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Evaluation of a community-based, hybrid STEM family engagement program at pre-kindergarten entry

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Introduction: This article investigates an early STEM family engagement program offered during the pre-kindergarten (pre-k) year. Pre-k is an important juncture for community organizations to support children's STEM engagement and parental involvement in informal STEM learning. We evaluated a program called Teaching Together STEM, which offers a series of museum outreach and family events at schools with the aim of broadening access to early STEM for children experiencing poverty. We replicated program content previously delivered using in-person events but shifted to a hybrid delivery approach that combined two virtual and two in-person events with linguistically diverse families of 3- and 4-year-olds. We evaluated whether attending events improved parent outcomes, such as involvement in STEM activities at home, and child outcomes, such as engagement in a STEM task.

Methods: The analytic sample included 59 families—35 randomly assigned families took part in the treatment and 24 families were assigned to a waitlist control group. Developed in Spanish and English, the informal STEM program was hosted by local children's museum educators for 21 pre-k classrooms using these components: (a) a series of four family education "funshops;" (b) parent tips and reminders via text message; (c) nine thematically related, take-home STEM extension activity kits; and (d) a family museum field trip for each school, as well as individual family museum passes.

Results: There were no significant impacts on primary outcomes of parent involvement (effect size [ES] = –0.03) or child STEM engagement/enthusiasm (ES = –0.73). There were improvements in some aspects of parents' STEM attitudes (e.g., math expectancy ES = 0.58), but other distal parent and child outcomes were not significantly changed.

Discussion: The hybrid delivery approach showed promise in terms of attendance and parent satisfaction but likely was not intensive enough to increase parent involvement. We discuss implications for other community-based family engagement programs focused on broadening participation in informal STEM.

KEYWORDS

science, technology, engineering, and mathematics (STEM), preschool, family engagement, museum-education, expectancy-value-cost theory

Introduction

Increasing access to informal STEM learning experiences in the early childhood years is important, particularly for children experiencing poverty (National Research Council [NRC], 2009; National Academies of Sciences, Engineering, and Medicine [NASEM], 2023). Although families can support children's early knowledge of science and math during routine family activities such as cooking, meals, chores, shopping, and play (e.g., McClure et al., 2017; Pattison et al., 2020; Leyva et al., 2022), many families need access to opportunities to learn how to integrate science and math into their daily lives. STEM-focused family engagement programs are important, in part, because typical family engagement offerings emphasize informal literacy rather than informal STEM learning (LeFevre et al., 2009; McClure et al., 2017).

This study considered if hybrid delivery of a STEM family engagement program was an accessible and effective means of increasing parent involvement and child STEM enthusiasm during the 3- and 4-year-old pre-kindergarten (pre-k) period. This experiment was a conceptual replication of a museum outreach program focused on broadening STEM access for families experiencing poverty, which we evaluated when delivered in person (Zucker et al., 2022), virtually (Zucker et al., 2024), and here with a hybrid approach. We previously found that families' in-person attendance was challenging due to limited time and scheduling conflicts (Zucker et al., 2022). Next, we found that virtual learning was more convenient, but it shifted too many steps for informal learning from the facilitator to the parents (Zucker et al., 2024). Thus, we expected that this shift to a hybrid delivery model might offer the "best of both worlds" (c.f., Hall and Villareal, 2015; Bashir et al., 2021) by providing convenient virtual sessions for busy families while maintaining social support for seeing other families doing STEM at in-person events and maintaining the learning supports offered by the in-person facilitator. Rigorous experimental designs that test a program under different conditions are valuable in education and informal STEM research because variations, such as hybrid delivery, can have noteworthy effects on findings (Hornby and Blackwell, 2018; Perry and See, 2022). More specifically, this conceptual replication sought to achieve a small but likely meaningful effect size on parent involvement (*cf.* effect size [ES] ≥ 0.18 Zucker et al., 2022) in early STEM with a relatively low-intensity but high-quality informal learning program that serves families experiencing poverty (Brandt et al., 2014). To further improve the rigor of our evaluation and measure more aspects of our theory of change (detailed below), this replication added new parent attitudes measures and new child measures of child STEM activity engagement and science and math knowledge.

Community-centered STEM outreach

Various organizations such as schools, museums, and libraries offer community events to engage young children in STEM and support their caregivers' behaviors and positive beliefs about supporting early STEM skills (e.g., Marti et al., 2018; Gaias et al., 2022). To broaden access to audiences unlikely to visit museum galleries, many museum-based informal STEM educators (ISEs) offer outreach events that bring museum-type experiences to community locations that may be less intimidating or more conveniently located in places where families already spend time (Farrell and Medvedeva, 2010; McWayne et al., 2022). ISEs from museums have unique expertise in making STEM learning engaging for young children and offering simple learning supports to enhance the quality of parent–child conversation during STEM activities (e.g., Haden et al., 2014; Franse et al., 2021). This study's family events were hosted at the children's school facility but delivered by the museum staff. School liaisons helped to coordinate the time and location of the event as well as communicate and advertise to families. We recognized that some families may not participate in school-led events due to individual family factors such as feelings of being unwelcomed in school settings, schedule conflicts, or factors such as the languages in which the event is offered (Hornby and Blackwell, 2018). Yet, the museum facilitators attempted to address barriers to attendance with this bilingual (Spanish/English) hybrid program.

ISEs play an integral role in the community and family systems, increasing young children's engagement in science and engineering. They help families understand how STEM relates to their everyday lives and to children's future achievement and potential STEM career interests (Pattison et al., 2020). ISEs are also trained to design innovative activities that elicit deep engagement and thinking about STEM concepts. We were interested in increasing children's *STEM engagement,* conceptualized as behavioral and affective evidence that children were attending to, discussing, or having emotional responses to STEM activities (Bell et al., 2019). The museum ISEs in this study leveraged a culturally sensitive, bilingual family engagement model (Garibay, 2007) designed to include diverse families to empower parents to see themselves as capable of doing STEM with their young children. The museum advertised the family engagement events as "funshops" to communicate that STEM with young children should be playful. The program encouraged families to have fun while using responsive, conversation-focused approaches to support their children's science and math skills during the pre-k period. This included multiple strengths-based approaches (Green et al., 2004; Welsh et al., 2014), including (a) an empowerment approach—workshop messages help families to see ways they are already doing STEM that they may not have recognized and ISE staff help parents celebrate their efforts while encouraging parents to set personal goals to increase informal STEM learning; (b) bilingual and cultural competency—ISE staff encourage families to do STEM in their family's preferred home language and in ways that respect and build on the families' existing cultural practices; and (c) social learning supports—the virtual and in-person events promote getting to know other families in their school community and learning about how to do STEM with guidance from a responsive ISE. Based on meta-analytic evidence, we expected that this randomized trial of a relatively low-intensity program could have small but noteworthy impacts on children's outcomes (Grindal et al., 2016; Alexandre et al., 2022).

