	4.8%	5.6%	1.9%	0%
Other	0%	0%	3.8%	5%
Annual Household Income				
< \$25,000	4.8%	2.8%	1.9%	5%
\$25,000–49,999	14.3%	16.7%	22.6%	20%
\$50,000–74,999	9.5%	12.5%	17.0%	10%
\$75,000–\$99,999	14.3%	20.8%	13.2%	20%
\$100,000–\$124,999	28.6%	22.2%	13.2%	15%
\$125,000–\$149,999	4.8%	8.3%	15.1%	15%
> \$150,000	23.8%	16.7%	0.0%	15%
Prefer not to answer	0%	0%	17%	0%

ADOS-2 Autism Diagnostic Observation Schedule, Second Edition. KBIT-2 Kaufmann Brief Intelligence Test, Second Edition

^a n = 16 due to missing data. ^b n = 18 due to missing data

included basic information about ASD prevalence, core symptoms, behavioral characteristics, strengths, and the compatibility between strengths exhibited by many

autistic individuals and STEM disciplines. Additionally, the training identified and gave examples of inclusion, accessibility, and accommodations. Staff attending the

training learned about the larger goals of the project (i.e., organizational change; inclusive strategies geared toward universal design; future scaling-up of the professional development training to work toward systems change).

After the initial staff training, leadership at each museum completed a checklist about inclusive practices adapted from the Inclusion Checklist for Programs (Kids Included Together, 2017) to identify areas where their museum could increase inclusion. The BCBAs then interviewed leadership to collect additional information about their current practices and to develop a training schedule that would be feasible and acceptable for each museum’s staff. Tailored to the needs of each organization, the BCBAs developed a plan for staff development with measurable goals for each staff member. The plan was reviewed with members of each museum’s leadership team to support organizational culture shift and integration of new practices across the museum.

BST was used to teach inclusive practices to 71 forward-facing staff members (i.e., front-desk; informal educators) from 4 PMs. Information on PMs and the type of

staff is reported in Table 2. This phase of the professional development training was referred to as “coaching” and focused on seven key components related to inclusive practices to support learning during museum visits (see Table 3). Coaching sessions included in-field supervision, verbal feedback, and checklists to provide meaningful and specific insights into maintaining or enhancing implementation practices. The total number of coaching hours (range 34 to 85) varied across museums depending on staff size. During coaching sessions, BCBAs introduced and provided rationale for the target skill, modeled the skill, provided an opportunity for the trainee to practice the skill (i.e., role plays and in-vivo interactions with visitors), and provided feedback iteratively until the trainee demonstrated the skill with fidelity (see Appendix A for an example competency, role plays, and fidelity of implementation checklist). The BCBA visited a respective museum for 3–4 h at a time and provided 1:1 coaching to staff members who were on site. After defining and modeling the respective skill, the BCBA set up at least three opportunities for the staff member to practice

Table 2 Partner and control museums

Museum	Approximate size	Focal topic	Trained staff
Partner 1	140,000 square feet	Science	15 front desk staff; 22 educator staff
Partner 2	80,000 square feet	Natural history of the American Southwest	6 front desk staff; 6 educator staff
Partner 3	20,000 square feet	Early learning in STEAM	5 front desk staff; 12 educator staff
Partner 4	5 Acres of Publicly Accessible Trail; 7,000 square feet of indoor space	Native American history	5 front Desk Staff
Control 1	80,000 square feet	Musical instruments	N/A
Control 2	48,000 square feet	Interactive learning and play	N/A
Control 3	31,000 square feet	Aircraft history	N/A
Control 4	20,000 square feet	Dinosaurs	N/A

The geographical area where the study was conducted does not have 8 STEM-focused museums. However, all museums included STEM-related exhibits

Table 3 Professional development training focal concepts

Concept	Definition
Composure	This concept was derived from the Behavioral Skills Framework and reflects “the extent to which a person is relatively calm, serene, and able to manage emotions effectively” (Colbow et. al, 2017) in interactions with a patron
Connection	The effort made to create a relationship with each patron, such that the interaction is more than a transaction
Engagement	A way of interacting with a patron which identifies what a person likes, identifies their communication style, provides a clear opportunity, and responds by providing feedback
Inclusive Language	Language that focuses on individual strengths and, in doing so, directly avoids language that focuses on deficits, negative impressions, and isolating patrons who are different
Accommodations and Accessibility	Strategies, tools, and equipment that support a patron to experience an environment or access learning content
Active Listening	An effort to not only listen to what someone is saying, but also to attune to their thoughts and feelings. Active listening turns a conversation with a patron into an active, non-competitive, two-way interaction
Visual Supports	Something a patron is shown, such as a picture, checklist, or map, to help them understand or remember information

during in-vivo interactions with museum visitors. If a real-world opportunity was not feasible (e.g., no visitors at the museum), the BCBA set up a role-play opportunity. The BCBA collected data on the staff member's fidelity of implementation and provided the staff member feedback after each practice opportunity. If the staff member did not demonstrate fidelity of implementation (mastery criteria = 80%) for the skill after three practice opportunities, they were given additional opportunities to practice, sometimes on a different day. The 1:1 coaching session ended after the staff member demonstrated competency in the respective skill, at which point the BCBA began working with a different staff member. Fidelity of implementation data were collected for each staff member on all skills at baseline and three additional time points to document progress. The goal was for all staff members to implement skills with fidelity before removing supervision. All but one staff member achieved this goal before the end of the project's training.¹

Partner and control museum visits Participants were given tickets to one of four PMs and one of four CMs. The characteristics of PMs and CMs are presented in Table 2. Importantly, all museums included STEM-related material even though some did not have an explicit STEM focus. For example, the CM with a focus on musical instruments includes a STEM gallery focused on STEM as it relates to musical instruments. CMs were chosen to match the square footage and focal topics of PMs; however, perfect matching was not possible due to the limited volume of museums in the geographical area. Visits were counterbalanced, with half visiting a PM museum first and the other half visiting a CM first. Participants were blinded to whether staff received professional development training and staff were blinded to the participants' visits. After each visit, parents interviewed their adolescents about their experience and parents were interviewed by a member of the research team. Interview protocols are reported in Appendix B. Adolescent interviews were recorded and shared with the research team using a HIPAA-compliant cloud-based system. Parents also completed a questionnaire about perceived inclusion, adolescent engagement, and impact. Participants were blinded to both interview and survey questions until after the completion of their first visit; thus, they may have been primed to look for more examples of inclusion (or lack thereof) during their second visit. However, visits to PMs and CMs were coun-

terbalanced, which means any bias introduced would be equal across PMs and CMs.

Measures

Participant demographics

Parents reported on demographics like adolescent age, gender identity, racial/ethnic background, and socioeconomic background. Participants in the parent attitudes sample reported on their adolescent's language level by choosing one of four responses that best described their adolescent. To facilitate a more nuanced examination of museum experiences of adolescents with varying levels of speech, Aim 1 participants were split into two groups based on parent report: (1) minimally speaking (ranging from no spoken words to simple phrase communication only) (2) fluent speech (spontaneous non-echoed flexible sentences).

