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Exploring STEM environments that broaden participation

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Exploring STEM environments that broaden participation

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Editorial: Exploring STEM environments that broaden participation

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Editorial on the Research Topic
Exploring STEM environments that broaden participation

Introduction

The persistent underrepresentation of marginalized groups in science, technology, engineering, and mathematics (STEM) fields remains a pressing concern, highlighting systemic inequities that impede innovation and the broad cultivation of our human potential and capital. "*Exploring STEM environments that broaden participation*," in Frontiers in Education, addresses this challenge by examining the barriers at key academic junctures that disproportionately impact historically marginalized groups. This collection features evidence-based practices and innovative approaches. Accordingly, this provides actionable insights for dismantling systemic barriers and cultivating rich learning environments that support the success of all.

The significance of this work cannot be overstated. The issue of broadening participation to make use of the full breadth of the United States citizenry in the STEM workforce is not merely an issue of social justice but also one of innovation and economic vitality. A robust talent pool brings varied perspectives, fostering creativity and driving solutions to complex, global challenges. Consequently, ensuring full participation in STEM education and careers requires strategies that tackle both overt and subtle barriers. The articles featured in this collection provide comprehensive examinations of these strategies. Moreover, they present clear pathways forward for educators, researchers, and institutional leaders.

Mentorship and self-efficacy: cornerstones of STEM persistence

Within the collection, the pivotal role of mentoring in enhancing student self-efficacy is explored in several articles. More specifically, authors investigated the impact of mentoring during critical junctures, such as academic transitions, and in unique contexts. Mentoring is widely recognized as a powerful intervention that can significantly influence students' academic trajectories and professional aspirations. Davis and Wilson-Kennedy exemplify this in their exploration of holistic mentoring ecosystems, demonstrating how structured, comprehensive mentorship can mitigate adverse external factors such as the COVID-19 pandemic, particularly for low-income STEM students. Their work highlights the vital role that robust support systems can play in fostering resilience and persistence among college students, especially for those navigating complex paradigms.

Similarly, Oyelaran calls attention to the significance of early research experiences and mentoring, especially for improving the persistence of underrepresented racial minority science majors. Peer mentors can provide meaningful interactions that help students build the self-efficacy necessary to persist through challenging coursework and competitive environments. These findings collectively suggest that structured mentoring is instrumental to helping students navigate STEM education and careers. Moreover, these studies reinforce that effective mentoring goes beyond academic advising; it involves psychosocial elements, i.e., nurturing self-belief, providing role modeling, and fostering a sense of belonging within the STEM community.

Redefining STEM learning environments

Beyond mentorship, the collection explores the transformation of STEM learning environments to nurture scientific creativity to stimulate STEM identity and engagement. Pont-Niclòs et al. argue that integrating creativity-focused educational strategies can revitalize students' interest in STEM by connecting conceptual learning to real-world applications, encouraging divergent thinking, and promoting metacognitive skill development. Their findings reveal that cultivating creativity is a vital, yet underutilized, tool for building inclusive and motivating STEM environments that prepare students to meet the challenges of the future.

Mori extends this conversation by examining collaborative educational outreach strategies between high schools and universities in Japan. This work demonstrates how outreach efforts can create pathways that reduce barriers to STEM engagement. Herein, outreach coordinators serve as bridges that connect academic institutions with target communities. This approach expands access to potentially underserved communities and fosters access at critical educational junctures. Additionally, this work positions scientific creativity as a core competency and leverages academic partnerships to build opportunities for expanding this creativity. Consequently, it illustrates how strategically designed STEM learning environments can expand opportunities for all students to be successful.

Innovative approaches to STEM engagement

The collection also presents innovative STEM engagement approaches. Delogu et al. explore the impact of culturally responsive learning experiences on undergraduate students. This work shows how course-based research experiences can increase engagement and understanding for STEM undergraduates. By embedding research directly into coursework, the study demonstrates an approach to expanding access to research experience. Access to research experiences is a common barrier to participation, especially for students balancing academics with competing responsibilities. This approach highlights a strategy for expanding access to meaningful STEM engagement.

Calkins et al. advocate for centering positive youth development approaches from sports in STEM education, encouraging environments to validate and leverage students' diverse backgrounds, minimize performance anxiety in math through continuous exposure, and skill development to enhance identity. By incorporating environments that engage role models and peers, STEM identity is fostered. Their work argues that in recognizing and respecting these diverse identities, engaging role models and peers, the sport model can profoundly impact women students' academic success and their sustained identity in STEM. Together, these studies explore innovative approaches to STEM engagement through reactive strategies that remodel traditional learning environments and leverage flexible, modern learning environments to broaden access, increase participation, and support sustained interest in STEM.

Addressing intersectionality and identity in STEM

Intersectionality emerges as another area of focus within the collection. Intersectionality examines how overlapping identities, such as race, gender, socioeconomic status, etc., can influence experiences and opportunities within STEM (McCurdy, 2021). Erichsen et al. discuss institutional strategies aimed at "warming the chilly climate" for women in STEM, advocating for macrostructural changes that address systemic biases. Their analysis highlights macrostructural strategies designed to dismantle systemic biases and alter institutional cultures that perpetuate inequities. Such comprehensive changes are critical in reversing historical patterns of exclusion and marginalization, facilitating environments where all students can thrive.

Zucker et al. examine the impact of culturally relevant informal STEM learning experiences on STEM family engagement, demonstrating how virtual and in-person STEM experiences can contribute to family self-efficacy in exploring STEM with children. Their findings emphasize the importance of delivering STEM programming in culturally responsive environments. It also advocates for modes of engagement that support families in developing confidence and capacity to participate in STEM learning together. Understanding intersectionality and identity in STEM is not only about acknowledging differences. It is about transforming systems to ensure engagement for all learners. By focusing on the varied lived experiences of students and their families, the studies in this Research Topic call for intentional efforts that recognize identity as a critical perspective for developing inclusive STEM environments.

Paving the way for inclusive excellence in STEM

As higher education in the United States, and beyond, continues to evolve, it is imperative that empirical insights inform ongoing efforts to create high-impact learning ecosystems where all students have the opportunity to excel. These contributions, featuring original research, reviews, perspectives, and commentaries, provide evidence for best practice. These works suggest actions for cultivating robust educational ecosystems that empower students from all backgrounds to succeed and contribute to STEM innovation and progress. This Research Topic offers evidence for strategies and practices within STEM education. It is a timely resource actively broadening STEM participation.

Author contributions

TW: Conceptualization, Writing – review & editing, Writing – original draft. ZW-K: Writing – review & editing, Writing – original draft. RR: Writing – original draft, Writing – review & editing.

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.

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Understanding the factors that influence matriculation and persistence in Black medical students

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Purpose: The Association of American Medical Colleges' (AAMC) Strategic Plan lists 10 action plans one of which is focused on understanding how systemic barriers, such as racism and access to quality education, may negatively impact diversity in academic medicine. Thus, the purpose of this study was to understand the factors that impact the matriculation and persistence of Black medical students.

Method: A qualitative phenomenological study using Tinto's Model of Institutional Departure as an organizing framework was used for this study. Participants were asked a series of questions covering topics related to their goals, their medical school experience, their preparation for medical school, what could improve their medical school experience, and advice for future Black medical students.

Results: Forty in-depth semi-structured interviews were conducted during the fall 2022 term from October to December with Black medical students enrolled in over 16 US or Caribbean medical schools. Findings reported that two factors impacted matriculation for Black medical students (exposure to the medical field and resources, particularly financial resources). Findings also reported that three factors impacted the persistence of Black students once in medical school (diversity, support, and emotional resources).

Conclusion: The five factors identified by participants that impact matriculation and persistence for Black medical students can be used by medical schools to increase their enrollment and graduation of Black students.

KEYWORDS

qualitative, medical students, matriculation, persistence, Black/African American

Introduction

Although America's population has trended toward diversity, statistics show that the physician workforce is a poor reflection of the diverse population it strives to serve. Specifically, Black Americans account for over 13% of America's population yet only 5% of physicians are Black (1). These statistics become even more concerning considering that the population of Black male physicians has trended downwards since 1978 and now Black men only account for

3% of all physicians (2, 3). Research has asserted the importance of racial/ethnic concordance in addressing health disparities and patient satisfaction (4, 5). And the COVID pandemic further highlighted how the physician workforce statistics correlate to greater health disparities and worsened outcomes (6, 7). With a projected shortage of physicians by the year 2034, now is the time to research solutions that will prevent a greater contrast between America's population and the physician workforce. Some medical experts believe that diversifying the physician workforce is an integral part of the solution to addressing the physician shortage altogether (1). However, increasing the population of Black physicians is preceded by increasing the matriculation and graduation rates of Black students through medical school.

Although 2021 AAMC data reported a 20% increase in first-year matriculants, data also indicate a variation between the matriculation of Black students and the persistence of Black students in medical school (8–10). Black student attrition rates more than double the attrition rates of white students, and studies show that even if Black matriculation rates were tripled, the time needed to correct the deficit of Black physicians would equate to more than 20 years (10, 11). Why are Black students less likely to graduate medical school than their peers? The answer to this question could help medical schools address both the physician shortage and the lack of Black physicians in the physician workforce by increasing Black student matriculation rates and decreasing the attrition rates of Black students. Therefore, it is important for research to address the barriers that Black students face while matriculating through medical school. Thus, the following research question guided this study: What factors impact matriculation and persistence in medical school for Black students?

Materials and methods

Design

This study employed a qualitative design with in-depth interviews using the approach of phenomenology. Phenomenology is a qualitative approach that describes "the common meaning for several individuals of their lived experiences of a concept or a phenomenon" (12, p. 75). Additionally, interview questions for this study were guided by Tinto's Model of Institutional Departure. Before recruitment and data collection began, this study received IRB approval from Mercer University.