Similar early STEM programs also serve families with strengths-based approaches that feature highly engaging science, math, and engineering. For example, a library-based program called Fun with Math and Science (FSM; see Gaias et al., 2022) includes a series of six 45-min family sessions that introduce parents of preschool children to strategies they can use to support their young children's early science and math skills using an interactive read-aloud approach in which ISEs at libraries model the strategy and offer activities for families to practice doing STEM. A pretest-posttest design study found that FSM parents reported increases in one proximal measure of using taught behaviors such as asking more "why" questions; however, they did find significant changes in other outcomes of parents' self-efficacy and general parenting style (Gaias et al., 2022). Another program called Head Start on Engineering (HSE) is hosted by informal learning staff at Head Start centers that serve families with low income or other risk factors (Pattison et al., 2018, 2020). HSE is offered in English or Spanish and includes a series of evening workshops hosted at the school site, take-home engineering activity kits, and a field trip to a local museum. A pretest-posttest design study found that HSE parents reported engaging their children in more frequent engineering activities and improved comfort in supporting their young child to problem-solve or do other engineering practices (Pattison et al., 2018). These two studies of similar informal STEM programs did not directly measure any child outcomes or use random assignment designs that evaluate causal impacts (Pattison et al., 2018; Gaias et al., 2022). A review of more diverse early informal STEM programs concluded that too little informal STEM research has supported linguistically diverse families and that studies using rigorous, experimental designs mostly occurred in museum settings or with children older than preschool (Alexandre et al., 2022). The current study addresses some of these gaps by conducting a rigorous evaluation of an informal STEM program with a culturally and linguistically diverse sample of young preschool children and their primary caregivers (hereafter referred to as parents, although we were inclusive of diverse families).

Early parent involvement in STEM

Parents are children's first and most important teachers. They introduce their young children to fundamental skills through everyday activities and with the experiences, materials, and toys that they provide for them in home-based, informal learning settings. Accumulated research demonstrates the importance of early parental involvement in improving children's academic outcomes (Boonk et al., 2018; Barnett et al., 2020). Exposure to early informal STEM experiences such as card games, board games, and cooking appears especially consequential for child learning (LeFevre et al., 2009). However, many parents, particularly low-income parents and marginalized populations in STEM, say that they do not know how to provide young children with appropriate STEM activities at home and that they need more resources to do science and engineering activities with their children (Silander et al., 2018; Caniglia et al., 2021; Ennes et al., 2023). Providing parents with culturally relevant resources is a fruitful step in engaging parents as collaborators in their young children's STEM learning (Roque, 2020a,b). Researchers also suggest that pre-k families need increased awareness of how early science and engineering opportunities may create pathways to support long-term STEM engagement (Morris et al., 2019; Pattison et al., 2020).

Thus, a primary goal of our Teaching Together STEM program was to equip parents to get involved in their child's STEM explorations by offering frequent, engaging, and effective informal STEM learning opportunities at home. We conceptualized *parent STEM involvement* as the frequency with which parents reported doing science, math, or engineering with their child in a typical week. Families participated in playful Teaching Together STEM activities, both in person and online, that incorporated STEM skills and received materials for STEM activities to support science and engineering processes at home. Key messages in the program emphasized the value of simply talking about science and math as well as ideas for playful, informal STEM activities for young children. We explained that everyday parent–child talks about STEM and parents modeling positive attitudes about doing science and math can create early STEM interest pathways for their child (e.g., McClure et al., 2017; Cian et al., 2021). Given that relationships between children's informal STEM learning and STEM skills are evident as early as kindergarten (e.g., LeFevre et al., 2009), our Teaching Together STEM program targeted families with children in pre-k, an age corresponding to a potentially critical juncture for supporting science engagement (Saçkes et al., 2011; Leyva et al., 2017; Silander et al., 2018).

Parent attitudes about STEM

Parents likely have diverse pre-existing attitudes about doing informal STEM with their children. Positive or negative perceptions about how much their family will enjoy or value doing STEM activities may influence the enthusiasm or frequency with which parents encourage STEM at home. These broad attitudes may be linked to factors such as parents' perceived self-efficacy or capability to successfully support and explain scientific concepts to young children (Albanese et al., 2019). Many adults report low *self-efficacy* for doing STEM or limited comfort and confidence in doing STEM with young children (e.g., Greenfield et al., 2009; Sonnenschein et al., 2021). This may be especially relevant for parents with less formal education and more competing priorities for their time (Green et al., 2007). Parents' attitudes about informal STEM may also be shaped by motivational factors such as the value they attribute to science and math and the opportunity costs they face for doing STEM activities rather than other activities (Eccles, 2015; Šimunović and Babarović, 2020; Zucker et al., 2021). Whereas in later grades, students' own STEM motivation is linked to increased longitudinal STEM interest, engagement, and achievement (e.g., Caspi et al., 2019; Butler-Barnes et al., 2021), and in the pre-k period, parents and families are key socializers whose attitudes and behaviors related to STEM influence their children (Eccles, 2015; Lv et al., 2022).

To understand how parent attitudes about STEM influenced their response to the treatment in the current study, we applied both self-efficacy (Bandura and Walters, 1977) and expectancy-value-cost theories of motivation (Eccles and Wigfield, 2020). In line with Bandura and Walters's (1977) focus on the contribution of specific ability beliefs to individuals' performance and choices, we expected that ISEs modeling learning strategies combined with engaging STEM take-home kits might improve parents' confidence in facilitating specific STEM activities. In addition, we believed that these treatments would more broadly increase parents' motivation to do science and math with their young children under the context of Eccles and Wigfield's (2020) *expectancy-value-cost theory* by equipping them with material and conceptual resources that establish positive expectations for their child's success in STEM, communicate the value of participating in STEM with their child, and remove key barriers/costs to this participation. Our theory of change for the Teaching Together STEM program emphasized that its strengths-based approaches could promote positive parent attitudes about STEM that would, in turn, increase their involvement in STEM. The program's engaging activities and parents' more positive attitudes were expected to increase children's immediate enthusiasm and engagement in STEM activities and, over time, more distal outcomes of children's STEM knowledge (see Supplementary Figure S1). Increasing children's science and math knowledge is important during preschool and likely requires both informal and formal learning experiences to make meaningful gains (Clements and Sarama, 2020; Lin et al., 2021).