Autism diagnostic observation schedule, second edition (ADOS-2; Lord et al., 2012)

Participants for Aim 2 completed an ADOS-2 with a research reliable rater to confirm parent report of a clinical ASD diagnosis. Calibrated severity scores are reported in Table 1.

Kaufman brief intelligence test, second edition (KBIT-2; Kaufman & Kaufman, 2004)

Participants recruited for Aim 2 completed the KBIT-2, a brief intelligence test that yields verbal, nonverbal, and composite IQ scores (see Table 1). This tool was used to efficiently and accurately confirm inclusion criteria and to characterize the sample. The KBIT-2 has acceptable convergent validity with more comprehensive and time-intensive intelligence tests (Kaufman & Kaufman, 2004).

Museum inclusion, engagement, and impact survey

The investigative team developed a 24-item survey that addressed four domains (i.e., Inclusion, Engagement, General Impact, and STEM Impact) hypothesized to be associated with a positive STEM-museum experience. Operational definitions for survey domains and survey items are reported in Table 4. Survey domains were identified by the multidisciplinary investigative team, including members with expertise in autism, informal learning, and STEM learning. The domains align with our overarching theory that increased inclusion in informal STEM learning settings will result in increased engagement during museum visits, and ultimately, increased impact of museum visits. Survey items within each domain were originally generated by the principal investigator and iteratively reviewed and revised based on feedback from the multidisciplinary investigative team and advisory board.

¹ The current study focuses on stakeholder perceptions of museum visits. A separate report describing staff-rated acceptability of the professional development training and staff fidelity of implementation of inclusive strategies is forthcoming.

Table 4 Museum inclusion, engagement, and impact survey domains and items

Domain	Operational definition	Items
Inclusion	The extent to which parents believed their adolescent and family could access museum content and have a successful museum visit during regular business hours	<ol style="list-style-type: none"> 1. My family felt welcomed during our visit 2. My family had a successful visit to this museum during their regular hours 3. The museum staff was understanding and helpful 4. Many of the museum’s activities and exhibits were as accessible to my child as they were to everyone 5. I believe my child enjoyed visiting this museum as much as a neurotypical child would 6. When appropriate, I felt comfortable letting my child explore the museum’s exhibits independently 7. If a staff member was presenting at an exhibit, and a small crowd formed, I felt comfortable with my child attending and interacting with other visitors or staff
Engagement	The parent’s perception of the quality of available opportunities to interact with museum materials and staff around topics of interest to the adolescent	<ol style="list-style-type: none"> 1. This museum offers activities and exhibits that cover a variety of topics that are interesting to my child 2. There were many opportunities for me to engage with my child around this museum’s exhibits 3. It was a fun experience for me and my child to visit this museum 4. This museum’s staff engaged with my child in a manner that supports and encourages discovery and learning 5. My family’s visit to this museum was enriched by the support and knowledge of museum staff 6. This museum’s staff interacted with my family at appropriate moments during our visit 7. This museum’s staff appeared to be invested in my child’s learning experience 8. This museum’s content is presented in a fun and engaging way that appealed to my child
General Impact	The extent to which the museum visit resulted in adolescent learning or application of knowledge during or after the visit	<ol style="list-style-type: none"> 1. My child learned something that sparked interest in a new topic 2. My child learned something new that aligned with their current interests 3. My child thrived in the learning environment at this museum more than they might have in a traditional classroom 4. My family discussed our experiences at the museum and recalled some of the interesting activities we took part in
STEM Impact	The extent to which the museum visit allowed for the development of STEM capital	<ol style="list-style-type: none"> 1. Visiting this museum helped my child understand the scientific process of asking questions and working to find answers 2. Visiting this museum helped my child build a personal connection to STEM 3. Visiting this museum helped my child realize that STEM learning can be fun 4. Visiting this museum helped my child build confidence in STEM 5. Visiting this museum helped my child imagine engaging in STEM activities in the future

Items were rated on a 5-point Likert scale ranging from 1- Strongly disagree to 5 – Strongly agree

Survey items were rated by participants in both aims, with the item wording changed slightly to maintain relevance to each sample (e.g., “I believe my child enjoyed visiting this museum as much as a neurotypical child would” was modified to “When we visit a museum during regular hours, my child enjoys the visit about as much as the average child would” for the comparison sample). Parents were asked to rank the extent to which they agreed or disagreed with each statement on a 5-point Likert scale ranging from 1- Strongly Disagree to 5- Strongly Agree. Item scores for each of the domains were averaged to create four composite scores: Inclusion, Engagement, General Impact, and STEM Impact

ranging from 1 to 5, with higher scores indicating higher inclusion, engagement, general impact, or STEM impact, respectively. Cronbach’s alpha indicated acceptable to excellent internal consistency, depending on the sample, for all domains (Inclusion $\alpha=0.84-0.91$; Engagement $\alpha=0.91-0.93$; General Impact $\alpha=0.74-0.80$, and STEM Impact $\alpha=0.89-0.94$).

Adolescent and parent semi-structured interviews

Adolescent and parent interview questions were generated by the multidisciplinary investigative team and project advisory board to probe for positive and negative features of museum visits, examples of inclusion,

engagement, and impact, and areas where museums could improve experiences for autistic learners. Parents recruited for Aim 2 interviewed their adolescents using a protocol provided by the research team. Research staff completed a semi-structured Zoom interview with each parent recruited for Aim 2 (see Appendix B for interview protocols). Recordings of adolescent and parent interviews were transcribed by research assistants and coded following the procedures described below.

Data analytic plan

Aim 1: Parent attitudes survey

Preliminary analysis indicated that Inclusion, Engagement, General impact, and STEM impact composite scores violated assumptions of normality; thus, non-parametric Kruskal–Wallis tests (McKnight & Najab, 2010) were used to compare these variables between parents of minimally speaking autistic adolescents, parents of autistic adolescents with fluent speech, and parents from the community comparison sample. When Kruskal–Wallis tests indicated a significant difference across groups, post-hoc non-parametric Mann–Whitney U (McKnight & Najab, 2010) tests were used to conduct pairwise comparisons between each group. Bonferroni correction ($0.05/12=0.004$) was applied to address increased family-wise error introduced by multiple comparisons (Haynes, 2013).

Aim 2: Perceived inclusion, engagement, and impact during visits to partner and control museums

Inclusion, Engagement, and General Impact composite scores violated assumptions of normality; thus, non-parametric Wilcoxon signed rank tests (Woolson, 2005) were used to compare these variables between PM and CM visits. A paired samples *t*-test (Ross & Wilson, 2017) was used to compare STEM Impact composite scores between PM and CM visits.