To describe matriculation and persistence among Black medical students, semi-structured in-depth interviews were used. Black medical students were recruited to participate in this study through email. The first author sent an email to Deans, Directors, and coordinators in the offices of Diversity & Inclusion, Admissions & Recruitment, and Multicultural Affairs at medical schools throughout the US explaining the study, providing a recruitment flyer, and asking them to send it out to students. Participants were also recruited by the first author sending the recruitment flyer to medical students they knew and asking them to send the information to medical students. Inclusion criteria for participation in the study were: (a) currently enrolled in a medical school in the United States or the Caribbean, and (b) self-identify as African American or Black. Recruitment and interviews took place during fall 2022.

Persons who were interested in participating in the study emailed the first author expressing interest in the study. At that time, they were sent a Google form with interview dates and times and asked to select one date and time from the list. After they signed up for an interview date, they were sent a calendar invite with Zoom information for the interview and the informed consent document. Participants were also sent a reminder email before their interview with the Zoom information.

Procedure

The first author who is mainly a qualitative researcher conducted all interviews. Interviews lasted no more than 45 min. Interview questions were guided by Tinto's Model of Institutional Departure (13). The model suggests that students have to be integrated into the social and academic system of their institution in order to maintain at that institution (13). The model suggests that students come into college with attributes (family background, skills abilities, prior schooling) that develop their goals and commitments (13). Once they engage in the social (activities and peers) and the academic (faculty/staff and their performance) environments at their college and become integrated, their goals and commitments may change which then determine if they stay at their college (13). The model further suggests that a student's external commitments to things such as family and work impact their goals and commitments which can ultimately influence whether they stay in school (13). For the purposes of this research, interview questions were developed around what impacted their preparedness for medical school, their goals, their connection to their medical school, their suggested improvements for their medical school, and their advice for future Black medical students. Interview questions were developed by the first author and were not reviewed by other researchers or student researchers. A list of interview questions is in Table 1.

Before all interviews began, participants were asked if they consented to have the interview recorded. Once they consented to the interview being recorded, informed consent was explained and obtained via Zoom recording. After informed consent was obtained,

TABLE 1 Interview questions.

1. How did your family impact your decision to pursue medical school?
2. How academically prepared do you believe you were for medical school?
3. How do you believe your race influenced your preparedness for medical school?
4. How do you believe your gender influenced your preparedness for medical school?
5. What goals did you have coming into medical school? (personal, academic, professional)
6. What goals do you have now that you are in medical school?
7. What connection do you have with your medical school?
8. What connection do you have with the faculty at your institution?
9. What connection do you have with your classmates at your institution?
10. What could be done to improve these connections?
11. How do your non-school connections (family, friends, partner) impact your work in medical school?
12. Have you faced any difficulties in medical school?
13. Have you had positive experiences in medical school?
14. What would make your medical school experience better?
15. What advice would you give future Black medical students?

participants were asked a series of demographic questions before the interview started. Zoom recordings of interviews were deleted after the analysis was conducted. Participants were provided a $50 gift card for their participation.

Analysis

All interviews were recorded via Zoom and transcribed using a transcription service. Through the use of deductive codes, the transcripts were analyzed using Dedoose software. To develop the deductive codes, authors 2–4 were assigned a certain number of transcripts and asked to develop codes along with definitions for elements that appeared frequently in the transcripts they were assigned. Once codes and definitions were developed, they were reviewed by the first author for clarity before using the codes to analyze the transcripts using Dedoose software. A determination of overall themes was initially determined by looking at codes that appeared in at least 50% of all transcripts which came out to three general themes (support, resources, and emotional). Once this was completed, the co-occurrence among codes was assessed with support and resources having the most co-occurrences across all transcripts. From this analysis, findings were developed and sent to participants for member checking to see if participants agreed with the findings and had edits or additions to the findings.

Results

There were 40 participants ranging from 22 to 40 years of age. Ninety percent of participants were enrolled in an MD program, while 10% were enrolled in a DO program. Almost half of the participants (48.8%) were 25 to 27 years of age (Table 2). More than half of the participants were female (65.9%). Among all participants, more than half were in their first year of medical school (73.2%). Half or more than half of the participant's mothers (57.5%) and fathers (50%) were college graduates or had a professional degree. Sixty-one percent of all participants were single with most single participants being female (77.8%). Most participants were paying for medical school through loans or scholarships or a mix of both. All male participants (14) were attending medical school at a Predominately White Institution (PWI). Among female participants, 11.1% of participants were attending medical school at a Historically Black College and University (HBCU). Table 3 lists the specialties the participants are planning to go into. While four participants listed more than one specialty area, the top three specialties that participants are planning to go into are (a) primary care specialty (12), (b) surgery specialty (9), and Dermatology (5).

Factors influencing matriculation and persistence

For this study, we are defining matriculation as the process a person goes through to get accepted into medical school. We are defining persistence as a person's ability to maintain through difficult moments once in medical school in order to get to graduation. Participants' responses to factors that impact their matriculation and

TABLE 2 Characteristics of interview participants.

Characteristics	Total (*N*=41)	Male	Female
	n (%)	14 (34.2%)	27 (65.9%)
Age			
22–24	11 (26.8%)	6 (42.9%)	5 (18.5%)
25–27	20 (48.8%)	6 (42.9%)	14 (51.9%)
28–30	6 (14.6%)	1 (7.1%)	5 (18.5%)
31–33	3 (7.3%)	1 (7.1%)	2 (7.4%)
34–36	–	–	–
37–40	1 (2.4%)	0	1 (3.7%)
Year in medical school			
First Year	30 (73.2%)	12 (85.7%)	18 (66.7%)
Second Year	5 (12.2%)	1 (7.1%)	4 (14.8%)
Third Year	3 (7.3%)	1 (7.1%)	2 (7.4%)
Fourth Year	3 (7.3%)	–	3 (11.1%)
Paying for school (could provide more than one option)			
Work part-time			
Work full-time			
On scholarship	21	10	11
Loans	34	10	24
Pell grant			
Work-study			
Other			
GI Bill	2	2	-
Savings	2	–	2
Parental support	1	–	1
Mother's education			
8th grade or less			
Part high school			
High school graduate	7 (17.1%)	1 (7.1%)	6 (22.2%)
GED	2 (4.9%)	1 (7.1%)	1 (3.7%)
High school graduate plus vocational training	2 (4.9%)	1 (7.1%)	1 (3.7%)
Part college	7 (17.1%)	1 (7.1%)	6 (22.2%)
College graduate	10 (24.4%)	3 (21.4%)	7 (25.9%)
Graduate or professional degree	13 (31.7%)	7 (50%)	6 (22.2%)
Father's education			
8th grade or less			
Part high school	1 (2.4%)	–	1 (3.7%)
High school graduate	3 (7.3%)	–	3 (11.1%)
GED	2 (4.9%)	1 (7.1%)	1 (3.7%)
High school graduate plus vocational training	1 (2.4%)	1 (7.1%)	–
Part college	6 (14.6%)	2 (14.3%)	4 (14.8%)
College graduate	7 (17.1%)	3 (21.4%)	4 (14.8%)

(Continued)

TABLE 2 (Continued)

Characteristics	Total (*N*=41)	Male	Female
Grad/Professional degree	13 (31.7%)	5 (35.7%)	8 (29.6%)
Unknown/not applicable	8 (19.5%)	2 (14.3%)	6 (22.2%)
Relationship status			
Single	25 (61%)	4 (28.6%)	21 (77.8%)
In a relationship	13 (31.7%)	8 (57.1%)	5 (18.5%)
Married/Partnered	3 (7.3%)	2 (14.3%)	1 (3.7%)
Separated/Divorced	–	–	–
Type of school			
PWI	37 (90.2%)	14 (100%)	23 (85.2%)
HBCU	3 (7.3%)	–	3 (11.1%)
Caribbean	1 (2.4%)	–	1 (3.7%)

persistence in medical school can be separated into five areas: exposure, resources, diversity, support, and emotional. Overall, participants' responses appeared to reflect that exposure and resources are important factors for their matriculation into medical school; however, diversity, support, and emotional factors are influential to their persistence in medical school.

Pre-entry attributes

Pre-entry attributes are factors that participants have or have experienced before coming to school. The two factors associated with this are exposure and resources.

Exposure

Exposure was related to not growing up being exposed to someone in medicine. Participants mentioned how not having this kind of access caused them to work harder to find out information that they needed to apply to medical school or to find other resources they needed to apply to medical school. As mentioned by two participants.

> Most of my classmates are children of physicians and if they are not children of physicians they – you know, somebody in the family is a physician. Some of them are like sixth generation doctors, you know, so with that comes a level of being put on game that I do not think I had….So I think there's a lot of insight that is reserved for people who have access to the inside of medicine early on and usually it's not people who look like me, so I feel like when I found the classmates who are Black or of color who have parents in medicine they are few and far in between.
>
> …literally every step of the way, like I do not have, you know, my – my dad, whose name is Tom, who has, you know, been a doctor for generations, I cannot just go like shadow at my mom's office. I had to literally not only like follow a path, but literally create a path and hope that it was like going in the right direction.

TABLE 3 Specialty participants are planning to go Into.

Specialty	Total (*N*=40)	Male	Female
Primary care (primary care, pediatrics, internal medicine, family medicine)	12+	4	8
Anesthesiology	3	2	1
Orthopedics	2	1	1
Surgery (general, neurosurgery, surgical specialty, trauma)	9	4	5
Dermatology	5^	–	5
Emergency medicine	2	1	1
Psychiatry	2	1	1
Obstetrics/Gynecology	4+	–	4
Unsure	1	–	1
Ophthalmology	1^	–	1
Otolaryngology	1	1	-
Pathology	1	–	1
Oncology	1	–	1

+One participant selected ob/gyn and Pediatrics.
^One participant selected Ophthalmology and Dermatology.