Hybrid approaches

Some argue that hybrid learning can "combine the best of online and face-to-face" experiences (Singh et al., 2021); however, these claims are based on reviews of adult learning studies that show combining in-person and online delivery is more effective than a single delivery modality (U.S. Department of Education, Office of Planning, Evaluation, and Policy Development, 2009). Although "hybrid" has become an umbrella term for many models, our *hybrid program* delivery is an alternating hybrid approach that switches between virtual delivery and in-person delivery after a few months, but where facilitators are never expected to offer simultaneous, blended in-person and remote learning because we expected that approach would have been exhausting to facilitate and challenging for informal learners (Bartlett, 2022). Few studies have undertaken family engagement approaches using technologies for hybrid delivery. This emerging work using hybrid approaches to family engagement recognizes that young children learn best in the context of warm, responsive relationships with adults who can jointly attend to media with their child and use this experience to engage in follow-up conversations and learning opportunities (McCarthy et al., 2013; Pasnik et al., 2015; Elias et al., 2022). As noted, challenges to in-person events are that some families may not be able to attend the family engagement events due to scheduling conflicts and competing priorities. Virtual family engagement approaches can use components of effective in-person programs, such as an expert facilitator who (a) models learning strategies, (b) provides families with responsive feedback, and (c) creates a supportive online community that may be more accessible to low-income families (Gaudreau et al., 2020; Eastman, 2021). Yet, the virtual modality challenges range from technology issues to a lack of sense of belonging, excitement, or community compared to in-person events.

In the current study, we evaluated a series of four family engagement sessions: two virtual and two in-person family events. We piloted this hybrid treatment delivery approach to evaluate if families experiencing poverty found this feasible to attend. In our past in-person versions of Teaching Together STEM, families attended about 25% of events, citing time constraints and scheduling challenges as the barriers to participation (Zucker et al., 2021, 2022). In our past virtual version of Teaching Together STEM, which occurred during the COVID-19 pandemic and may not represent typical behavior, we observed an average of 40% attendance (Zucker et al., 2024). We hoped that offering some virtual events in addition to the in-person events would improve participant engagement, as the chief benefit of online learning is convenience, which often outweighs technology challenges/discomforts (Bashir et al., 2021). If promising, technology for providing virtual alternatives to in-person STEM could be considered within broader systems of early STEM education that increasingly feature various digital applications (e.g., videos, robotics, and digital games; Nikolopoulou, 2022).

Study purpose

We built on our prior experiment that showed providing families with resources to do science and math at home produced larger, albeit non-significant, changes in parent involvement than attending family education events alone (Zucker et al., 2022). This study replicated the pre-k Teaching Together STEM content and materials but used a hybrid delivery approach to determine if this produced meaningful increases in parent involvement while improving attendance for a similar sample of families who were experiencing poverty and likely had competing demands on their time. We view this study as a *conceptual replication* (i.e., reuse of methods/materials in a new sample) rather than a direct replication because this study follows directly from our prior study's findings (Zucker et al., 2022, 2024) but does not use identical delivery methods (Wiggins and Christopherson, 2019). The same informal STEM educators from a local children's museum delivered the treatment in the prior studies and the current study. The position of museum facilitators was that of a bilingual community partner who sought to empower parents and broaden access to informal STEM learning at schools where most children were experiencing poverty and schools serving linguistically and culturally diverse families. We addressed these research questions (RQ):

RQ1-Feasibility: To what extent did families attend events and did participation vary by modality (virtual/in-person) or family background characteristics? Were parents satisfied with virtual and in-person funshops?

RQ2-Parent outcomes: Did parent outcomes change from pretest to posttest and were there differences between treatment and control groups related to STEM: (a) parent involvement, (b) self-efficacy, or (c) motivation?

RQ3-Child outcomes: Compared to the control group, what was the impact of the intervention on children's: (a) STEM enthusiasm and engagement during a family engineering task and (b) distal science and math knowledge?

We expected that the hybrid offerings would allow parents of diverse backgrounds to attend at least one event. We hypothesized that small increases in the proximal outcome of parent STEM involvement commensurate with a past similar cohort (ES = 0.18, Zucker et al., 2022). We had not previously evaluated the proximal outcome of children's STEM engagement and enthusiasm with the "Bridge Challenge" task described below but hoped it would be sensitive to treatment impacts because it was a malleable outcome in more intensive, prior pre-k parenting studies (*cf.* Landry et al., 2017, 2021). We explored potential impacts on other distal outcomes, but only very small findings seemed possible given the low intensity of the treatment and the fact that these standardized measures were not directly related to program content.

Materials and methods

Participants

This study took place in 2022 with 59 focal families from 21 classrooms. Participants were eligible if their child was enrolled in pre-k classrooms. Demographics are summarized in Table 1. Most children were 4 years old (M = 59.29 months at pretest, SD = 5.48,

TABLE 1 Participant baseline demographic characteristics and balance check for analytic sample ($n = 58$).

Variable	Control ($n = 24$)		Intervention ($n = 35$)		Difference as effect size
	Mean	SD	Mean	SD	
Child's race is White	0.89 ($n = 16$)	0.32	0.50 ($n = 10$)	0.51	−0.90*
Child's race is Black	0.00 ($n = 0$)	0.00	0.20 ($n = 4$)	0.41	NA
Child's race is other than Black or White	0.11 ($n = 2$)	0.32	0.30 ($n = 6$)	0.47	NA
Child's ethnicity is Hispanic	0.92 ($n = 22$)	0.28	0.88 ($n = 29$)	0.33	−0.12
Child is female	0.52 ($n = 12$)	0.51	0.61 ($n = 20$)	0.50	0.17
Family speaks language other than english at home	0.95 ($n = 21$)	0.21	0.73 ($n = 24$)	0.45	−0.60*
Father's highest level of education[a]	3.09	1.74	3.00	2.61	−0.04
Mother's highest level of education[a]	4.05	2.19	3.70	2.56	−0.14
Household income[b]	3.14	1.62	3.00	1.65	−0.09

*p-value < 0.05. [a]Education range is 1 to 10. 1 = eighth grade or less, 2 = some high school but no diploma, 3 = high school diploma or GED, 4 = some college but no degree, 5 = trade school or other certification, 6 = AA/AS 2-year degree, 7 = bachelor's degree, 8 = some postgraduate or professional schooling, 9 = master's or postgraduate degree, 10 = professional degree. [b]Income ranges is 1 to 8. 1 = $11,000 or less, 2 = $11,001–$20,000, 3 = $20,001–$30,000, 4 = $30,001–$40,000, 5 = $40,001–$70,000, 6 = $70,001–$100,000, 7 = $100,001–$150,000, 8 = $150,001 or more.

min = 42.00, max = 68.03), and most families were Hispanic and/or White ethnicity/race. Eligible schools were serving a majority of students experiencing poverty, with an average of 91% of students identified as economically disadvantaged. More than half of the children were attending bilingual pre-k programs (13 bilingual, 8 English classrooms).