Although the overall project was guided by an overarching theory (see Introduction), thematic analysis was not guided by an existing theoretical framework. In the context of limited existing research on this topic, inductive thematic analysis was conducted to identify data-driven themes across adolescent and parent interviews. Interviews were coded by three female coders following the six phases of thematic analysis outlined by Braun and Clark (2012). Positionality of the coding team was as follows. Two of the coders had bachelor's degrees in psychology. The third was a developmental psychologist with more than ten years of experience in autism research. One of the coders had an immediate family member diagnosed with ASD; none of the

coders were autistic. Coders were not involved in the study design or professional development training and were blinded to whether interviews were conducted after PM or CM visits. Coders met 1 to 2 times per week to establish and refine a codebook with codes and their definitions and come to consensus on coding for each interview. After coding was completed and themes were identified, frequency of codes supporting themes and subthemes were compared across PMs and CMs using the Code-Document analysis function in ATLAS.ti 23.2.2 (ATLAS.ti Scientific Software Development GmbH, 2023). Disproportionate support for a theme was defined as $\geq 60\%$ of examples from one museum group. Unless specifically noted, themes and subthemes were supported relatively equally by examples from PM and CM visits. Consistent with the inductive, data driven approach to analysis, themes and subthemes were identified based on all codes. Specifically, all codes and resulting themes were considered even if they could potentially represent experiences that are also relevant to non-autistic individuals.

Results

Aim 1: Parent attitudes survey

Average Inclusion, Engagement, General Impact, and STEM Impact composite scores are reported for parents of minimally speaking autistic adolescents, parents of autistic adolescents with fluent speech, and the general population comparison sample in Table 4. Non-parametric Kruskal Wallis tests indicated significant between group differences in Inclusion ($H(2)=54.66, p<0.001$), Engagement ($H(2)=42.89, p<0.001$), General Impact ($H(2)=32.73, p<0.001$), and STEM Impact ($H(2)=14.46, p=0.001$) across groups. Post-hoc Mann–Whitney U pairwise comparisons indicated that comparison group parents reported higher Inclusion ($z=5.55, p<0.001$), Engagement ($z=5.32, p<0.001$), General Impact ($z=4.98, p<0.001$), and STEM impact ($z=3.30, p=0.001$) than parents of minimally speaking autistic adolescents. Comparison group parents also reported higher Inclusion ($z=6.33, p<0.001$), Engagement ($z=5.22, p<0.001$), and General Impact ($z=4.07, p<0.001$) than parents of verbally fluent autistic adolescents; however, there was not a significant difference in reported STEM Impact between comparison parents and parents of verbally fluent autistic adolescents ($z=2.65, p=0.01$). Last, parents of verbally fluent autistic adolescents reported higher Inclusion ($z=3.03, p=0.002$), Engagement ($z=3.01, p=0.003$), and General Impact ($z=3.11, p=0.002$) than parents of minimally speaking adolescents. There was not a

Table 5 Descriptive Statistics for Parent-rated Inclusion, Engagement, General Impact, and STEM Impact Composite Scores

	Parent Attitudes Survey			Museum Visit Sample		
	Parents of Minimally Speaking Adolescents (n = 21) <i>M (SD)</i>	Parents of Adolescents with Fluent speech (n = 72) <i>M (SD)</i>	Parents of General Population Comparison Sample (n = 53) <i>M (SD)</i>	Adolescent-Parent Dyads (n = 20) <i>M (SD)</i>		
				Partner Museums	Control Museums	Cohen's <i>d</i> effect sizes
Inclusion	3.06 (0.93)	3.73 (0.65)	4.52 (0.54)	4.55 (0.65)	4.32 (0.96)	0.30 (small)
Engagement	3.23 (0.76)	3.76 (0.68)	4.43 (0.58)	3.84 (0.95)	3.69 (1.19)	0.13 (negligible)
General Impact	3.36 (0.69)	3.81 (0.63)	4.31 (0.59)	3.71 (0.66)	3.50 (1.22)	0.22 (small)
STEM Impact	3.56 (0.89)	4.01 (0.59)	4.32 (0.72)	3.52 (0.93)	2.86 (1.17)	0.65 (medium)

significant difference between ASD groups in STEM Impact ($z = 2.21, p = 0.03$).

Aim 2: Perceived inclusion, engagement, and impact during visits to partner and control museums

Average Inclusion, Engagement, General Impact, and STEM Impact composite scores are reported in Table 5. Non-parametric Wilcoxon Signed Rank tests indicated no significant differences in Inclusion ($z = 1.00, p = 0.32$), Engagement ($z = 0.36, p = 0.72$), or General Impact ($z = 0.81, p = 0.42$) between PMs and CMs. A paired-samples t-test indicated significantly higher STEM impact for PMs relative to CMs ($t(19) = -2.89, p = 0.01$). Four themes were identified by thematic analysis: (1) *Spectrum of Museum Impact*; (2) *Adolescent-Environment Fit*; (3) *Barriers to Engagement*, and (4) *Barrier Breakers*. Selected example quotations are included in the narrative below. Themes, subthemes, and additional example quotations are reported in Table 6.

Theme 1: Spectrum of museum impact

Families reported a range of outcomes related to learning and application of material that, when taken together, suggest a spectrum of museum impact. For the purposes of this study, impact was defined as learning and application of knowledge, including learning something new, connecting material to pre-existing knowledge, developing a new or existing interest, applying information learned at the museum, or learning about careers related to the museum content. Notably, these are all key elements of science capital (Archer et al., 2015). The adolescent interview protocol included specific questions to explore whether and how museum visits were impactful and built science capital among autistic adolescents. Subthemes are presented in order from low to high impact and include (1a) Limited engagement and learning; (1b) Learning and application of knowledge; (1c) Desire for

continued learning, and (1d) Connecting museum experience to potential careers.

Subtheme 1a: Limited engagement and learning At the minimal impact end of the spectrum, participants reported being bored and disengaged with the museum materials, not learning anything new, and not taking any concepts home, meaning participants may have learned something new but did not demonstrate application of new knowledge after the museum visit. For example, after a visit to a CM, 15-year-old Arthur shared, “*I’m going to be honest; I didn’t learn anything new-ish. [...] ‘Cause I was already aware of most of the instruments’ existence and their cultures and whatnot.*” Additionally, many participants had difficulty making a connection between museum content and potential careers, were not interested in careers related to museum content, or did not think they were capable of succeeding in these careers. This subtheme overlapped with *Theme 2: Adolescent-Environment Fit*, including pre-existing interests, motivation, and self-esteem. Many adolescents reported not enjoying their visit or not learning anything new when they were not interested in the museum content. Notably, more examples of limited engagement and learning were shared from CM visits ($n = 44$) relative to PMs ($n = 27$). This difference was mostly driven by adolescents reporting that they did not learn about any new careers during their visit (CM $n = 18$; PM $n = 10$), they did not learn anything new during the visit (CM $n = 8$; PM $n = 4$), and that they had no interest in bringing museum concepts home (CM $n = 4$; PM $n = 0$).