Resources

Resources were related to things participants needed to help progress toward their goals. Participants mentioned how a lack of resources hindered their preparation for medical school. As mentioned by one participant, "…MCAT was my biggest holdback, because I did not have thousands of dollars for a Kaplan course, so I did a lot of self-study. I took the MCAT three times. And that definitely held me back."

Participants also mentioned how having access to resources was helpful for their medical school preparation. As mentioned by two participants.

> I was thankful to have known a couple of Black physicians going in, and that was definitely helpful. Being able to talk to them, like know what it's like, like see where like things I needed to work on, things I did not need to work, where like economically I realized that I would need more help, I got most of that advice from Black physicians.
>
> …I think that the reason why I was able to even prepare for med school was because of my race. Like I qualify for the pay assistance program through the AAMC, so I did not have to pay for any of my primaries that I sent, and that was like a really big help, and I know like, you know, not even just my race, but also my like socioeconomic status helped with that.

Institutional experience

Institutional experience deals with the factors related to the experience participants have with their institution, their classmates, and the faculty and staff. The three factors associated with this are diversity, support, and resources.

Diversity

Diversity was related to the importance of having diversity reflected at their medical school. Participants understood the importance of diversity and wanted there to be more strategic efforts by their schools to have diversity. As mentioned by two participants.

> …just more diversity. I feel like I really bonded with the previous class because they have more Black folks. They had like 15 Black men, 20 Black women to our like eight Black men, five Black women, but I think just more diversity specifically, yeah, that would make me more happier hanging out with more people like me.
>
> …what would make my experience better…I would say more critical mass, and what I mean by that is it does not necessarily have to be more African-American students, but it's just more people that I have things in common with. I think that always makes the experience great, because you do not feel so isolated, you know, feel so bogged down with school.

While participants wanted more diversity, some also mentioned that their schools have made some changes toward diversity, but that more efforts were needed. As mentioned by one participant.

> …they have been trying to put an emphasis on, you know, the diversity and equity and inclusion and like making sure our curriculum is supporting those efforts…I definitely know that it has improved since, you know, X number of years when they started doing these things, but there is a lot of room for growth…I would love for treating patients of color to be better than it is…I think the avenues to get those changes made are very, very frustrating…that it has not happened yet because it's so difficult to make those changes…

Support

Support was related to having assistance or someone to lean on when facing difficult times. Participants mentioned how having support from all leadership levels at their school was important to their success along with having support from classmates. One participant mentioned how having support pushes them to succeed.

> …I definitely know that when you have that like support system from like, you know, people with higher powers or higher positions than you that want you to succeed, like – and even though they say it, whenever they show it, you know, through things like meetings, one on one meetings, yeah, stuff like that definitely helps you to feel like, you know, it's more – there's more kind of pressure, but like motivating pressure on you to succeed, because now it's not only about you.

Another participant mentioned how having support would have helped them academically.

> …they have dropped the ball with me and everybody else who has been in my same position because there are a lot of us. And they – most of us look like me, who have been through this of like failing classes and like struggling through, you know, board exams. I just – if you saw that there was a problem I feel like you should have intervened sooner and offered me something else from what everybody else is doing, because obviously what everybody else is doing is not working, so that would have helped a lot.

Another participant spoke about the importance of having support from other Black students for their success.

> They have provided opportunities for first-year medical students to kind of engage and interact with upperclassmen who are underrepresented in medicine, which has been great because we have been able to establish relationships with some M2s, which is very, very helpful in navigating.

Another participant spoke to why having support from classmates is critical for Black medical students, "It's already hard being the minority, (laughs) but yeah, having people that, you know, relate to on a deeper level, you know, culturally definitely helps out a lot. It's – Yeah, much easier to talk to them."

Resources

Resources were related to things participants needed to help progress toward their goals. Participants mentioned how having support from their school along with tangible resources would help them while in medical school. As mentioned by one participant.

> …I think a lot of schools do this where they recruit students of color just like you know, recruit them, and then once they get here it's kind of just like they just drop you off and like there's no support once those students get here.

Other participants mentioned how having access to tangible resources is important to their success in medical school.

> Office of multicultural affairs is so supportive. Like they have like books…like everybody has access to an electronic copy, but if you want the book version, you can just go to the office and see if they have it, and then you can borrow it, and your only situation is like when you are done you can give it back so another student can use it next year, which I think is very lovely. Just like that, kind of like community has been really nice.
>
> …wellness has been one thing that us as a class have really wanted to be addressed better is feeling like the workload is high, but like we are at a point where like mental health resources and just the state of mental health for a lot of medical students, especially those who are entering during the pandemic is at like – it's really

> suffering, and so we need the resources, the time, the space to unwind.
>
> …it would be nice to actually have a real school building… I've been to like other med schools…and they have an actual building and the students are there. You see them all the time. They have different floors, and it's just for them. We have like a floor on one big building and then like a floor on another big building. It's –…it's just not enough.

External community

External community deals with factors related to the participants' family, work, and other commitments. The two factors associated with this are support and emotional.

Support

Support was related to having assistance or someone to lean on when facing difficult times. Participants mentioned how having tangible support from their family and friends was critical to them being able to be in medical school. As mentioned by one participant.

> …my family is my – They're a village. Like I really do have a village. I have my family – when I went through some financial troubles… all of my refund was gone, so…my parents took over trying to pay wherever they could. I've had my friends send me gas money…

Another participant mentioned the importance of tangible support from their family.

> My parents, they help cover the living expenses, mainly rent, so that's not a financial hurdle that I have to worry about for right now. And they helped me move in. They helped get a lot of things for me when I moved in here, like bed, dresser, night stand, another monitor so I do not have to stare at everything on my laptop. So they really helped me there.

Even if a participant's family could not provide tangible support, they mentioned they were still able to provide emotional support which was just as important.

Emotional

Emotional was related to support from family, friends, or partner that you can lean on who keep you level-headed.

> …just being able to like have someone to talk to I think is really important, who is not in medicine – or not in med school with you rather. Yeah, I think that's really important just to pull you back from all the studying your doing and just remind you that you are an actual person, and that you can enjoy some personal time, so yeah.
>
> …So…family-wise…they are very supportive. Usually call them a couple times a week or once a week, know they are in my corner, so that's just a very good thing to have, just – yeah, a level of support that helps me do well in school…

Discussion

Although diversity within medical schools has increased over the years, there has been a lack of growth for Black applicants, students, and graduates (14, 15). Understanding the factors that impact matriculation and persistence among current Black medical students may be beneficial to medical schools looking to increase the enrollment and graduation of Black students. Participants in this study reported their barriers to matriculation into medical school were a lack of exposure and a lack of resources. Exposure was related to a lack of exposure to someone in medicine while resources were related to things they needed to achieve their goals. The findings from this study on a lack of exposure being a barrier are similar to research on diversity in neurology which found that among Black medical students, a lack of exposure was the second reason for not choosing neurology as a specialty behind having a strong interest in another field (16). A lack of exposure to medicine was also cited by Black high school students as a barrier to pursuing a career in medicine (17). This study also reported financial challenges as a barrier to Black high school students not pursuing medicine which is similar to our findings related to a lack of resources, particularly financial resources, being a barrier to medical school (17).

Participants also reported that factors impacting their persistence once in medical school were diversity, support, and emotional resources. Diversity was related to the importance of diversity; support was related to having assistance or someone to lean on during difficult times; and emotional was related to having support from family, friends, partner, faculty/staff that they can lean on who keep them level-headed. The idea of diversity being important for persistence through medical school is similar to findings from a study looking at matriculation and graduation among minority medical students. While the findings were not statistically significant, the study reported that if minority students perceived they had enough racial/ethnic minority faculty members at their school, they had higher odds of graduating in 4 years than minority students who did not perceive they had enough racial/ethnic minority faculty (16). Additionally, the study reported statistically significant findings that minority students who had adequate mentorship had higher odds of graduating in 4 years compared to minority students who did not have adequate mentorship (16). Mentorship being important for graduating in 4 years for minority medical students is similar to our findings of having emotional support from faculty/staff being important for persistence while in medical school. Minority students who reported having a strong support system also had higher odds of graduating in 4 years compared to those without a strong support system (16).

This study revealed that barriers to matriculation are not the only factors that greatly affect the medical education of Black medical students. Findings show that a student's path is influenced by experiences while in medical school, so access to a diverse and supportive environment can greatly improve a student's success and emotional well-being. Institutions can use this information to establish programs and funding that can enhance a Black medical student's experience by promoting an inclusive and welcoming environment.

While providing a diverse faculty and staff is part of creating an inclusive and welcoming environment, medical schools should also work on how to make their curriculum, programming, and policies more inclusive and welcoming for Black students.

Future research in this area should approach this topic from the perspectives of undergraduate Black students interested in pursuing medicine, Black faculty within medical schools, family members of Black medical students, Black residents, and Black physicians. Having the perspectives of these different groups whom this study and other research have shown have an influence and impact on matriculation and persistence can greatly improve the scope of assessing the problem which can lead to a better understanding of this issue which can lead to more Black medical students in the future.

Limitations

While this study included more than 16 medical schools in the US and Canada, most participants came from universities in the southern region and on the east coast; thus, findings may not be generalizable to all Black medical students. Additionally, most participants were first-year medical students who were in their first semester of medical school; thus, the findings may not have been as full or complete since these participants did not have a wealth of experiences yet in their medical school journey. Along this vein, most participants were not first-generation students so the findings may not be reflective of these students. However, being a Black medical student makes one a minority within a minority group that the authors do not believe the findings would have been drastically different if more participants were first-generation. Lastly, recruiting participants by reaching out to current medical students and medical school diversity offices may have accounted for participants coming from certain regions of the US. The sample may have been more representative of all Black medical students had a listserv been used; however, the first author had difficulties with that so convenience sampling was used. However, the similarity of responses across interviews shows that saturation of the data was reached and it is believed that findings would have been the same with a wider sample or more participants.