Recruitment

As part of an ongoing collaboration, three school districts agreed to take part in this research. From those school districts, we recruited 10 eligible schools and 21 classrooms (i.e., school sites must serve ≥50% of socio-economic disadvantaged students, as indicated by eligibility for free/reduced federal lunch subsidies in state education agency records) and provided instructions to pre-k students in English or Spanish, as those were the two languages the treatment was available in. The study enrolled classrooms only if three or more families provided informed, written consent. Enrolled classrooms had a range of five to nine consented families. Eight of the 10 recruited schools were from a large urban public school district. The remaining two schools were recruited from smaller school districts located in the urban Houston metro area. Our recruitment procedures were approved by our local IRB (HSC-MS-15-0759) and required written parent consent. We used multiple methods to recruit families, including hosting virtual parent meetings, flyers in home-school communication folders, and sending emails/text messages via classroom teachers.

Randomization

In January 2022, researchers randomized 21 classrooms (J) to treatment ($J = 11$, $n = 51$) or control ($J = 10$, $n = 39$). The classroom was the unit of assignment because all 90 initial families, regardless of consent, were invited to in-person treatment workshops (see Treatment Description section).

Attrition

We observed substantial attrition at the posttest, with only 59 of the original 90 families completing the posttest. Families who attrited at the posttest were not responsive or not reachable (e.g., disconnected their phone and changed address) after multiple attempts to schedule the posttest. The analytic sample includes only those families with at least partial posttest data. The flow of participants through the research activities is detailed in Supplementary Figure S2 (CONSORT flowchart).

Treatment description

The 4-month treatment approach used a hybrid delivery model that was anchored with "funshops." This included two virtual sessions (February–March 2022) and two in-person events (April–May 2022). As noted, this program used several strengths-based practices, including (a) an empowerment approach in all messaging; (b) staff with bilingual and cultural competency to support diverse families; and (c) social learning support of the other participating families and from the ISEs who facilitated events. The bilingual program included all written materials in English and Spanish and facilitation by two female bilingual museum ISEs with multiple years of experience providing family engagement services. There were four treatment components that aimed at empowering families to do science, math, and engineering activities with their children.

Hybrid family education events

The first two funshops were virtual, 20-min sessions. For each virtual unit, families picked up a box from their children's teacher that contained three activity materials and videoconference dates/instructions. During the synchronous, virtual session, the museum ISE led an icebreaker activity and explained the focal STEM practices and unit topic. Then, she previewed the asynchronous kit activities and explained key parent strategies (e.g., ask open-ended inquiry questions). Families had bilingual instructions with photos and links/QR codes to a YouTube channel in English or Spanish (see links in Table 2), in which the ISE gave more detailed parent strategy information and modeled step-by-step instructions for included activities. Activities were designed so that the parent and the child could complete three STEM inquiry activities after the virtual event and at a convenient time for the family any time before the next event. Only consented treatment families within each classroom were invited to a virtual session for their class; parents could select a session in English or Spanish.

The final two funshops were ~75-min in-person events hosted after school within the child's school cafeteria. Classroom teachers were encouraged to attend and support in-person events. Teachers invited all families into research activities in treatment classrooms to in-person events, regardless of the consent status. At in-person sessions, families had a snack, watched the unit introduction video, participated in an interactive read-aloud of a related children's book, and were supported by the ISE in five activity stations setup around the room. As illustrated in Table 2, whether virtual or in-person, the first part of funshops included ISEs explaining parent strategy (e.g., asking open-ended questions) and modeling the unit's STEM concepts during a read-aloud (e.g., using STEM language when planning and carrying out investigations). The second part of the funshops gave families opportunities to practice using these strategies and explore the STEM concepts at three to five STEM activity stations through which families rotated.

The detailed unit names, descriptions, and activities are in Supplementary Table S1. The units addressed these topics are as follows: Unit 1-STEM questions and language; Unit 2-Early math; Unit 3-Gathering data; Unit 4-Engineering. The 75-min in-person events included all aspects of the educator, the explaining and modeling, followed by family practicing applying the strategy at three activity stations. We selected a relatively short, 20-min synchronous event to allow time for families to complete the remaining steps in a total of about 75 min and balance the total duration across the two modalities. We also used a relatively short Zoom session because preschool children are still developing capacities to maintain their focus of attention (e.g., Diamond and Lee, 2011). After the 20-min Zoom session, families asynchronously viewed a ~10-min recorded read-aloud in which the museum ISE modeled focal strategies. Then, the family used a series of three short activity instruction videos posted on YouTube and completed the three STEM activities (~15 min each).

Text messages

Before and after each funshop, the research team communicated with parents via text message. Text messages were sequenced to increase attendance before funshops and to encourage families to extend funshop learning after these events. Parents received tips to embed the concepts in routine family activities, links to extension activities that used regular household materials, and reminders to use the specially provided take-home activities described below. Sample text messages and the communication sequence are outlined in Supplementary Table S2.

Take-home activity kits

Families received another set of STEM-related activities. These included commercially available activities linked to each unit; the list of the curated activities (valued at $155) is in Supplementary Table S3. These materials were provided because prior samples of families experiencing poverty reported limited access to toys/materials designed for STEM (Zucker et al., 2022). Families received these nine activities at the end of the first funshop; if they did not attend that event, they were delivered via the classroom teacher.

Family museum visits

Museum ISE encouraged families to continue STEM explorations at their local children's museum by giving families a free family museum pass. Up to four museum passes (valued at $90) were included in virtual kit boxes or distributed at the end of in-person funshops. Researchers also worked with a school liaison to coordinate family field trips to the museum by providing a bus/transportation from the school to the museum. Each treatment classroom received an invitation to attend on one Thursday evening during the treatment period. Teachers invited all families into research activities in treatment classrooms, regardless of the consent status.