Subtheme 1b: Learning and application of knowledge Participants reported informal learning during their visits. This included positive experiences engaging with materials, learning a new skill, and the application of newly learned concepts during or after the visit through

Table 6 Qualitative Themes, Subthemes, and Example Participant Responses

Theme 1: Spectrum of Museum Impact	
Subtheme 1a: Limited Engagement and Learning	
Parent of 13-year-old Calvin	<i>"[...] so the questions in the feedback survey were like, well, do you see yourself with a job [related to museum content]. And there was literally no tie for him [...] there weren't any staff members present to facilitate or talk about [careers] [...] So, I would say more interaction or interactive staff would be helpful."</i>
Subtheme 1b: Learning and Application of Knowledge	
Parent of 12-year-old Eliza	<i>"She would get really excited. I loved watching her. [...] she actually had her notebook and she wanted to take notes on it. And that tells me that she was really interested in the stuff. And then as we were driving home, she was talking to me about a couple of the stories [...] so that really hit home with her. And [...] when we were done going through the museum and she did her flight simulation, then she wanted to go back through again [...] normally she is kind of withdrawn, you know, kind of held back, but she was really into that museum."</i>
Subtheme 1c: Desire for Continued Learning	
13-year-old Calvin when asked whether he had fun visiting the museum	<i>"Yeah, it kinda got me passionate about stop motion animation."</i>
16-year-old Laylah when asked whether she would enjoy visiting the museum again in the future	<i>"I would enjoy visiting it again to look at the prehistoric mammals and to continue learning about the dinosaurs."</i>
Subtheme 1d: Connecting Museum Experience to Potential Careers	
16-year-old Laylah	<i>"I got to learn about paleontology because there was a paleontologist there that was answering questions and I also learned about creating replicas of ancient objects."</i>
Theme 2: Adolescent-Environment Fit	
Myah, 11-year-old female	
Pre-existing interests and/or STEM Capital	
Parent of Sawyer, 18-year-old male	
Pre-existing interests and/or STEM capital	
Parent of Ethan, 14-year-old male	
Adolescent preference for interacting with staff	
Parent of Laylah, 16-year-old female	
Adolescent preference for interacting with staff	
Parent of Sawyer, 18-year-old male	
Desiring clearer visual and audio guidance	
Parent of Braden, 15-year-old male	
Sensory aversive characteristics	
Parent of Laylah, 16-year-old female	
Sensory aversive characteristics	
Parent of Sawyer, 18-year-old male	
Desiring clearer visual and audio guidance	
Parent of Braden, 15-year-old male	
Sensory aversive characteristics	
Parent of Laylah, 16-year-old female	
Sensory aversive characteristics	

Table 6 (continued)

<p>Parent of Liam, 16-year-old male Desiring sensory friendly options</p>	<p><i>"Like just signs, like that they're inclusive and if [you] need help with anything or any accommodations for sensory overload or anything, just ask the staff or that they would have stuff like [partner museum] did. Because that made him very included, you know, like he could still participate in these activities and not be distracted by sensory overload."</i></p>
<p>Parent of Myah, 11-year-old female Low gender inclusion</p>	<p><i>"But this other guy came over and I guess they give like little commemorative spark plugs to kids. You know, he walked up and gave one to the little boy. And Myah was like 'Oh cool.' [...] And he goes, 'Oh, you're a girl. Girl don't like spark plugs, right?' [...] Myah was like, 'Wait, is he serious? Like, what's happening?' And so, I just told her 'We'll see if we can talk to somebody else.'"</i></p>
<p>Subtheme 3c: Poor Quality of Museum Materials Parent of Cole, 13-year-old male</p>	<p><i>"There were quite a few things that were supposed to be interactive [...] that were broken. Or some things that were in disrepair. I mean, that's disappointing anyways, but for him it's extra frustrating when you're expecting something and it doesn't work."</i></p>
<p>Subtheme 3d: Lack of Variety of Museum Content Arthur, 15-year-old male, when asked what could have made the day more fun Riley, 13-year-old non-binary individual</p>	<p><i>"A lot more stuff to do. That would be great. A lot more to explore. The trip was so short because the building was short."</i> <i>"Uh I think that might be one that I would visit if they changed frequently. But if they didn't, I don't think I would. [...] you can enjoy the activities once or twice but after that, it tends to get a bit repetitive."</i></p>
<p>Subtheme 3e: Other Museum Visitors Parent of Marlie, 15-year-old female</p>	<p><i>"She liked the [...] Zen Den. There were actually people in there, so she was really disheartened that she didn't want to go in when they were in there. But she liked the idea of the Zen Den a lot."</i></p>
<p>Theme 4: Barrier Breakers Subtheme 4a: Interactive Staff and Exhibits Parent of 16-year-old Laylah</p>	<p><i>"She was interested, but [...] she doesn't sustain eye contact very long and then she can hear you, but she'll walk in circles. [...] They just continued talking to me loud enough for her to hear and she got the information out of it. So we spoke to a paleontologist. She was fascinated by that, and she could regurgitate everything he said at the end. But she wasn't anywhere near, you know, the two of us having conversation, but she overheard it all. [...] Overall, very positive because they weren't thrown by that at all. [...] Some people can take that personally, like, oh, the kids not interested. No, she was interested. She just couldn't stay in one place and process the information. So, they never took that personally and I really appreciated that."</i></p>
<p>Parent of 11-year-old Marlie when asked if there were any exhibits her daughter enjoyed more than others</p>	<p><i>"The first one we went to was a drawing exhibit. She really liked that they gave you a little starter cue, like some lines or a squiggle on paper, and you were supposed to start from there [...] The other one was a fan that blows up through a tube and you would put different things like coffee filters or a little scarf or something, and it would blow up and they would all blow up differently. She really enjoyed that one, too. [...] She was already talking about the fan and how the velocity of the air and if the fan was turned up higher than those things would really fly [...] that's something I don't think she considered before."</i></p>
<p>Subtheme 4b: Freedom to Engage Parent of 17-year-old Lillian</p>	<p><i>"So when I say to you 'the quiet environment,' we weren't prompted to be quiet. We had the benefit of, it wasn't busy, so she stayed longer. And attended better [...] Because when it gets busy, she flips."</i></p>
<p>Subtheme 4c: Inclusion and Accommodations Parent of 13-year-old Riley</p>	<p><i>"I think they had posted signs, 'hey, everyone does things their own way. If you need help accessing a certain exhibit, please let us know.' [...] if they were wheelchair bound, they could get a table pop-up thing to better access things on their lap. I just got a very good sense that they wanted to be accessible and inclusive for all different kinds of people."</i></p>
<p>Subtheme 4d: Parent as Facilitator 16-year-old Liam</p>	<p><i>"I liked walking around and I liked it when you would read the [plaques] to me."</i></p>

Participant names were replaced with pseudonyms to protect participant confidentiality

conversations with their family members. After their visit to a PM, Arthur's parent reported, "*You know, Arthur is 15, so you'd think he's not still into building things. My whole family [...] just sat down and spent probably 30 min just building stuff and trying different challenges. And it was really cool that there was something that just really struck his interests and pulled him in and kept him engaged.*" For some, visits deepened their understanding of an already familiar topic or connected to pre-existing knowledge learned in academic courses. This also took the form of adolescents reporting that they already knew about the topics presented at the museum, but they learned additional facts. One participant also reported that museum exhibits debunked misinformation.