Data availability statement

The datasets presented in this article are not readily available because the data is qualitative, it is unable to be provided. IRB approval does not cover making the data available to others. Requests to access the datasets should be directed to KM, mincey_kd@mercer.edu.

Ethics statement

The studies involving human participants were reviewed and approved by Mercer University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements. Verbal informed consent was obtained from all participants.

Author contributions

KM conceptualized the research, conducted the analysis, and wrote the paper. BR assisted with the analysis and writing of the paper. RJ assisted with the analysis and writing of the paper. MH assisted with the analysis. All authors contributed to the article and approved the submitted version.

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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.

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The science of citizen science: a systematic literature review on educational and scientific outcomes

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Citizen Science is an ever-growing field of public engagement with science, and recent years have seen an increasing number of studies examining its potential. This study reviews this research to determine the educational and scientific outcomes of Citizen Science. A literature search produced 1,240 articles that were subsequently coded according to their main focus. Articles fell into one of three main categories: (a) empirical scientific articles, (b) narrative project descriptions, and (c) theoretical and technical conceptualizations. Hundred and forty-eight studies investigated educational outcomes of participation in Citizen Science such as effects on interest in science or motivation. These studies were examined further to assess the achievement of educational outcomes of Citizen Science. In terms of changing epistemological beliefs, for example, Citizen Science seems to have little effect. Overall, there is currently a lack of empirical studies to assess the educational outcomes comprehensively. In contrast, many empirical scientific articles answered research questions in different scientific disciplines based on Citizen Science data and many studies confirmed a high level of Citizen Science data quality providing information on the scientific outcomes. Implications for future research on Citizen Science are discussed.

KEYWORDS

citizen science, science education, motivational effects, literature review, validity

1. Introduction

1.1. Citizen science

Recent years have seen an increasing number of Citizen Science (CS) projects designed to promote citizens' participation in science. In CS, citizens contribute to clarifying current scientific issues through active participation in real scientific studies even though they are not institutionally involved in the field of research (Bonn et al., 2016; Haklay et al., 2020). In particular, the expansion of the internet and new technologies have made citizen involvement much easier and more extensive, because tools are designed to enable worldwide participation (Bonney et al., 2014). Although CS projects differ regarding the extent of citizen participation, their associated scientific disciplines, and the use of scientific methods (Bonney et al., 2009), a shared goal can be identified. This goal is to achieve two specific outcomes (Brossard et al., 2005):

The first dimension represents educational outcomes and refers to citizens' benefits through participating in CS. These outcomes include increased motivation and interest in science, trust in science, and expanded knowledge about the scientific inquiry or specific project contents. The second dimension represents scientific outcomes and refers to scientists and an added value for science. Participation in CS can help create large data sets contributing to the clarification of scientific research questions and advancing the scientific discourse. CS projects differ in the extent to which they address these two dimensions (Phillips et al., 2014; Bonney et al., 2016). Whereas some projects pursue more educational outcomes, others focus more on scientific ones. Meeting both dimensions in one CS project is preferable but particularly challenging, because they sometimes compete, e.g., due to the project design (Bonney et al., 2016; Roche et al., 2020). So far, despite an increasing number of research articles on CS, there is still no sufficient synthesis of the results that would allow a summary assessment of the degree to which these outcomes have been produced. The present review intends to contribute to clarifying this issue.

1.2. Dual purpose of citizen science

CS projects are special learning environments that correspond in many respects to the characteristics of informal learning settings (European Commission, 2016). However, there are many CS projects for school classes that qualify as non-formal education. Even though CS in schools occurs in a planned manner, it is much more flexible and adaptive than formal learning contexts and could contribute to authentic science education. Thus, whether and to what extent the educational outcomes are achieved is particularly interesting from an educational research perspective. Phillips et al. (2014) developed a framework for evaluating the effect of CS projects on the participants. In this framework, the outcomes likely to be influenced by participation in CS are divided into different categories. One of the outcomes of participation in CS is interest in science and the environment. According to Hidi and Renninger (2006), interest describes a specific relationship between a person and a learning object. Interest creates the basis for meaningful learning and enhances the autonomous acquisition of knowledge without external influences (Krapp, 1999). Especially in the institutional context, CS could counteract the declining interest in science to be found in many students over the path of their education (Potvin and Hasni, 2014). Further, Phillips et al. (2014) mention motivation to join scientific or environmental activities as a dependent variable resulting from participation in CS. With reference to Ryan and Deci (2000), motivation can be defined as an intentional action that directs behavior toward a future action outcome. Motivation is enhanced when the three basic needs of competence, autonomy, and social inclusion are satisfied in an authentic and interactive learning environment (Ryan and Deci, 2002). These three basic needs can be met extensively in CS projects, because participants are actively involved in the scientific process, contribute personally to the clarification of scientific research questions, and are part of a large community (Bonney et al., 2009). Other educational outcomes of CS might be changes in attitudes toward science that could be described as "cognitive and emotional opinions about various aspects of science" (Kind et al., 2007, p. 873). These are relatively stable mental constructs based on previous personal experiences (Sigel, 1985; Pajares, 1992). Because they are an essential aspect of scientific literacy, change in such attitudes toward science is an important aspect for evaluating the educational outcomes of CS. Roche et al. (2020) point out that "the development of scientific literacy in tandem with the contribution to genuine scientific outcomes has been a longstanding goal of the field" (p. 2). The second aim of CS is to produce scientific outcomes (Bonney et al., 2009). In the course of the change from the deficit model to the dialogue-between-science-and-society model (Stilgoe et al., 2014), it was recognized that not only science can have positive effects on society, but that there is also a reciprocal relationship between both sides. Individuals outside the scientific community can contribute to science and the clarification of scientific research questions by, for example, providing their own particular expert knowledge. Using data from individuals, socioscientific issues can be addressed more easily. Today, the extent of participation in the scientific process can vary (Bonn et al., 2016). Whereas some projects limit participation to classifying existing data, others involve citizens in collecting new data. Apart from collecting and analyzing data, citizens can also be involved in the publication process of the results. However, few projects actively involve citizens in all steps of an empirical study, i.e., from developing a research question, over planning and implementing a research design, all the way to analyzing and interpreting the data (Bonney et al., 2009; Shirk et al., 2012; Haklay, 2013).

1.3. Aims of the present study

As mentioned above, high expectations are placed on CS (Socientize, 2015). It is increasingly addressed from a variety of perspectives and "is establishing itself as a field of research" (Vohland et al., 2021, p. 2). The science of CS, considered as a collection of all scientific findings on CS (popularity/dissemination of CS, project forms, participants, data quality, ethical challenges, and more) is getting larger and more complex. At the same time, there is an increasing need for scientific evidence on the positive effects of CS practices; and the scientific community is required to respond to this development (Perelló et al., 2021). So far, there are a few reviews on the effects of CS on educational outcomes (e.g., Stepenuck and Green, 2015; Groulx et al., 2017; Schuttler et al., 2018; Peter et al., 2019; Aristeidou and Herodotou, 2020). However, the "existing literature reviews on the topic have had very specific thematic or methodological foci and, therefore, may have limited application for the wider field of citizen science" (When et al., 2021). To date, there is still no comprehensive review integrating all CS projects regardless of scientific discipline or project form. Further, most reviews focus on effects on behavior and knowledge (Stepenuck and Green, 2015; Groulx et al., 2017) and we know very little about motivational effects of CS. For example, in the studies reviewed by Peter et al. (2019), only one study on interest is considered and motivation is not examined at all as a potential outcome in the studies considered. Thus, one central aim is to provide a comprehensive review of the research on educational and scientific outcomes of CS across disciplines. Against the background of the intended outcomes of CS, we address the following research questions:

1. What conclusions can be drawn from previous studies regarding educational outcomes of CS in terms of interest, motivation and attitudes toward science?

2. What conclusions can be drawn from previous studies regarding scientific outcomes of CS?

To this end, we first need to identify studies on the outcomes of CS and synthesize those results that focus particularly on educational outcomes. To select relevant articles, the first step is to classify all studies on CS and to provide an appropriate structuring of the science of CS. This fine-grained portrayal of research in the field of CS serves to keep track of the increasing number of research articles. On the basis of this classification, we can select those studies that address which educational outcomes have been produced. We shall examine how many studies are available that report educational outcomes of participation in CS and whether these studies are sufficient to allow generalized statements (see 3.1). Because we quantify not only those studies that deal with educational outcomes of CS but also the remaining research articles, we shall also be able to make statements about scientific outcomes. This review will start by showing how many scientific publications answer their research question based on CS data. This number of studies provides first indications on scientific outcomes of CS (see 3.2).

2. Methods

2.1. Literature search

Systematic literature reviews follow a guided and elaborated scientific procedure when searching for and analyzing literature, and they summarize the results concisely (Cooper, 2016). To gain a systematic overview of the literature on CS, we followed Cooper's (2016) guidelines for research syntheses. We searched for the term "Citizen Science" within the titles of publications in English or German. At the beginning of May 2020, we searched the databases Web of Science and FIS Bildung for entries published up to and including April 2020. In addition, all articles of the journal Citizen Science: Theory and Practice (CSTP) were considered, as this journal is an important source for studies in the field of CS, but is not indexed in the databases. This search resulted in 1,495 hits (Web of Science: $n = 1{,}315$; FIS Bildung: $n = 93$; CSTP = 87). A first screening through exclusion criteria (e.g., removing duplicate articles and articles without an abstract available) left 1,240 research articles. We also excluded articles in which the participants themselves were the object under study. The understanding of CS underlying this article is not that participants are surveyed, which is a common social science research method, but that they conduct research themselves.