Waitlist control

Families in classrooms assigned to the waitlist control group received the school's standard family engagement approaches. After the posttest and during the summer months, each control classroom was invited to complete one virtual funshop and a museum field trip that included a bus from the child's school to the museum. We offered the first funshop theme for this experience on STEM language and questions, as it was easy to apply without any specialized materials.

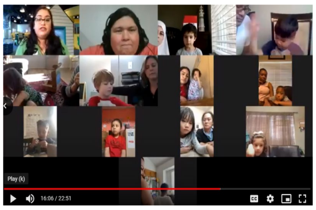
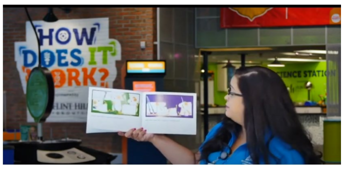
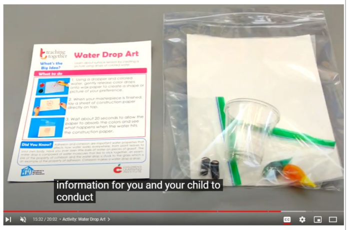
Reminders and incentives

All families who took part in the pretest and posttest activities received an eGift card for $50 for taking part in each timepoint. We worked to improve attendance for parents who did not attend the first virtual event. For the 35 treatment parents who did not attend the initial funshop, we sent a text message with these parts: (a) stating "we missed you" at the recent funshop, (b) sharing the YouTube link to the activity videos, and (c) asking if they would like to receive $10 if they attended the next event. We did this because small monetary incentives may provide a short-term boost in parent STEM involvement (Zucker et al., 2022). Eleven of these 35 parents (31.4%) replied "yes," this incentive motivated them to attend the next event (2 did attend), one answered "no," and twenty-two (62.9%) did not reply.

Measures

The pretest was conducted in January–February 2022 by trained research staff using a virtual approach. We chose a battery of measures

TABLE 2 Teaching Together STEM sample images of activities in virtual and in-person modalities.

	Virtual funshop components	In-person funshop components
Part 1: ISE modeling of focal strategy and concept	ISE leads video chat/Zoom and sends videos (reads-alouds, etc.) [a]   ISE models activities in video recording.   	In school library or ISE reads aloud and explains activity stations setup around room.[b] 
Part 2: Parent–child practice strategy and explore concept	Family uses mailed STEM activity kit. 	Families do activities while ISE provides parent–child dyad with feedback. 

[a]Parents were sent a link with video instructions that were in their preferred language. Themes 1 and 2 instructional videos are available at this YouTube channel in English: https://www.youtube.com/playlist?list=PLPZCH1CZOF9IJPQOxPJ0Xp0fkp8egc_NG and here in Spanish: https://www.youtube.com/playlist?list=PLPZCH1CZOF9JhZI7gtiCwYEvgXAJBakzZ. [b]Facilitator guides and materials are available for use at this site: https://public.cliengage.org/tools/quality/family-engagement-resources/hosting-family-events-to-support-childrens-development/.

that could be completed by parents and children via videoconference for family convenience and because of ongoing hesitations in 2022 about COVID risks. Posttests were conducted in person (May–July 2022) at families' homes as the pandemic concerns were subsiding.

Parent outcomes

At the pretest and posttest, we gave parents a bilingual online survey that took about 10–15 min to complete. The primary outcome was the frequency of *parent involvement in STEM,* which was measured by asking how many times per week parents and children engaged in math activities (e.g., "How many times in the past week have you counted different things with your child") or science (e.g., "How many times in the past week have you talked with your child about plants, animals, or other living things?"). The nine parent involvement items were the same as our past studies (Zucker et al., 2021, 2022, 2024) and adapted from national surveys (West et al., 2007). Items ranged on a scale from *1* = not at all; *2* = once or twice; *3* = three or more times, but not daily; *4* = every day. Parents reported doing STEM activities once or twice a week; see descriptive statistics for all items in Supplementary Tables S4, S5.

Distal parent outcomes were related to parents' attitudes about doing STEM with their children. This included *math and science self-efficacy* items ("I am confident that I can support my child's math learning") using a 7-point scale (*1* = not true at all, *7* = very true). These items were based on self-efficacy theory (Bandura and Walters, 1977) and adapted from the 2006 Program for International Student Assessment (see psychometrics Bybee et al., 2009). We used the *expectancy-value-cost motivation* theory (Eccles and Wigfield, 2020) to adapt items from multiple sources (Bybee et al., 2009; Jiang et al., 2018) that measured parents' perceptions of how exerting their own effort or encouraging their child would occur for science and math. Included items measured expectancy (e.g., "I expect my child to do very well in math"), value (e.g., "It is important to have good math knowledge and skills to get any good job in today's world"), and cost/effort ("It requires too much effort for me to get materials I need to do science activities with my child"), and used the same 7-point rating. Parents generally rated their STEM expectancy and value as high, but self-efficacy was lower, particularly for science (see descriptives in SM4).

Finally, to treatment families only, we asked *satisfaction* questions (e.g., "How helpful were the funshops in helping your family…learn how to do science and math at home? …access materials focused on math and science"), with a 4-point Likert scale (1 = very helpful, 4 = not helpful).

Bridge challenge task

This task was designed to capture in-the-moment behavioral evidence that learners were achieving high levels of engagement during a video-recorded STEM task (*cf.* Bell et al., 2019) that focused primarily on engineering practices that are appropriate in informal STEM (National Research Council [NRC], 2009; Barroso et al., 2016). The primary child outcome was *engagement/enthusiasm* during an 8-min bridge challenge task that was repeated at the pretest and posttest. Examiners challenged parent–child dyads to build a bridge with provided construction materials—tape, straws, blocks, cardboard, and ruler—that met these criteria: (a) ≥3 inches high, (b) support a 0.5 lbs. rock, and (c) support a toy car moving across. The first 7 min of the videos were coded to measure child engagement and enthusiasm on a 5-point scale (*5* = Almost always enthusiastic/engaged; *1* = Almost never enthusiastic/engaged). Coding training emphasized that ratings were based on observed behaviors and talk, including (1) verbal initiation—the extent to which the child talks about the STEM activity; (2) verbal response—the extent to which the child responds to the parent when prompted; (3) interest—the extent to which the child is consistently involved in the activity versus disinterested or distracted; and (4) positivity/tone of voice—the extent of child's positive talk or praise related to the activity versus negative or critical comments. We used established rating scales for this task (Landry et al., 2017, 2021).