Subtheme 1c: Desire for continued learning One of the clearest indicators of museum impact was when visits sparked a new interest in a topic or re-sparked an existing interest. Some adolescents demonstrated the development of STEM capital, evidenced by new STEM-related interests, further development of existing interests, bringing a new topic home, or wanting to return to learn more. For example, 16-year-old Laylah's parent shared, "*But [Laylah] was like, 'Yeah, I really liked it and I want to go back.' But she wants to go with dad, too, and she wants to show all the things that she saw that she was excited about.*"

Subtheme 1d: Connecting museum experience to potential careers Adolescents were specifically asked whether they learned about potential careers. As discussed in Subtheme 1a) Limited Engagement and Learning, most adolescents responded 'no' or had difficulty identifying potential careers related to the museum topics. However, there were a handful of examples ($n=9$; 22% of museum visits) of adolescents reporting that they learned about a new career or learned more about a career of which they were already aware.

Theme 2: Adolescent-environment fit

Adolescent-environment fit refers to the relative compatibility of adolescent characteristics (i.e., intrinsic individual differences between adolescents) and characteristics of the museums. Strong adolescent-environment fit facilitated successful museum visits that were characterized by high engagement and impact. In contrast, relatively low adolescent-environment fit served as a barrier to engagement and impact. Examples of adolescent-environment fit were pervasive in families' reports and overlapped or interacted with all three of the other themes (i.e., Spectrum of Museum Impact, Barriers to Engagement, Barrier Breakers). For example, many parents and adolescents reported pre-existing interests (STEM capital) that were in alignment with focal museum topics and

increased engagement with exhibits. Additionally, some adolescents demonstrated emotion regulation skills in aversive situations, which facilitated continued engagement despite overwhelming or distracting stimuli. For example, 17-year-old Lillian shared, "*The activity that I did not enjoy was the memory game because [...] it can be kind of a little frustrating. [...] I stayed calm but didn't really enjoy it so I just walked off calmly and looked around.*"

Conversely, relatively low adolescent-environment fit was reported to limit the impact of museum visits. When a museum topic or activity was not preferred, several adolescents reported feeling bored and wanting to leave. Some parents reported ASD-related characteristics affected engagement with museum exhibits and/or staff. As discussed below in *Subtheme 3b: Low Inclusion*, many adolescents experienced specific aversions or difficulty with change that prevented them from fully engaging during their visit. For example, when explaining that a private party at one of the museums resulted in their family having to visit the museum at a different time than expected, the parent of 12-year-old Victoria shared, "*We were unaware of the private party and so—huge meltdown. I hadn't seen one that bad in like a long time, so it really caught me off guard. Because of that, I just couldn't seem to get her back on a happy track. So, I think it would have been a better experience if that hadn't happened.*" Some parents reported that their adolescents were unlikely to share newfound knowledge with others after their visit due to a general disinterest in initiating social interaction, which limited the potential impact of visits. Parents also shared that signs of anxiety, inattention, and hyperactivity in some adolescents also inhibited engagement. For instance, some parents reported that their adolescent "rushed" through the museum or were distracted by non-exhibit facilities (e.g., escalators), which interfered with engagement with exhibits. Reports of relatively low adolescent-environment fit serving as a barrier were higher for CM visits ($n=21$) relative to PM museum visits ($n=16$). Driving this difference were codes describing adolescents rushing through the museum (CM $n=4$, PM $n=1$) and adolescent aversions to stimuli (CM $n=2$, PM $n=0$).

Notably, adolescent-level factors like disposition or preference not only affected engagement with museum materials, but also interactions with staff members. Whereas some adolescents were receptive to engaging with staff, others desired to explore independently. For example, the parent of 13-year-old Calvin shared, "*[The staff] didn't really interact with Calvin at all, but he's also not one to make eye contact or especially at animation, not really going to invite you in. So, it would've taken a pretty special person to come in and try to interrupt*

that. That was his biggest complaint. His complaint was that there were people interrupting [him].” All examples of adolescents choosing to engage with staff members ($n=3$) were reported for a single CM that offered tours with thematic experts. These examples may demonstrate a bidirectional relationship between engaging staff and adolescents’ willingness to engage.

Theme 3: Barriers to engagement

This theme encompassed various environmental factors encountered by participants and their families that served as barriers to engagement with museum content. Five subthemes include: 3a) Inadequate guidance; 3b) Low inclusion; 3c) Poor quality of museum design and materials; 3d) Lack of variety in museum content; and 3e) Other museum visitors.

Subtheme 3a: Inadequate guidance Two forms of inadequate guidance were identified: 1) staff issues, and 2) inadequate visual and audio guidance. Staffing issues included non-interactive staff, negative or unprofessional staff, or a general lack of staff. Many participants suggested more staff and/or increased interaction from staff would have better supported learning opportunities and improved the quality and impact of their visit. Some participants reported that although there was an adequate number of staff available, there was a lack of staff-initiated interaction. In contrast, other participants commented on the low number of staff present during their visit (e.g., only at the entrance), which precluded interaction with staff.

Participants desired clearer visual and audio guidance for navigating museums and engaging with exhibits. Improved signage and/or audio guidance would have improved adolescents’ ability to engage with the exhibits independently and reduce the need for parents to prompt or facilitate the child’s engagement. Technology-supported approaches (e.g. mobile apps) were also suggested by parents. Inadequate signage left one family feeling uninformed about sensory accommodations they could have accessed. These materials were not offered to all visitors, and the signage indicating that they were available was not prominently displayed. Notably, there were considerably more examples indicating a desire for increased visual and/or audio guidance after visits to PMs ($n=12$) relative to CMs ($n=2$).

An example demonstrating both staff issues and inadequate visual guidance was shared by the parent of 14-year-old Noah:

“[...] there was this room that was closed off and it didn’t say it was closed, but we couldn’t get in either door. [...] There was actually a family in there doing something, and it looked like it might have been cool.”

There was no display, no signs to know what was going on in there. [...] And then when I tried to get in the second door, she opened it and said something like, ‘The program starts at 11.’ But didn’t say what it was. Yeah, that might have been something really fun that we missed.”

Subtheme 3b: Low inclusion Inadequate inclusion was reported by some participants, and at times, low or absent inclusion affected adolescent engagement. Limited sensory-friendly options and sensory-aversive characteristics (e.g., poorly regulated temperature or sound) affected some children’s ability to engage with exhibits. Approximately twice as many examples of aversive sensory stimuli were reported at CMs ($n=9$) relative to PMs ($n=4$).