2.2. Literature analysis

To provide a fine-grained portrayal of research in the field of CS and to retrieve studies related to educational and scientific outcomes, we developed a coding manual for our literature analysis. We developed the manual by following deductive and inductive processes: first, the intended outcomes of CS served as an initial orientation for sorting the studies (deductive process). Then, in an iterative process, a team of several social scientists grouped similar content areas of the articles (inductive process). The resulting coding manual differentiated between (a) empirical scientific articles, (b) narrative projects descriptions, and (c) theoretical and technical conceptualizations of CS (see Table 1). Within Category a, we first coded articles reporting educational outcomes of participating in CS projects (a1: *educational outcomes*). Further, we coded articles analyzing the quality of data gathered in CS projects (a2: *data quality*). Finally, we coded articles using CS data to answer scientific research questions in different disciplines (a3: *data use*). Within Category b, we coded descriptions of one to three CS projects (b1: *≤3 project descriptions*) and descriptions of more than three CS projects (b2: *>3 project descriptions*). Within Category c, we coded theoretical representations of CS (c1: *theory*) and technical devices for use in CS projects (c2: *technical devices*). Research articles were sorted into these categories based on the information given in their abstracts containing, in most cases, between 150 and 300 words. Two hundred and twenty six articles were selected randomly by a random number generator to be subsequently coded for assessing interrater reliability (Cohen's kappa = 0.78).

2.3. Assessing educational and scientific outcomes

To gain insight into whether and to what extent CS produces educational outcomes, we examined the studies on educational outcomes separately and in detail. To identify the relevant research articles, we applied the following inclusion and exclusion criteria.

- Participation in a CS project: We included studies in which the respondents had already participated in a CS project. We excluded studies in which participants were asked, for example, about their interest in participating.
- Effect of project participation: We included studies in which participation in CS was considered to be the independent variable having a potential effect on educational outcomes. We excluded studies examining, for example, the effect of invitation emails on the participation rate.
- Effects on interest, motivation, or attitudes: We included studies examining motivational outcomes. We excluded studies on knowledge and behavior since the effect on knowledge and behavior has often been the subject of previous reviews (e.g., Stepenuck and Green, 2015). Further, many studies suffer from methodological limitations in terms of the operationalization of constructs as they measured knowledge/behavior with self-reporting questionnaires or interviews. Questionnaires are subjective ratings and record the subjective assessment of one's knowledge/behavior that is often inaccurate (Zell and Krizan, 2014). For this reason, the results do not necessarily allow for conclusions about CS-influenced knowledge/behavior (Ajzen, 1991; Sheeran and Webb, 2016).

We could use the remaining studies to illustrate the implementation of research on CS and highlight associated problems and opportunities. The significance of their results will be reflected against the background of their methodological approach, referring in each case to their internal, external, and construct validity.

TABLE 1 Brief description of coding manual categories.

a1: Scientific findings on educational outcomes The object of investigation is educational outcomes of participants in CS projects. In this context, outcomes of participation in CS are focused on in more detail as dependent variables. Articles in this category examine whether there is any change in educational outcomes (motivation, knowledge, attitude, curiosity, consumer behavior, etc.) through project participation.
a2: Scientific findings on data quality The object of investigation is the quality of data collected by project participants. In this context, the collected data represents the dependent variable. This involves a comparison of CS data with, for example, data collected by researchers—not only to check the quality of CS data but also to identify, for instance, possible errors in CS data collection. Another subject can be the quantity of data (i.e., where there are many data points).
a3: Specific use of CS data The objects of investigation are quite diverse, being research questions from different scientific disciplines. Regardless of the diversity of these studies, the key common feature is that they address their research questions exclusively with the help of data collected by citizen scientists—either in the respective project itself or in a previous project.
b1: Description of one to three CS projects The object of investigation is one to a maximum of three CS projects. These projects are investigated or presented scientifically and systematically. Project characteristics are presented such as the organization and duration of the CS project, the number of participants, and other framework conditions of the project along with the scientific research methods. Comparisons of two or three projects may also be cited.
b2: Description of more than three CS projects The object of investigation is four or more CS projects. These projects are investigated or presented scientifically and systematically. Project characteristics and scientific research methods are presented. Unlike Category b1, studies in this category review and present a range of projects usually under a defined umbrella topic addressing an overlapping question related to CS. Comparisons of four or more projects may also be cited.
c1: Theoretical representation of CS The object of investigation is CS itself from a theoretical point of view. It is explained in more detail and differentiated with the help of a textbook, overview, or introductory chapter.
c2: Technical devices for CS projects The object of investigation is innovative technical developments (apps, tools, devices) and their possible application in the context of CS projects to enable access to the research object or data collection for the citizen scientist and to support collaboration between citizen scientists and researchers.

- Internal validity: This is the extent to which effects on educational outcomes can be causally attributed to participation in CS. It is influenced significantly by the implementation of control groups and multiple measurement points (Campbell and Stanley, 1963; Fraenkel et al., 2012).
- External validity: This is the extent to which a study's results are transferable to other CS contexts and projects. It is influenced by, among other things, the sample. Similarly, results cannot be generalized if studies are always limited to a similar setting or a particular discipline. Generalizable statements on the effects of CS are possible if several studies in varying contexts and with different samples provide similar results regarding an effect on personal variables (Shadish et al., 2002).
- Construct validity: This is the extent of appropriateness of inferences drawn from the results of a measurement instrument and is given mostly in measurement instruments that are developed on the basis of theory (Cohen and Swerdlik, 2009). Besides developing an instrument, theoretical foundations are equally important for selecting existing instruments. By referring to adequate theory, a distinction is made from the everyday understanding of a construct. Then, the findings of individual studies can be used to test theoretical assumptions about CS and to further develop scientific theories.

The assessment of scientific outcomes requires a different approach and depends on various aspects. As a basis for scientific outcomes, citizens need to participate in collecting or analyzing data to create appropriate data sets. Narrative project descriptions (Category b) can provide information on how many people are participating in current CS projects. Furthermore, the data have to be of high scientific quality to allow them to be evaluated for scientific purposes. The quality of CS data, as well as possible strategies for quality assessment, can be addressed by articles on data quality (a2). For CS to achieve its goal of answering relevant research questions, researchers need to publish scientific research articles to make the findings available to the scientific community. In a first approach, this review shows how many scientific publications answer their research question based on CS data. This number of studies provides first indications of scientific outcomes of CS.

3. Results

The following section presents findings on educational and scientific outcomes of CS. Before considering individual studies in detail, Figure 1 illustrates the process of categorization and the assignment of the studies to the three main categories: (a) empirical scientific articles, (b) narrative projects descriptions, and (c) theoretical and technical conceptualizations of CS.

About 50% of all studies were empirical scientific articles (Category a). The remaining 50% was split equally between narrative project descriptions (25%) and theoretical and technical conceptualizations of CS (25%). First, we focus on empirical articles on educational outcomes (a1) that may provide empirical evidence for the generally assumed effects of CS on individuals. We further look at studies on data quality and on scientific outcomes as well as the distribution of studies among the other categories to address whether scientific outcomes were achieved.

3.1. Educational outcomes

Overall, only about 10% of all studies ($n = 148$) investigated the effect of CS projects on individual participants and might provide evidence for educational outcomes. Applying the inclusion criteria (2.3) to these empirical articles left 51 studies with which to analyze in more detail the conception of the CS project as the independent variable, the sample composition, the study design, empirical methods, and educational outcomes in terms of dependent variables.

3.1.1. CS and interest

Seven studies examined the effect of CS on interest in science or project-specific content. Most of these studies had a low internal validity because they used simple research designs (e.g., Hiller and Kitsantas, 2014; Kelemen-Finan et al., 2018). For example, Kelemen-Finan et al. (2018) implemented a one-time posttest with $N = 428$ students after participation in a biodiversity CS project and had no control group. Because one major weakness of this research design is that it could not measure a change in individual outcomes (Campbell and Stanley, 1963), causal assumptions about the effects of CS on interest are not valid. Causally attributing a positive effect on interest to participation in CS, this study serves as an example of overly interpreted posttest data. As shown in Table 2, only two studies investigating the effect of CS on students' interest met the criteria of two measurement points (Seifert et al., 2016; Wallace, 2018). Seifert et al. (2016) examined the effects of a CS project on ticks and Lyme disease. After a one-hour introduction in the classroom, more than 200 high school students collected field data and ticks along 100-m transects in the surroundings of their schools, which where then committed and analyzed in university research. They implemented a pre- and posttest with a subsample of $n = 23$ students and were able to measure changes in the interest in science. Their results showed that students had an increased interest in pursuing science in college and graduate school after participation in CS. However, in the absence of a control group, the increase in interest cannot be causally attributed to participation in the CS project. Further, the absence of theoretical work leads to low construct validity. That is, these findings are of limited use for testing theoretical assumptions about CS and further developing basic scientific theories. Wallace (2018) implemented experimental and control groups as well as pre- and posttests, and was thereby able to control for group differences. In this study, $N = 137$ ninth-grade students (53.3% female) participated in the CS project *BudBurst* and were asked to monitor phenological changes of local tree species. To further investigate the effects of mobile devices, students were divided into three groups (participation in CS, participation in CS with mobile devices, no participation in CS). The different groups were surveyed before and after participation, that consisted of an introduction in the classroom and –depending on condition– two data collection events over a 5 week period. Results indicated an increase in STEM interest through participation in CS. Groups had comparable pretest scores and differed from each other statistically on the posttest score. Both experimental groups (participation in CS) had a significantly higher score than the control group on the STEM interest scale, but they did not differ from each other. To sum up, both studies (Seifert et al., 2016; Wallace, 2018) had an institutional context, whereas CS addresses the general population. This casts results in a critical light regarding their transferability to the overall population (external validity). External validity was limited further because both studies investigated the effect of a multi-day participation in CS projects in the field of biodiversity. These limitations to a specific sample and certain project forms do not yet allow any general conclusion about the effect of CS on interest in science. Given the importance of interest in learning processes, the results at least supported the role of CS in the school context and have an individual informative value.