Parent contingent responsiveness was also measured via coding of the same 7 min of the bridge challenge task (*5* = Almost always warmly responsive to child's signal; *1* = Almost never responsive or highly negative). This included the following multiple factors: (1) Control agenda—the extent to which the parent allows the child to control the activity; (2) Attentive—the extent to which the parent attends to the child's signals and shifts to their interests; (3) Pacing—the extent to which the parent's pace matches the child's understanding; (4) Control Materials – the extent to which the parent allows the child to control the material choices and manipulate the materials to design a bridge. Coders were blind to the condition and reached an index of reliability of 0.86–0.93 on a set of practice videos before coding. Parent responsiveness was not an outcome measure because it was not an explicit focus of the Teaching Together STEM program; however, the ISEs modeled responsive behaviors that followed the child's lead during activities. Parents' responsiveness was significantly lower at the pretest for the treatment group than families in the control group (see SM6), and at the posttest, neither group of parents showed highly responsive behaviors that attended to children's interests or offered support without overly controlling the task when children signaled they needed assistance ($M = 2.57$ to 3.36; see SM4).

STEM knowledge

Distal child outcomes included standardized *science and math knowledge*, measured with the Woodcock–Johnson Test of Achievement (Schrank et al., 2014) Science subtest and Applied Problems math subtest at the pretest and posttest. We calculated the total raw scores for these measures. These measures were not closely aligned with the Teaching Together STEM program, but we included achievement measures that are widely used in early education and psychology research to ensure rigorous measures (e.g., Rittle-Johnson et al., 2017).

Covariates

We measured child attention and inhibition using subtests from a widely used Kindergarten Entry Assessment (Montroy et al., 2020) and included the scores as covariates in our model to account for the effect of these skills on outcomes. The attention subtest measures children's ability to focus their attention on a task and respond quickly and accurately to prompts; the inhibition subtest measures children's ability to respond accurately while inhibiting a response. We also included caregivers' highest level of education and language of assessments as covariates.

Baseline equivalence

We did not see evidence of baseline equivalence for some measures, as detailed in SM6. Parents in the treatment group had significantly more parental involvement and parental math effort at baseline than those in the control group. Additionally, there was evidence of scores approaching the ceiling for the treatment group on measures of parental self-efficacy for math and science. Children in the control condition were more likely to be White and speak a language other than English at home (Table 1).

Analysis

We used descriptive statistics and the Kruskal–Wallis test to answer Research Question 1 and determine if differences in parent participation varied by modality or background characteristics. To answer Research Questions 2 and 3, we estimated two models that regressed the parent or child outcome on treatment conditions and covariates. Model 1 had basic controls (i.e., pretest, language of assessment, and age in months). Model 2 added additional covariates and demographic characteristics (i.e., attention and inhibition at pretest and highest caregiver education). We were unable to add school-fixed effects due to the small sample size. For our confirmatory outcomes, we completed an intent-to-treat (ITT) analysis to investigate the effect of being assigned to the treatment using OLS regression. As an exploratory approach, we also considered treatment-on-treated (TOT) effects, calculated by dividing the ITT estimate by the compliance rate of treatment receipt for all pooled treatment group members (Bloom, 2008). We considered families that participated in at least one treatment event/funshop, in either modality, as "treated" to calculate this compliance rate.

Results

All results should be interpreted with caution, given the high attrition.

RQ1-feasibility of hybrid program

On average, treatment families in the analytic sample attended 1.34 funshops (*SD* = 1.24) or 33.57% of four events. Of the 35 families that were assigned to the treatment condition, 24 (68.57%) attended at least one session. Family attendance patterns were similar for each modality, with 51.43% attending at least one virtual session and 54.29% attending at least one in-person session. More specifically, for the virtual events, 14 families attended one Zoom session and four attended both Zoom sessions. For the in-person events, attendance was similar, with 13 attending one of the events and six families attending both events at the school. The Supplementary Table S7 detail the number of attendees by modality and show that some families attended only virtual or in-person, such that less than one-third of treatment families attended zero events of any modality. In Table 3, the Kruskal–Wallis tests showed family attendance (across all sessions) related to some family background characteristics, with mothers having lower education levels attending more frequently ($p = 0.056$). Treatment parents reported visiting the museum for about once during the program ($M = 0.91$, $SD = 0.60$).

Parent satisfaction with both virtual and in-person modalities indicated that events were helpful with an average of 2.35 (*SD* = 0.71) on a 4-point rating (*1*-very helpful to *4*-not helpful). When asked what they liked about the virtual sessions and if we should continue virtual funshops even after the pandemic, 91.67% of the responding parents said "yes" with four parents noting the convenience of this modality with responses such as "si, es mas conveniente (Yes, it [virtual] is more convenient)" and that "sometimes parents do not have time to make it in-person." However, 38.46% of the respondents reported virtual barriers. For example, two parents reported poor internet connections. One parent felt virtual sessions were too short, saying we "did not have much time to do the (virtual) activities," which may have referred to the duration of the video chat and/or the time to complete the asynchronous kit of STEM activities with their child.

Only two parents reported barriers to the in-person modality of timing or scheduling conflicts after school. Multiple parents noted that there were better features of the in-person modality. For example, one parent said, "I think it's better in person; there is a better interaction between child and parent in person and the instruction method is easier to understand in person as well." Several parents reported (33.33%) that social interaction with other families or the museum ISEs was more beneficial in person with comments such as: "I like for Justin to be social with other kids." and "Me gusta todo lo que le ensenan a mi hija y la paciencia que tienen con ella (I like everything they teach my daughter and the patience they [museum ISE] have with her)." The majority of families (66.67%) enjoyed in-person activity stations they described as "fun, well-organized."

RQ2-parent outcomes

The ITT analyses suggest that when compared to parents in the control condition, parents in the treatment condition significantly

TABLE 3 Workshop attendance for virtual/in-person by background characteristics.