Building on the need for improved sensory sensitivity, when asked what museums could have done to improve their experience, some participants reported that more accommodations for neurodivergent visitors would be appreciated, including sensory friendly hours to decrease noise, stimulation, and judgment from other visitors. For example, the parent of 13-year-old Cole made a point that there are benefits to both inclusion with neurotypical peers and accommodations like sensory-friendly hours: *“[...] But there are just some kids that [...] aren’t really going to have fun until they feel comfortable. They’re not going to explore things until they’re comfortable [...] So I think it would be good to do both and then like occasionally have like a certain night [...] where there are less people, dim the lights, whatever it is, you know?”* Consistent with reports of aversive sensory stimuli, more participants reported the desire for increased accommodations for neurodiverse individuals at CMs ($n=15$) relative to PMs ($n=5$).

A mismatch between adolescent age/developmental level and exhibits was commonly mentioned as a factor that limited inclusion. In some instances, the adolescent and/or parent believed that the museum content was focused on younger children without relevant activities for older children, which negatively affected adolescent interest and engagement. However, in some situations, the adolescent was interested in the content but self-conscious about being noticeably older than a perceived target demographic. More examples of a mismatch between adolescent age/developmental level were reported for CMs ($n=15$) compared to PMs ($n=8$).

Participants also reported examples of low inclusion related to gender and ability. One parent reported an incident where her daughter was treated differently than male visitors, which created a perception that the museum was not inclusive to all genders and negatively affected her daughter’s motivation to engage. The family’s feedback about other staff was overwhelmingly

positive, but this negative interaction was identified as one of the most memorable parts of their visit. Several parents indicated that some museums included reading passages that were above their child's reading level or were too long for their child. Although not directly relevant to the participants in the current study, reports indicated that some museums did not provide adequate accommodations for those who are visually impaired, hearing impaired, or physically disabled. Participants also identified additional fees to engage with some exhibits as a barrier, which demonstrates limited inclusion for families from lower socioeconomic backgrounds.

Subtheme 3c: Poor quality of museum materials Participants reported that broken technology, outdated material, and inauthentic exhibits lowered the quality of their experience. Many individuals with ASD experience distress when events do not go as planned, so broken materials and technology resulted in an especially negative experience for some. When asked what the museum could have done to improve his visit, 18-year-old Jaylan shared, "Try to have everything in working order. Like, there were a few animatronics that weren't working. There were a few little information pads that weren't working. They had like backup measures in place, but it would have been nice to see the actual intended thing." Examples of poor quality of materials were more frequently reported for PMs ($n=13$) than for CMs ($n=4$).

Subtheme 3d: Lack of variety of museum content The variety of exhibits as well as the size of the museum impacted the quality of participants' visits. Participants reported that visits to small museums were relatively short, and the exhibits did not change frequently enough to make a return visit worthwhile unless new exhibits were added. Four participants made an upward comparison to other museums that offered more space and a greater variety of exhibits.

Subtheme 3e: Other museum visitors Frequently, participants reported that other guests, particularly crowds, were barriers to engagement due to general aversion to unfamiliar people, overstimulation, and/or feeling self-conscious. The presence of other museum visitors dissuaded some participants from engaging with specific exhibits. For example, 16-year-old Liam shared, "[...] I want to go to see the cars or play with the cars, but there was a family up there and I didn't wanna go be around unfamiliar people." As discussed in *Subtheme 2b: Lack of Inclusion*, large crowds naturally increased noise and decreased the personal space participants had to interact with exhibits.

Theme 4: Barrier breakers

Participants reported external factors that helped them overcome barriers to engaging with museum content. These experiences are captured in six subthemes below.

Subtheme 4a: Interactive staff and exhibits Interactivity in multiple forms was identified as a museum characteristic that facilitated participant engagement. Specifically, participants appreciated positive interactions with staff and interactive museum materials, and these interactive experiences were often identified by participants as the most memorable part of their visits. Staff who were friendly, helpful, informative, interactive, and had a personalized interaction with guests contributed to positive experiences. For example, the parent of 17-year-old Lillian shared, "[...]she had a really sweet conversation with an employee. He asked her which dinosaur she liked and when she was done, he said, you know, I always make a point of pointing those dinosaurs out because they are native to Arizona. And so they talked about that for a little bit. And, you know, conversations outside of the family are always impactful." Efforts from staff to accommodate barriers experienced by neurodivergent participants were also appreciated. Staff who supported participant engagement through presentations or tours were valued, especially when staff made a personal connection with participants.

In addition to interactive staff, participants also valued interactive exhibits related to art, music, STEM, and museum shows and animatronics that could be experienced as an individual or shared with friends and family. Beyond enjoyment, participants reported these exhibits were conducive to learning. Incentives for engaging with exhibits (e.g., stamp passport; mining for fool's gold) were reported to be motivating for most adolescents. There were more examples of adolescents enjoying interactive or hands-on activities at PMs ($n=56$) relative to CMs ($n=38$). Responses indicating a desire for more interactive learning opportunities were common across PMs ($n=10$) and CMs ($n=13$), indicating their perceived value.

Subtheme 4b: Freedom to engage Intentional and incidental museum characteristics, including a layout that enabled adolescents to engage freely and safely and the absence of large crowds, facilitated positive experiences and engagement. Some parents reported that they appreciated museum designs that allowed their adolescent to explore without the need for prompting or close monitoring by the parent. This included open spaces that were still relatively contained so that parents did not need to worry about losing their child. Many parents shared that they incidentally visited museums

when they were not busy, and the absence of crowds allowed their adolescents to explore exhibits more fully and interact with staff more than they likely would have had the museum been busy. Last, a handful of families valued exhibits or activities that encouraged the adolescent's agency. For example, one parent valued that the museum allowed visitors to touch most parts of the exhibits so that their adolescent could explore freely without worrying about getting in trouble or breaking something. Another example involved an art project that could be approached in multiple ways so that adolescents could engage in their own way. Examples of appreciating freedom to engage were more frequent for PMs ($n=17$) than CMs ($n=10$). This difference was mostly driven by the absence of crowds (PMs $n=5$; CMs $n=0$), which may be at least partly due to the time of day that families visited the museums.

Subtheme 4c: Inclusion and accommodations For the most part, parents and teens reported that teens could be themselves without judgment from other visitors or staff during visits to PMs and CMs. Counterexamples are described under *Subtheme 3b) Low Inclusion*. Museums that provided extra engagement and sensory materials, quiet spaces to de-stimulate, and signage to indicate the potential for sensory aversions were perceived to be more inclusive. For example, when asked whether she believed the museum was inclusive of everyone, the parent of 16-year-old Laylah shared, *"I feel like it was very inclusive. I've gone before [...] but I had never seen the signage about sensory things. That was incredible to me. So, before we even walk in a room, we know if it's loud [...] it seemed to me probably the most inclusive museum visit I've ever had."* Several families shared appreciation for one of the museums that lent backpacks with materials like sound canceling headphones, fidget toys, and other items to facilitate engagement with museum materials (e.g., binoculars). Participants reported that these "discovery backpacks" demonstrated that museum staff had thoughtfully considered how to make autistic individuals feel more included. More examples of sensory friendly features were reported at PMs ($n=16$) compared to CMs ($n=5$). Participants also noted when museums appeared to be inclusive of a range of ages and abilities, including people with physical disabilities (e.g., vision, hearing, and mobility impaired; PMs $n=11$; CMs $n=6$). Content and topics presented within museum exhibits also contributed to perceived inclusion. Participants reported museums to be inclusive when a variety of races, cultures, and genders were represented in a respectful way (PMs $n=2$; CMs $n=13$). The difference between PMs and CMs was driven by more examples of cultural representation at CMs.