3.1.2. CS and motivation

In contrast to the studies on CS and interest, the 43 studies found on motivation rarely investigated a change in educational outcomes. There was often a different research interest, such as why people participated in CS (descriptive) or how motivation related to the extent of participation (correlative). Consequently, only four studies

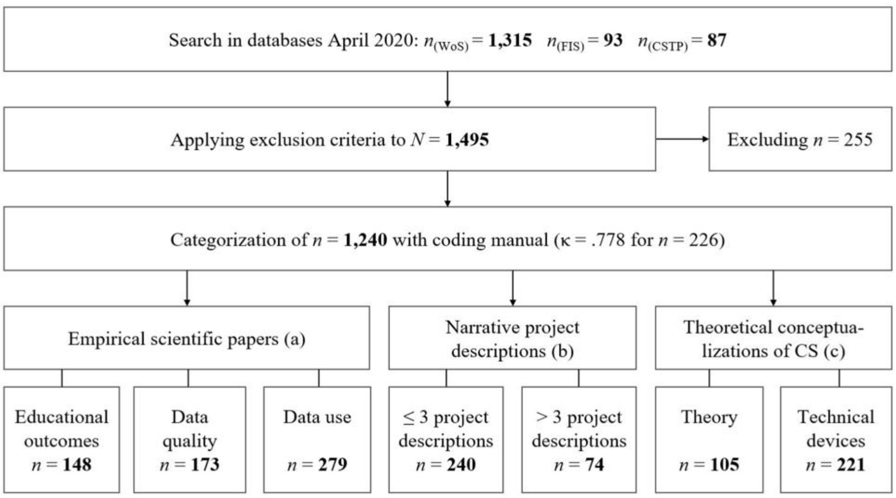

FIGURE 1
Categorization process.

TABLE 2 Studies investigating the effect of CS on educational outcomes with two measurement points.

Source	CS project	Activity	Participation	Sample	Outcome	Effect
Seifert et al. (2016)	Lesson on Lyme Disease	Collection of ticks and field data in nearby forests	2 days	23	Interest	+
Wallace (2018)	BudBurst	Observation and report of phenological changes of local tree species	3 days	137	Interest	+
Sandhaus et al. (2019)	Garden-roots	Collection of garden samples (e.g., plants and water)	1 day	16	Motivation	+
Condon and Wichowsky (2018)	STEMhero	Analysis of utility consumption and increasing own energy efficiency	2.5 weeks	551	Motivation	+
Basham (2012)	Mastodon Matrix Project	Sorting through sediment and documentation of identified organic and inorganic materials	8 weeks	11	Attitudes	/
Brossard et al. (2005)	The Birdhouse Network	Observation of birds and report of data on installed nest boxes	≥1 day	~200	Attitudes	/
Crall et al. (2012)	The NISS Project	Monitoring of invasive plant species	1 day	214	Attitudes	/
Price and Lee (2013)	Citizen Sky	Formulation of hypotheses and analysis of data about stars	≥ 1 day	333	Attitudes	+
Jordan et al. (2011)	Invasive Plant Atlas of New England	Monitoring of invasive plant species	3 days	33	Attitudes	/
Vitone et al. (2016)	School of Ants; Backyard Bark Beetles	Monitoring of ants in the surrounding area; monitoring of beetles with a simple collection trap	2 days each	102	Attitudes	/
Gottschalk-Druschke and Seltzer (2012)	Chicago Area Pollinator Study	Monitoring of bees in private gardens	1–4 days	25	Attitudes	/

"+" Indicating a positive effect; "/" indicating no effect.

implemented two measurement points providing evidence for changes in motivation. However, a key problem with two of these studies (Domroese and Johnson, 2017; Dem et al., 2018) was that they did not use the same pre- and posttest. Due to these methodological limitations, any potential change in motivation through CS cannot be correctly confirmed empirically. The remaining studies surveyed participants of the CS projects *Gardenroots* (Sandhaus et al., 2019) and *STEMhero* (Condon and Wichowsky, 2018). In the study by Sandhaus et al. (2019), $N=94$ participants were trained in data collection and were asked to collect plant, water and soil samples in their private gardens. After the samples have been analyzed by researchers, the results were presented at multiple data sharing events. The study revealed few significant changes in motivation for science learning and environmental action on the level of individual items. Due to the small number of completed posttests ($n=16$) the external validity is rather low. The study by Condon and Wichowsky (2018) was based on a larger sample of N = 551 students from Catholic middle schools. In course of the CS project *STEMhero*, that was carried out by the respective teacher of a class, students were asked to track their water meters at home, to analyze their consumption, and to implement strategies to increase water efficiency. Results revealed that the experimental group, that was participating in *STEMhero* over a period of 2.5 weeks showed significantly greater gains in motivation to pursue further study in science or math. However, since this study has particularities regarding the sample and the extent of participation, the available data on an eventual change in participants' motivation do not allow for generalized statements.

3.1.3. CS and attitudes toward science

We found 15 studies focusing on attitudes toward science. Similar to the studies on interest and motivation, only a few studies ($n=7$) investigated the effect of CS on attitudes toward science using questionnaires at multiple measurement points (Table 2). Six studies (Brossard et al., 2005; Jordan et al., 2011; Basham, 2012; Crall et al., 2012; Gottschalk-Druschke and Seltzer, 2012; Vitone et al., 2016) did not find any effect of CS on attitudes toward science. In the study by Basham (2012), for example, the effect of the *Mastodon Matrix Project* was studied with $N=11$ participants of an English Language course for adults. They were asked to collect data on organic and inorganic materials by sorting through soil samples over a period of 3 weeks after having received a short introduction. The project also included a collaborative analysis and discussion of data. However, the results did not show any significant change in attitudes toward science.

Beyond these results, what these studies did have in common was their advanced research design: all had two measurement points, and two studies implemented a control group (Brossard et al., 2005; Crall et al., 2012). The CS Project *The Birdhouse Network* (Brossard et al., 2005) asked participants to submit data on the use of nest boxes over a certain time period. In this study, the use of an established measurement scale (MATOSS) was theory-driven and provided high construct validity. However, the comparison between pre- and posttest in the treatment group did not show any statistically significant change in attitudes toward science. $N=214$ participants (75% female in experimental condition, 61% female in control condition) in the *NISS project* (Crall et al., 2012) were required to map invasive plant species after receiving 8 h of training. Participants in the experimental and control groups similarly received the MATOSS (Brossard et al., 2005) for pre- and posttests to validly capture attitudes toward science and ensure comparability of findings. Nonetheless, as in the study of Brossard et al. (2005), the comparison between pre- and posttest did not show any differences in attitudes toward science. Only one study investigating the effect of a CS project in the field of astronomy found a positive effect of CS on attitudes toward science (Price and Lee, 2013). The effect of CS on attitudes toward science was studied using the online CS project *Citizen Sky*. Since this project placed particular emphasis on communication between scientists and citizens and on empowering citizens to independently conduct their research, this study further investigated whether the level of participation was responsible for these effects. Overall, $N=333$ citizen scientists of which the majority were men participated in monitoring the star epsilon Aurigae and responded to pre- and posttest. Because this study included established measurement instruments, a certain degree of construct validity in the results can be assumed. Besides a positive effect of participation on attitudes toward science, the results of the study revealed that those who participated more actively in the communication (e.g., online discussion forums) showed a significantly greater change from pre- to posttest. In contrast to the other studies, the CS project *Citizen Sky* provided for a high degree of participation, and the sample consisted of people with long-term participation in the project (posttest during the first login to the website 6 months after pretest). Thus, long-term participation in the project might have been a crucial condition for this positive effect. However, results were of lower internal validity due to the absence of a control group. All things considered, the methodological approaches used in these studies allow more general statements to be derived. Due to the implementation of control groups in some studies, their results were of high internal validity because they were able to test for causal assumptions on CS (Kaya, 2015). The main trend is that attitudes toward science tend not to be changed by brief participation in a CS project. Initial study results suggest that long-term and intensive participation in a CS project is likely to be required to achieve change in this relatively stable personal variable (Price and Lee, 2013). Participation in the entire scientific process and its reflection can provide enough occasions to initiate change. To support this assumption, however, further research is necessary in this field. In terms of design, research should be oriented toward the studies conducted to date and, if possible, include further measurement instruments.

3.2. Scientific outcomes

The next step is to look at the empirical studies using CS data (a3). Since the successful implementation of CS is a basic condition for successfully generating data and answering research questions, it is not just empirical scientific articles, but also narrative project descriptions and theoretical and technical conceptualizations of CS that provide information about scientific outcomes. That is why we briefly discuss the remaining categories below.

3.2.1. Category a2: data quality

A total of 173 studies addressed the question of data quality. This high number is probably due to the controversy over the ability of CS data to answer scientific research questions (Hunter, 2013; Callaghan et al., 2019). Recent studies have reported an alignment of data derived by citizen scientists with those gathered by experts—e.g., a classification accuracy of trail camera images of more than 93% (Clare et al., 2019). Callaghan et al. (2020) also mentioned a similarity of data collection performance (regarding frogs in Australia) between citizen scientists and field experts. However, they also emphasized a bias toward certain sampling areas (i.e., citizen scientists favored areas with high human populations when collecting data). To overcome this issue and other potential flaws of citizen-generated data, Fucillo et al. (2015) found that training citizen scientists on data collection skills proved to raise data quality close to the experts' level. Twenty-eight citizen scientists received formal training for plant observation and the accuracy of nearly 11,000 observations was compared to those collected by a professional. An overall accuracy of 91% was found for CS data, which did not differ for different extent of participation (few vs. many observations). A less resource-intensive strategy was introduced by Torre et al. (2019), who showed that giving the option "I do not know" in classification activities enhanced accuracy and thus data quality. Ninety-four participants were asked to classify images of polluted water bodies whether this pollution was a threat to the environment or not. If the participants received the option "I do not know," there was an improvement in the true negative rate, i.e., this group showed higher accuracy in the identification of "no threat" than the group without this option. The increased data quality goes along with a reduction in data quantity, but may be accepted to ensure the accuracy of CS data.