Variable	Group 0: 0% (*n* = 11)	Group 1: 25% (*n* = 10)	Group 2: 50% (*n* = 7)	Group 3: 75% (*n* = 5)	Group 4: 100% (*n* = 2)	Kruskal–Wallis Test	
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Chi Square (*df* = 4)	Prob
Mother's highest education	4.00 (2.79)	5.44 (2.79)	2.71 (1.70)	2.20 (0.84)	1.50 (0.71)	9.23	0.056
Father's highest education	3.30 (2.67)	4.67 (3.50)	1.86 (0.90)	1.80 (0.45)	1.00 (0.00)	7.55	0.110
Home language other than English	0.60 (0.52)	0.67 (0.50)	0.71 (0.49)	1.00 (0.00)	1.00 (0.00)	3.50	0.477
Hispanic caregiver	0.78 (0.44)	0.89 (0.33)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	3.13	0.537
Race caregiver Black	0.38 (0.52)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	6.57	0.160
Race caregiver White	0.50 (0.53)	0.63 (0.52)	0.75 (0.50)	1.00 (0.00)	1.00 (0.00)	3.05	0.549
Household income	2.22 (1.48)	3.78 (2.05)	2.67 (1.51)	3.33 (0.58)	3.50 (0.71)	4.26	0.373

increased their expectations for their child to do well in math ($p = 0.01$, $ES = 0.58$); the TOT analysis shows a larger impact on this outcome when a higher rate of families took part in at least one treatment event ($ES = -1.38$; See Table 4). There were no significant treatment effects for other parent outcomes, including the primary outcome—parent STEM involvement ($ES = -0.03$). However, there was a pattern in the TOT for most parent self-efficacy and motivation effect sizes to be larger and meaningful sizes, including increased self-efficacy for math ($ES = 0.69$) and science ($ES = 0.45$) and increased expectancy for math ($ES = 1.38$) and science ($ES = 0.96$), although, descriptively, parents still felt less slightly comfortable doing science than math (see SM4). Parents' perceived value for math also increased for the treatment group ($ES = 0.67$) and decreased effort/costs to do science when families took part in the treatment ($ES = -0.79$). There was also a negative, non-significant ITT effect on parents' contingent responsiveness ($ES = -0.26$; See Table 4).

RQ3-child outcomes

In addition to investigating the effect of the treatment on parent outcomes, we also investigated the effect on child outcomes. The ITT analyses suggest that when compared to children in the control condition, children's STEM engagement/enthusiasm ($ES = -0.73$), math knowledge ($ES = -0.06$), and science knowledge ($ES = 0.02$) did not significantly change after participating in the treatment. If a higher rate of families took part in at least one event, the TOT analysis showed that the magnitude of effect sizes for child math knowledge ($ES = -0.03$) and science knowledge ($ES = 0.01$) decreased, whereas it increased in the unexpected direction for engagement and enthusiasm ($ES = -1.12$) (Table 4).

Discussion

This study used a rigorous experimental design to test a conceptual replication in which we shifted the key dimension of the delivery modality to hybrid (virtual and in-person), whereas our past studies used either in-person or virtual delivery (Zucker et al., 2022, 2024). The current project produced two main insights about using a hybrid approach to deliver informal STEM family engagement programs to families experiencing poverty. First, although the hybrid approach satisfied participants and offered the "best of both worlds" in terms of family convenience, it was not robust enough to improve primary parent or child outcomes. Notably, the magnitude of the posttest effect sizes for parent STEM involvement was smaller in this replication study (ES = −0.03) than in our prior delivery method (ES = 0.18; Zucker et al., 2022). However, the hybrid Teaching Together STEM treatment showed some promising trends for improving parents' self-efficacy and motivation to do STEM with their young children.

Disparities in STEM achievement start early and relate to later STEM career pathways (Butler-Barnes et al., 2021; Morgan et al., 2023). The present study included families experiencing poverty, many of whom spoke Spanish at home, and provided a bilingual, strengths-based approach to empowering parents to do STEM with their young children. These populations often face opportunity gaps, such as limited time for parent–child play and learning activities, as well as limited access to bilingual early STEM experiences (National Academies of Sciences, Engineering, and Medicine [NASEM], 2023). Recommendations to improve these gaps often include community organizations, such as museums, using innovative outreach strategies to broaden access (e.g., Ishimaru and Bang, 2016; Hurst et al., 2019). Hybrid delivery approaches as a strategy for broadening access to informal STEM warrant further evaluation because parents reported

TABLE 4 Main impact models comparing treatment to control condition.

Outcome	ITT estimate	Standard error	Adjusted *p*-value	ITT Effect size	TOT estimate	TOT effect size
Parent outcomes						
STEM involvement	−0.02	0.17	0.917	−0.03	−0.06	−0.10
Math self-efficacy	0.21	0.25	0.404	0.25	0.53	0.69
Science self-efficacy	0.18	0.22	0.417	0.19	0.40	0.45
Math expectancy	0.60	0.22	0.010*	0.58	1.23	1.38
Science expectancy	0.44	0.27	0.109	0.43	0.91	0.96
Math value	0.13	0.19	0.511	0.18	0.38	0.67
Science value	−0.08	0.26	0.761	−0.10	−0.21	−0.30
Math effort[a]	0.03	0.42	0.947	0.02	0.04	0.03
Science effort[a]	−0.61	0.40	0.137	−0.44	−0.94	−0.79
Contingent responsiveness[b]	−0.28	0.49	0.569	−0.26	−0.55	−0.51
Child outcomes						
Engagement/Enthusiasm[b]	−0.72	0.52	0.177	−0.73	−1.55	−1.12
WJ applied problem raw score	−0.27	1.26	0.831	−0.06	−0.13	−0.03
WJ science raw score	0.07	0.72	0.919	0.02	0.04	0.01

ITT, Intent-to-Treat; TOT, Treatment-on-the-Treated. [a]7-point scale with lower scores a better, whereas higher scores are better for other expectancy/value measures. [b]5-point ratings (1 = Low, 5 = High) of parent and child behaviors during bridge challenge with higher scores better. *$p < 0.05$.

that both in-person and virtual sessions were satisfying for different reasons. They enjoyed the virtual modality for its convenience and the in-person format because it promoted social interaction with other families. Thus, there may be worthwhile advantages to offering both modalities. However, in future work, we would recommend scheduling the in-person community building events first (e.g., to start with higher social support) and scheduling virtual offerings afterwards—or as a secondary, make-up option for parents who missed the in-person event. It is possible that the social connections and sense of belonging imbued during the in-person events may have been more effective at orienting parents to their integral role in facilitating their children's learning had they occurred earlier in treatment (see Hattie et al., 2020; Roque, 2020a). It is also possible that we did not replicate the magnitude of past effect size on parent involvement because the two hybrid sessions offered fewer opportunities for the ISE to provide support and guidance to families.