Subtheme 4d: Parent as facilitator Parent characteristics (e.g., parent facilitating engagement) were reported to promote positive learning experiences. For example, the parent of 18-year-old Sawyer shared, *"Sawyer and I went to the 4th floor first. And then started from the 4th floor coming down. So, there was like less traffic, less because I was trying to really get him to be interested in, you know?"* However, some parents felt that they needed to direct and maintain their child's attention due to inadequate guidance or engagement provided by museum personnel (see *Subtheme 2a: Inadequate Guidance*).

Discussion

The current study is the first to our knowledge to develop and pilot a professional development training aimed at improving inclusion for autistic individuals in informal STEM learning settings at the organizational level. We propose that increased inclusion will lead to increased engagement during museum visits, which will help autistic youth to build science capital and increase the likelihood of educational and vocational success in STEM disciplines. Findings from an initial parent attitudes survey supported the need for increased inclusion and accessibility for autistic adolescents in STEM museums. After professional development training was delivered to staff at four PMs, parents of autistic adolescents reported higher STEM impact during visits to PMs compared to CMs. However, parent-reported inclusion, engagement, and general impact did not differ significantly between PMs and CMs. Qualitative analysis of adolescent and parent interviews identified several themes that provide context for quantitative findings and will inform future efforts to improve inclusion in informal STEM learning settings. Together, findings provide insight for continued development of initiatives to increase access to informal learning opportunities that build STEM capital among autistic youth.

Findings from the parent attitudes survey indicated significantly lower inclusion, engagement, and general impact of STEM-related museum visits in the ASD groups compared to the comparison group, which aligns with existing literature related to challenges autistic individuals and their families face in public spaces (Antonetti & Fletcher, 2016; Davidson, 2010; Farrugia, 2009; Ryan, 2010). Furthermore, it affirms the importance of organizational change through training in inclusive practices at all levels of the organization to mitigate differences and increase learning opportunities for autistic individuals. Differences in STEM impact were less pronounced but still evident, specifically between parents of minimally speaking adolescents and the general population comparison group. Overall, findings from the parent attitudes survey reinforced the need for professional development

training related to inclusive practices for museum staff so they can facilitate opportunities for autistic learners to build STEM capital. Findings also informed modifications to an existing professional training in inclusive practices.

Inconsistent with our hypotheses, we did not observe statistically significant differences in parents' quantitative ratings of inclusion, engagement, or general impact between PMs and CMs. Due to the pilot nature of this study, the sample size was small and statistical analyses were underpowered to detect small differences. Effect sizes indicated small differences in inclusion and general impact favoring PMs and parent ratings of STEM impact were significantly higher for PMs than CMs. This may indicate that professional development training was associated with increased inclusion and ultimately, increased opportunities for building STEM capital. Notably, these findings are preliminary and should be interpreted with caution for several reasons. Identifying "matched" CMs in a single US city was a challenge. Existing differences in content, staff, quality of materials, and overall public favorability between PMs and CMs may have obscured effects of staff training. On the other hand, pre-existing differences in the amount and nature of STEM content at PMs relative to CMs may have contributed to the significant difference in STEM impact, considering the smaller effect size for general impact. Whereas all museums included STEM-related exhibits, a higher proportion of PMs (Partners 1 and 3) had an explicit STEM focus compared to CMs (Control 4). Results of qualitative analysis (discussed below) shed light on these potential interpretations. Future projects should utilize a pre/post-training design where museums serve as their own control to better assess the impact of professional development training.

Qualitative findings provided considerable insight and context that facilitates interpretation of quantitative findings and identified areas that future professional development training should address. Four themes were identified, including (1) *Spectrum of Museum Impact*, (2) *Adolescent-Environment Fit*; (3) *Barriers to Engagement*, and (4) *Barrier Breakers*.

One goal of the qualitative interviews was to understand whether and how autistic adolescents build STEM capital during visits to PMs and CMs. Adolescents and parents were specifically asked about opportunities for learning and if their visits inspired new interests or a desire to learn more about any topics. Interview responses indicated that the impact of museum visits ranged considerably across participants and museums. Some participants reported limited engagement and learning during their visits citing disinterest in the museum's focal topic or that they did not learn anything

new. Fewer examples of post-visit impact, like the visit sparking a new interest or adolescents sharing what they learned with others, were given. Especially notable was that very few participants reported connecting museum content to a future career, which may suggest the need for more explicit instruction. For example, museums may consider hosting career events tailored to neurodiverse populations. Additionally, previous research has demonstrated usefulness of pre-visit materials (e.g., social story, accessibility map, and communication book) for children with autism (Fortuna et al., 2024). Pre-visit materials could be used to make an explicit connection between exhibits and STEM careers and include suggestions for learning more during and after (e.g., online) the visit. To our knowledge, causal links between STEM museum visits and career knowledge and interests in the general population have not been tested. Thus, it is possible that this type of explicit instruction would benefit all adolescent learners. Notably, more examples of limited engagement and learning were shared from CM visits, which is consistent with lower quantitative ratings of general and STEM impact reported for CMs relative to PMs.

Importantly, the impact of museum visits was influenced by the goodness of fit between adolescents and museum environments. For example, interview responses indicated that adolescents with pre-existing interest in museum topics and/or STEM capital experienced increased engagement and impact of visits, whereas the absence of or limited interest in museum topics was challenging to overcome. This highlights the importance of staff establishing rapport with autistic individuals and their families from the start of their visits to identify existing interests and potentially engage visitors' interest in something new. It is important to note that interest in informal learning settings among general population adolescent samples is low relative to early childhood samples (Mulvey et al., 2020). Thus, it is possible that these findings may be due to a general disinterest in visiting museums among adolescents. However, findings from Aim 1 indicated that autistic adolescents experienced less engagement and impact during STEM-focused museum visits than same-aged general population adolescents, which supports the need for inclusive practices at STEM-related museums to facilitate interest among autistic adolescents. Autism-related characteristics (e.g., sensory aversions) and characteristics like anxiety, inattention, and hyperactivity were reported by parents to interfere with some participants' ability to fully engage with materials, particularly at CMs. This supports the need for continued training in inclusive practices for neurodiverse individuals. Last, autistic adolescents had different preferences for engaging with staff. Although many families reported a desire for increased initiation

of interaction from staff, it is important to consider that not all autistic individuals will appreciate this approach. Flexible, multi-faceted approaches for facilitating autistic individuals' engagement at STEM museums are likely needed to increase the likelihood of visits contributing to the development of STEM capital.