3.2.2. Category a3: data use

About 20% of the studies ($n=279$) used CS data to answer scientific questions. CS data is not limited to a few scientific fields but is very diverse. One example is clarifying how coral reefs change as an ecosystem and might react to future disturbances (Gouraguine et al., 2019). In this study, a decline in coral was revealed with data from about 275 citizen scientists who monitored permanent transects over a period of 10 years. Another example is using CS data to provide answers on how Yellowhammers' song dialects are distributed in Czechia (Diblíková et al., 2018). For this purpose, nearly 4,000 recordings were used, which were collected from citizens over a period of 6 years. Apart from questions on various organisms, data gathered by citizen scientists have also been beneficial in other disciplines: for instance, American astronomers identified a new planet with the help of CS data from the project Planet Hunters (Citizen Science Finds Planet, 2012). Data from citizen scientists have also aided in the medical field, e.g., by providing information on the prevalence of ticks carrying pathogens causing borreliosis in the US (Nieto et al., 2018). Citizens collected over 16,000 ticks and submitted them with information on where they were found (host, location) to Northern Arizona University where the ticks were tested for pathogens.

3.2.3. Category b1: ≤3 project descriptions

There were 240 project descriptions. A suitable example for studies in this category is Chiovitti et al.' (2019) presentation of an educational barcoding project in which students ($N=406$) extracted and analyzed DNA from reptile livers. *Inter alia*, the authors describe the project's process, the (scientific and educational) materials used, and compliance with the school curriculum. The participating students collected and analyzed about 200 samples creating also new sequences for 8 reptile species. Most studies in this category aimed to describe a particular CS project and present results covering the number of samples and species that the participants examined. However, they did not report empirical results on either a project's effects on its participants or on a project's empirical findings and the quality of generated data.

3.2.4. Category b2: >3 project descriptions

There were 74 studies dealing with the clustering of numerous studies in one area such as biodiversity. For example, the study by

Pocock et al. (2017) conducted a systematic search for environmental and ecological CS projects. Each of the 509 projects found was scored systematically for 32 attributes—*inter alia*, methodological approaches, types of data recording, and target groups. It was found, for example, that the number of biodiversity projects increased exponentially and over 90% of the analyzed CS projects limit citizen involvement to data collection. Hence, this study clustered and described the projects without either going into detail on possible influences on the participants or discussing the data quality.

3.2.5. Category c1: theory

There were 105 publications theoretically describing the advantages and disadvantages of CS. Pocock et al. (2018), for example, derived opportunities for, benefits of, and barriers to CS in East Africa from a collaborative prioritization among 22 experts because CS is insufficiently distributed in developing countries. From this systematic theoretical assessment, the authors concluded that biodiversity and environmental monitoring are opportunities, that increasing environmental awareness as well as useful data and approaches are benefits, and that institutional capacity and (lack of) ascribed value to such activities are barriers that are applicable across developing countries. As another example, Fritz et al. (2019) described how CS as a non-traditional data source could support the Sustainable Development Goals (SDGs). As traditional data sources are presented as insufficient for measuring the SDGs, the potential uses of CS data are outlined as well as a roadmap for integrating CS in SDG reporting.

3.2.6. Category c2: technical devices

Almost 20% of the articles ($n = 221$) dealt with developing technical devices that could be used in the implementation of CS projects. Ožana et al. (2019) presented a mobile application to map species occurrences of dragonflies. The technical structure of the app as well as the various functions, such as support in the classification of dragonflies or the storage of GPS data, are presented. Another example is the study by Dennis et al. (2017) presenting new approaches for the analysis of biodiversity data with logistic regression, as CS data usually have a large spatial coverage and provide an important basis for biodiversity monitoring.

The large number of project descriptions (b1, b2) show that there are already many different CS projects in which numerous people participate and can thus contribute to an extensive database. Additionally, studies on technical devices (c2) show that numerous tools further facilitate participation in CS projects; and, in some cases, allow it to take place at any time around the globe. The large number of studies using CS data (a3) shows that scientific publications based on CS data have already been published very frequently, and that they have contributed to relevant research questions. Finally, many studies on data quality (a2) provide evidence of high quality in CS data allowing confidence to be placed in the scientific publications. All these results together provide initial evidence for scientific outcomes of CS.

4. Discussion

CS is attracting increasing attention as an innovative form of science communication (Haklay et al., 2020). This is reflected by various CS projects and an increasing number of research articles in recent years. To give some structure to the growing literature in this emerging field, this review provides a fine-grained portrayal of research on CS. We developed a coding manual and sorted the systematically searched literature into predefined categories. Empirical scientific articles (Category a) account for a share of about 50% ($n = 600$). This points to a considerable need for empirical studies in the large research field of CS in general. Narrative project descriptions (Category b) usually do not have a specific research question that is investigated empirically. Instead, they present specific CS projects descriptively. With a share of around 25%, they make up a large proportion of all research articles and clearly show that there are already numerous and diverse CS projects. Theoretical and technical conceptualizations of CS (Category c) account for about 25% of all articles. Studies in this category present theoretical assumptions and frameworks about CS or the development of technical devices showing that many tools have already been created to support and facilitate participation in CS projects.

4.1. Educational and scientific outcomes

We initially used our coding to find out about both educational and scientific outcomes of CS. We asked how many studies are available that report educational outcomes of participation in CS and whether these are sufficient to allow us to make generalized statements in terms of motivational outcomes (interest, motivation, attitudes).

Although interest plays a central role in individual learning processes (Hidi and Renninger, 2006), only a few research articles are available on the development of interest through CS. The fact that only two studies used a scientifically sound research design emphasizes a substantial research gap in this area. Even though these two studies (Seifert et al., 2016; Wallace, 2018) provide initial evidence for the positive effect of CS on interest, it is not yet possible to generalize this assumption. Because both studies were conducted in institutional contexts and focused on one specific domain, the transferability (external validity) of their results is limited. We cannot conclusively assess whether participation in CS is likely to increase the interest of the participants and, thus, a great amount of research still needs to be conducted. In contrast to the small number of studies on interest, many studies are available on motivation. However, very few studies focus on a possible change of motivation through participation in CS, indicating a general deficit of research studies in this area. Due to this lack of empirical studies, it is not yet possible to provide any generalizable statements concerning the positive effect of CS on motivation. Research on the development of attitudes toward science is already quite extensive and provides consistent results. The present findings suggest that short-term participation in CS has no positive effect on attitudes toward science. Particularly those studies with an advanced design often fail to show any effect. One possible explanation for this lack of change could be the theoretical assumptions on the construct of attitudes. This points to the importance of sound theoretical foundations: due to their deep grounding in early subjective experiences, attitudes are stable personality traits (Pajares, 1992). Nevertheless, attitudes are assumed to be changeable to some extent. Although they may not be changed measurably by a short participation in CS, Price and Lee's (2013) study does suggest that a high level of participation may effect such change. Potential changes in attitudes may well become visible when central theoretical assumptions and their implications are taken into account. To validate the results on the effect of CS on attitudes toward science, future research should focus mainly on project forms in which citizens are highly involved. Moreover, because our conclusion is limited on the effect of CS on attitudes toward science, future studies might consider investigating possible change in other attitudes (e.g., attitudes toward nature or wildlife).

To assess the scientific outcomes, we paid particular attention to studies using CS data (a3). Overall, they account for a large proportion (50%) of all empirical scientific articles. This demonstrates that a considerable number of scientific publications have already been generated with CS data. In addition, studies in other categories, such as studies on data quality, also provide important indications on scientific outcomes. About 25% of all empirical scientific articles relate to the quality of CS data in different scientific disciplines. In most cases, they indicate a high quality of CS data, that is an initial indication of scientific outcomes. To consider the scientific outcomes, however, it is not sufficient to publish scientific research articles. A precise distinction still has to be made between the mere number of studies based on CS data and the acceptance of these studies in the respective research discipline—which represents a further significant step toward solid scientific outcomes. However, due to the large number of studies from various disciplines using CS data, the impact of the individual research articles cannot be verified within the scope of this review, especially because such an in-depth analysis would also require expertise in all the respective disciplines. The study by Odenwald (2018) is a very successful example for the evaluation of scientific outcomes in a specific scientific discipline. Odenwald (2018) analyzes the citations of 143 CS publications in the specific field of astronomy. In total, the papers were cited over 4,500 times. Comparing these papers to a group of comparable papers in the same journals, results suggest that there is high interest in CS publication but "remain of interest for only half as long as other papers" (Odenwald, 2018, p. 1) in the field.

4.2. Limitations

One potential limitation of the review is the reliance on quantitative studies. This focus was chosen with the aim of making generalizable statements on the outcomes of CS projects. Qualitative studies, in contrast, pursue the goal of exploring a research field and generating hypotheses rather than testing causal effects and do not allow for generalizable statements. However, since the effects of CS projects may be context dependent and qualitative studies provide insights into participants' thoughts and perceptions, it may be useful to review these studies on educational outcomes of CS as well. The central issue in the present review is the limited sample size. We searched for relevant articles in the two different databases, Web of Science being only one of the international databases for scientific articles. In this database as well as the German database FIS Bildung, we searched for the term "citizen science" in the title, but not in the abstract or keywords, possibly further limiting the sample of relevant research articles. Since the terms used to describe CS are very diverse (for an overview see Haklay et al., 2021), the results should be consolidated with other search terms. However, since we have additionally taken into account all articles from the journal Citizen Science: Theory and Practice and our sample still includes more than 1,200 research articles, we can draw relatively firm conclusions from it. The results of the review show that, overall, there is still limited evidence on which to base generalizable statements on educational outcomes of CS. Also, with regard to the scientific outcomes, further efforts need to be made because of the need to evaluate the acceptance of the studies in the respective scientific community.