Most families in the treatment group attended at least one funshop with an average attendance of 33.57% across the four events; this is comparable to other similar family engagement approaches (*cf.* Heath et al., 2018; Pattison et al., 2018; Zucker et al., 2022, 2024). A promising finding for broadening participation was that mothers' average education level significantly varied across levels of participation, and mothers with lower education levels attended more funshops. This finding related to maternal education may be due to unique characteristics of this sample; for example, it could be that these mothers had more available time, found the community-building aspects worthwhile, or found the bilingual aspects accessible. Consistent with our approach, effective early family engagement programs for mothers with limited education often include socially supported learning and the provision of hands-on resources (books, toys, and games) designed to empower parents to engage their children (Welsh et al., 2014). Other linguistically inclusive approaches to engaging families of young children show promise (e.g., McWayne et al., 2022; Surrain et al., 2024) and suggest that bilingual approaches may be essential for creating spaces conducive to supporting marginalized students and families.

It was disappointing that our primary parent and child outcomes were not significantly improved by the hybrid program. In fact, children's engagement and enthusiasm trended in the wrong direction. Although the bridge challenge task was reliable to code, children in the treatment groups may have been overly exposed to these ideas and less enthusiastic because bridge building occurred not only at the pretest and posttest but was also texted to parents as a possible extension activity to try with household materials such as cardboard boxes. Unfortunately, we did not gather data on whether treatment families used that particular home extension activity to determine if this is a likely explanation. Additionally, young children's STEM engagement and enthusiasm can be hard to measure and are unstable (National Research Council [NRC], 2009; Pattison et al., 2020). Nonetheless, we conclude that the hybrid approach or the intensity of the program was insufficient to improve these primary outcomes because abundant research suggests quality and social learning experiences can improve parent involvement and children's early STEM outcomes (Welsh et al., 2014; Grindal et al., 2016). It is possible that parents and children were not sufficiently engaged and supported by the initial virtual events, which resulted in reduced motivation to engage in aspects of the later in-person events, the class field trip, or the use of provided activity kits and resources. From a motivational perspective, the in-person environment provides unique affordances for the ISE to provide social modeling and feedback, as well as supportive social comparisons and interactions with other families (Schunk and DiBenedetto, 2020).

However, although we did not capture significant changes in parent and child outcomes, we observed promising trends that can be interpreted under the self-efficacy theory and the expectancy-value-cost theory of motivation, which view parents as key socializers who influence their children through their own beliefs and behaviors (Bandura et al., 2001; Eccles and Wigfield, 2020). Parents' self-efficacy for doing science and math with their child showed positive, albeit non-significant trends after completing the program (ES = 0.45 and 0.69, respectively), as did factors related to parental motivation (e.g., TOT math expectancy ES = 1.38). Given that this program was relatively brief, with just four sessions and support provided for 4 months, the magnitude of the effects we observed for parents' specific ability beliefs about facilitating STEM activities and more general related beliefs and attitudes may warrant further investigation and comparison to other more intensive and costly family engagement approaches (c.f. Grindal et al., 2016). These outcomes warrant further exploration because parents convey their beliefs about how important STEM is to their children in various ways that relate to children's own STEM value beliefs (Lv et al., 2022) and that can influence children's later selection of STEM careers (Šimunović et al., 2018; Šimunović and Babarović, 2020). More importantly, during early childhood, there is some evidence that parents who report higher STEM values are more likely to be involved in doing science and math activities with their young children (Zucker et al., 2021). To improve parents' beliefs about STEM, it is important to broaden access to museum outreach programs and other initiatives designed to empower parents to do developmentally appropriate, engaging, and high-interest STEM activities with their children (Hurst et al., 2019).

Limitations and future directions

There were several limitations to this study that limit the conclusions we can draw. First was the substantial attrition at the posttest. Second, variability in family event attendance might have resulted in insufficient treatment intensity to detect treatment effects. In an effort to improve attendance and quality of future hybrid family engagement programs, a comprehensive logistics checklist for researchers, educators, and community members is provided in Supplementary Table S8. This checklist outlines approaches that may improve family attendance, along with all other steps needed to host a successful virtual or in-person funshop event. Future research could explore if attendance differs when pre-k family STEM events are hosted at schools (like the setting of this study) or other community sites such as libraries where we have successfully delivered this program in the past (Garibay, 2007) and other STEM programs (e.g., Gaias et al., 2022) because elementary school settings with older students are not always welcoming sites for families from historically minoritized populations (Leyva et al., 2022; McWayne et al., 2022). Similarly, future implementation studies could randomly assign families to virtual, in-person, or hybrid treatment modalities as well as a control group to understand the causal impacts of each delivery method and compare the magnitude of differences for different treatment methods.

A third limitation is that there may have been some ongoing disruptions for families due to the COVID-19 pandemic during this study; indeed, it was concerned about potential temporary classroom closures that led us to host the first two events virtually rather than alternating each event modality (e.g., A/B schedule switching between virtual and in-person events). Although no events were canceled due to COVID and participating schools were offering entirely in-person instruction, families may have been experiencing pandemic-related stressors during this study period. Future research might consider (a) using parallel hybrid approaches that let families select their preferred modality or (b) other alternating hybrid approaches that interleave face-to-face activities and virtual events (*cf.*, Bartlett, 2022). For example, we recommend future alternating hybrid STEM programs start with in-person rather than virtual for a more supportive, community-based program kickoff. However, there are various design alternatives that could intertwine the social support of in-person events with follow-up home activities while investigating how to encourage families to bring examples of their STEM creations and explorations back to the community via social media and/or in-person events with the larger community. It is also possible that there is no need for synchronous virtual events if families are provided with bilingual kits and/or video instructions that they can use at any time. Future work should also add other data sources, such as parent interviews, to understand how families perceive virtual versus in-person modalities and more information on families' technological resources.

Conclusion

The pre-k period is a critical juncture for community organizations to engage families in supporting their children's STEM learning. Although the current study had limitations, such as a small, underpowered sample due to attrition, our findings suggest that further research is warranted to understand how community-based programs can use online and face-to-face experiences to create linguistically and culturally responsive spaces for families experiencing poverty to engage in informal STEM learning. Future research should consider spiraling between online and face-to-face (or vice versa) to evaluate conditions in which hybrid approaches may be a creative solution to improve convenience while also enhancing parents' self-efficacy and motivation to explore science with their children.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Committee for the Protection of Human Subjects at UTHealth Science Center Houston. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

Author contributions

TZ: Conceptualization, Formal analysis, Funding acquisition, Investigation, Resources, Supervision, Writing – original draft, Writing – review & editing. MM: Data curation, Formal analysis, Validation, Visualization, Writing – original draft. DD: Project administration, Supervision, Writing – original draft. YO: Data curation, Supervision, Validation, Writing – original draft. MA: Supervision, Writing – original draft. CM: Funding acquisition, Investigation, Writing – original draft. VB: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author disclaimer

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1281161/full#supplementary-material

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