Museum features that allowed adolescents the freedom to explore independently, without the need for direct prompting or guidance from parents, were highly valued by participants, particularly parents. Parents of autistic children commonly play a highly active role (DePape & Lindsay, 2014); however, when staff-initiated guidance or materials were naturally engaging and allowed for independent exploration, it was meaningful to both adolescents and parents. Additionally, many families shared that the incidental absence of large crowds was a facilitator of engagement, particularly for adolescents with sensory sensitivities and/or aversions to unfamiliar people. It may be beneficial for museums to identify and share days and times that are naturally low and high (e.g., school field trips) in traffic on their websites so that visitors with sensory differences can strategically plan their visits. This strategy could complement occasional sensory friendly nights or hours that are restricted to visitors with sensory differences. Sharing low traffic hours with the community would offer an option that is both responsive to those with sensory needs and facilitates inclusion. Also related to sensory sensitivities, museums with sensory features like "discovery backpacks" containing materials to facilitate engagement, sensory rooms or quiet spaces for guests to take a break, and signage to indicate exhibits that may be sensory aversive were highly appreciated.

Other characteristics that facilitated independent exploration included interactive staff, interactive exhibits, and clear visual and audio guidance. In contrast, inadequate guidance was regularly identified as a barrier to adolescent engagement and independent exploration, and this was more commonly reported for PMs. Many suggested that increased staff and increased initiation of interaction from staff would have improved their visits. Notably, the effectiveness of professional development training is contingent on museums being adequately staffed to implement inclusive strategies. In the absence of adequate staffing, other methods of increasing guidance, and by extension inclusion, could be pursued, including audio (e.g., interactive headsets; mobile app) and visual guidance (e.g., signage). Additionally, pre-visit materials (Fortuna et al., 2024) could facilitate guidance without the need for additional staff.

Participants also shared that quality of museum materials impacted their visits. Many reported disappointment and frustration when interactive exhibits or animatronics were not in working order. Although it is unreasonable

to expect that exhibits will always function perfectly, it is important that museum staff and leadership are aware of the potential implications of broken or malfunctioning materials for neurodiverse learners.

Most themes and subthemes were supported by codes from PM and CM post-visit interviews; however, several were disproportionately supported by codes from one or the other. Adolescent-environment fit appeared to more strongly influence visits to CMs, and CM visits had more examples of low inclusivity and limited engagement and learning. In contrast, participants reported more examples of inadequate guidance and poor quality of museum materials at PMs. Regarding barrier breakers, there were more codes from PM interviews that supported interactive exhibits, freedom to engage, sensory friendly features, and inclusion of a range of ages and abilities. This is consistent with quantitative findings indicating that parents rated inclusion slightly higher at PMs relative to CMs. However, examples of inclusion related to cultural representation were more commonly identified in CM interviews.

Notably, several themes and subthemes identified in the current study (e.g., pre-existing interest in museum topics as a facilitator to engagement; preferences for museums that offer a variety of exhibits) are likely to be applicable to the general population. The qualitative analysis used an inductive, data-driven approach, so potential codes and themes were not excluded for not being specific to the autistic population. This is consistent with the idea that inclusive practices can and should benefit everyone, not only individuals with disabilities (Meyer et al., 2014).

Despite coders being naïve to existing literature, themes identified were remarkably consistent with the only other study to our knowledge that has examined experiences of families of autistic children in a science museum (Lussenhop et al., 2016). Lussenhop and colleagues approached their analysis from existing theoretical frameworks, the social inclusion and ecological models of occupational therapy, which acknowledge environmental barriers or enhancements to individual performance. Although the current qualitative analysis utilized an inductive approach that was not guided by a theoretical framework, both studies identified similar environmental barriers and facilitators during museum visits. Similar to the current study, Lussenhop and colleagues (2016) found that interactive exhibits, a variety of options for engagement, clear signage, and interactions with engaging staff facilitated social participation. "Family strategies" were also identified as enhancing visits, and two of these strategies (i.e., "providing one-on-one support for the child with ASD" and "engaging in science talk") were similar to the subtheme of *Parent*

as *Facilitator* in the current study. Barriers identified by Lussenhop and colleagues included sensory aversions (i.e., loud noises) and other visitors, which align with two of the barrier subthemes in the current study (i.e., *Low Inclusion* and *Other Museum Visitors*). The convergence of themes from two studies conducted in two different US cities (i.e., Phoenix, Arizona and Boston, Massachusetts) speaks to the validity of findings and the likelihood that current recommendations will be applicable to STEM-focused museums throughout the United States.

Limitations

The current project had several limitations, many of which were introduced by the COVID-19 pandemic and the infeasibility of assessing focal variables before and after professional development training. Pre-existing differences in focal topics, public favorability, and existing inclusion initiatives between PMs and CMs may have obscured effects of training. For example, based on information published on their websites, two control museums engaged digital tools (but not staff training) to improve inclusion and accessibility for learners with developmental disabilities. Future research utilizing a pre/post training design will better elucidate potential effects of training. Another significant and unexpected limitation was museum staff turnover, which limited the potential impact of staff training. Future phases of this project will address increased sustainability of training in inclusive practices by delivering training in a more accessible and scalable format (e.g., online learning modules; community of practice) with support from museum leadership. Participants in all samples were predominantly white and of relatively high socioeconomic status. Future research with more diverse samples is necessary to understand the generalizability of findings.

Conclusion

Taken together, findings from the current project underscore the need for increased inclusion for autistic individuals in informal STEM learning environments like museums to provide access to opportunities for building STEM capital. This project also identified several themes that should be considered for future iterations of professional development training in inclusive practices. Findings point to opportunities for museums to improve their support of the neurodivergent community through flexible approaches that can be tailored to learner preferences. These include increased guidance (staff-initiated, audio, and visual), increased interactivity of staff and exhibits, sensory friendly features (e.g., communicating low traffic times) and materials (e.g., discovery backpacks), and increased variety and quality of interactive exhibits. Additionally, explicitly connecting STEM

museum topics and related careers will likely increase science capital of autistic adolescents and improve their outlook for choosing a STEM academic path or career. In the next phase of this project, the absence of social distancing restrictions will allow for improved methodology to examine effectiveness of professional training at improving inclusion in STEM museums for autistic adolescents and their families.

Abbreviations

STEM	Science, Technology, Engineering, and Mathematics
PM	Partner museum
CM	Control museum

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

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Author contributions

NM, HH, and MM analyzed and interpreted quantitative and qualitative data and drafted the manuscript. AJ and SK contributed significantly to data acquisition and revision of the manuscript. AB, MM, and KS contributed to the design of the study and revision of the manuscript. SH, MV, JK, and JB contributed to the conception and design of the study, acquisition of data, and revision of the manuscript. CS contributed to the conception and design of the study, acquisition, analysis, and interpretation of data, and revision of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

All study procedures were approved by the Heartland Institutional Review Board.

Consent for publication

Informed consent and assent were obtained from participants as applicable.

Competing interests

The authors declare they have no competing interests.

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