4.3. Increasing the validity of research on educational outcomes of citizen science

The great need for further research, especially with regard to educational outcomes, is due to the fact that the weak research designs in many studies do not allow causal inferences. Focusing on the assessment methods of environmental attitudes, behavior and knowledge, Somerwill and Wehn (2022) also point out that "in many citizen science projects, impact evaluation is still overly simplistic" (p. 1) despite the many frameworks and expertise from different specific disciplines. In order to obtain valid results, with which "a greater understanding of citizen science could be obtained, supporting relevant policy and research in the future" (Somerwill and When, 2022, p. 10) we derived central implications for future research in CS.

4.3.1. Internal validity

One key requirement for future studies is to be of high internal validity, because it "is the basic minimum without which any experiment is uninterpretable" (Campbell and Stanley, 1963, p. 5). Internal validity is significantly ensured by the implementation of control groups. To achieve a true experimental design, participants need to be randomly assigned to different groups (Campbell and Stanley, 1963). If random assignment cannot be realized (quasi-experiment), confounding variables must be controlled with at least one pretest allowing control of preexisting group differences. It is certainly challenging to conduct experimental designs in CS contexts, because numerous organizational and ethical aspects have to be taken into account. One organizational aspect that limits feasibility in the context of CS is the difficulty in recruiting comparable control groups. In addition, it is necessary to balance the contrast between the voluntary nature of participating in CS to actively conduct research and the fact that participants become the research object in the experiment itself. This is probably why only a few studies are available with quasi-experimental designs ensuring a moderate internal validity (e.g., Wallace, 2018). Because only studies implementing control groups provide robust results on the effect of CS on educational outcomes, the implementation of such designs should be a central goal for future research. Further, it is important to consider the evaluation of effects from the outset "largely because many impact measurement tools (particularly those offering high-quality data) require baseline measurements before participation" (Somerwill and Wehn, 2022, p. 9). Dickinson and Crain (2019) also emphasize that "controlled studies are needed to determine whether citizen science projects meet the specific learning objectives for which they are designed" (p. 1). This lack of experimental studies has already been noted in previous reviews focusing on changes in knowledge, behavior, and attitudes through participation in CS (Peter et al., 2019; Aristeidou and Herodotou, 2020) and we can generalize their demands to cover empirical studies.

4.3.2. External validity

Causal knowledge of individual experiments does not allow conclusions to be drawn on whether this causal relationship holds over variations in participants and settings (Shadish et al., 2002). To make generalized statements about the effect of CS on educational outcomes, numerous experiments would need to achieve similar results while differing in terms of sample, setting, treatment, and measure (Shadish et al., 2002). Many recent studies have been carried out in an institutional context granting continued access to the participants for recurring surveys. These limitations to a specific sample and setting restrict the transferability of previous results on the effect of CS. Future research should try to focus on CS projects outside of institutional boundaries, because the majority of projects have been developed for the general population and not for classroom implementation. Further, most of the studies on educational outcomes examine CS projects in the subject field of biodiversity (e.g., Aivelo and Huovelin, 2020). Other subjects that are also represented more frequently are astronomy and water quality (e.g., Price and Lee, 2013). To ensure the generalizability of results, future research needs to provide equal representation to the different scientific disciplines in which CS projects are offered. With regard to the treatment, the vast majority of studies investigate CS projects providing for a low level of citizen participation in the scientific process (e.g., Seifert et al., 2016; Tinati et al., 2017). To further clarify the effect of CS on educational outcomes and to confirm the findings with respect to attitudes toward science, future research should consider different project forms providing for different levels of participation (e.g., full participation in the scientific process). Finally, different (motivational) variables should become the object of investigation. This would allow comprehensive statements on educational outcomes. In this context, different and, ideally, already established measurement instruments should be used. This leads to the aspect of construct validity.

4.3.3. Construct validity

Construct validity is another fundamental concern in any empirical study on the effect of educational outcomes of CS. In the referenced studies, we observed a frequent absence of theory-based operationalizations of constructs and consequently the use of self-developed measurement instruments with no assessment of their quality. Our results also confirm previous reviews criticizing "the scarcity of established theoretical frameworks" (Peter et al., 2019, p. 14) and the "tendency to use self-reported methods" (Aristeidou and Herodotou, 2020, p. 9) in CS projects. Due to the lack of theoretical work, findings from individual studies can mostly be used only to a limited extent for testing theoretical assumptions about CS and further developing basic scientific theories. To validly draw inferences about the construct under consideration, it is important to define it theoretically before developing suitable items. Moreover, the use of established measurement instruments should be preferred. For instance, scales to measure attitudes have been developed and evaluated by, for example Kind et al. (2007), Lederman et al. (2014), and Hartman et al. (2017). Levontin et al. (2022) suggest a standardized, theory-based approach to measure participants' motivation in a comparable manner. These measures ensure the validity of the intended interpretation of the results and enable further development of basic scientific theories. Because theoretical work and the use of instruments with high test quality are rare to date, this should be given greater consideration in future research. Interdisciplinary cooperation may be helpful in theoretically defining the constructs and in carrying out a well-founded selection of instruments here.

4.4. Outlook

Concerning educational outcomes, the available studies on interest and motivation provide too little evidence to empirically confirm the assumed effects of CS on its participants. According to the data on attitudes available so far, CS seems to have a positive effect only if the level of participation is high and long lasting. Thus, the effect of CS on attitudes is minimal, and educational outcomes are produced only partially. With regard to scientific outcomes, review results indicate that CS has already taken an important step, because it has produced many scientific studies based on CS data. To come to reliable conclusions regarding scientific outcomes, future research must examine the acceptance and use of the CS studies in the respective disciplines (e.g., Odenwald, 2018). In general, there is a need for more research on CS, with the effect of CS on educational outcomes being just one of the many important questions for the future. The increasing number of exciting CS projects will make it possible to answer important research questions in various scientific disciplines and to investigate potential effects on participants in a variety of CS contexts. However, valid statements on the effect of CS on personal variables can be made only if future research takes even greater account of methodological standards than has been the case to date.

Author contributions

MS, VB, JW, and LF: conceptualization. LF and VB: literature search. LF: literature analysis. LF and LS: writing – original draft preparation. JF, KS, MS, VB, and JW: writing – review and editing. JW: supervision. All authors contributed to the article and approved the submitted version.

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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.

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Positive aspects of sport for fostering strong STEM identities

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Introduction

With the growing demand for Science, Technology, Engineering and Math (STEM) careers it is important to increase female participation in STEM. Females entering the STEM workforce will enhance ingenuity in STEM fields as they will bring new and diverse perspectives to spaces that have been historically male-dominated. On average, females and males have displayed similar scores in studies on math achievement (Else-Quest et al., 2010), however, females are still a minority within many STEM academic degrees and careers (Frank, 2019; Government of Canada, 2021).

A study on individual and gender differences in choice of STEM careers identified that more females were in the high-math/high-verbal ability category compared to males, and that females with high math ability were likely to also have high verbal ability (Wang et al., 2013). This is an important identification because it highlights the potential for high achieving females in STEM to have choice and considerations of occupations in the field (Wang et al., 2013). Even if an individual has greater choice when considering career options, their belief that they will be successful in a particular career is important during their decision making (Eccles, 2009). Therefore, women who could succeed in STEM careers may gravitate away from them given the prevailing gender stereotypes associated with these fields.

Other fields where gender diversity is already more prevalent, such as some sport programs, could be explored to offer alternative frameworks that position positive experiential approaches for increasing female participation and retention in other traditionally male-dominated fields, such as STEM. Parallels between sport and STEM exist. Sport and STEM programs exist on a continuum scale where negative and/or positive qualities influence youth. You may ask yourself, what within the realm of sport allows females to flourish? And, how can the positive factors that have increased female participation in sport be utilized within STEM teaching? Previous research has analyzed ways to increase a student's motivation for STEM fields, but none to-date have explored how positive aspects of sport can be utilized in STEM. For example, a sport-based Positive Youth Development (PYD) model offers an example to counter the current deficit-oriented approaches to increasing diversity in STEM (McCullough, 2011; Ilumoka, 2012; Saucerman and Vasquez, 2014; Cronin et al., 2022; Mossman et al., 2022). Models such as Social Cognitive Career Theory (SCCT) (Betz and Hackett, 1997) are based on interest and choice and "encompass a variety of constructs such as self-efficacy in a particular domain, outcome expectations, and interests as well as contextual factors that influence career choices" (Fouad and Santana, 2017). This includes positive math performance activities (Navarro et al., 2007) and positive role models in STEM careers (Ericksen and Schultheiss, 2009).

Our position is that PYD sports model has specific skill building steps that work to increase self-efficacy and provide positive contextual factors. It does not replace theories such as SCCT or how STEM is integrated into curriculum (Moore et al., 2020), it sets up positive skill building opportunities for females. The PYD model focuses on strengths and assets for developmental growth rather than focusing on problems (e.g., Holt et al., 2007, 2012). A sports-based PYD model is multifactorial and involves appropriate role models, programs promoting life skills and positive peer and parent influence. PYD programs provide opportunities for youth to flourish in the future by instilling positive qualities (Gould and Carson, 2008). With this approach, PYD components in STEM could offer opportunities for increasing the number of females that pursue STEM careers.

Increasing diversity in STEM: sport as a model

Performance anxiety and exposure

A contributing factor currently affecting female students' feeling of control with STEM learning is math anxiety since it is directly related to math performance (Stoet et al., 2016) and this anxiety needs to be addressed when looking to increase the number of students in STEM (Foley et al., 2017). It has been validated that in multiple countries females have greater math anxiety than males (Haynes et al., 2004; Stoet et al., 2016). Increased math anxiety could account for math avoiding behaviors and lack of intent to enter a STEM field (Wang, 2013; Stoet et al., 2016). STEM exams are analogous to sport performances because each requires applying skills to unique situations under pressure. For example, in a math exam students need to use "algorithmic reasoning" as opposed to "memorized reasoning" (Bergqvist, 2007). There is a need to recognize and apply the correct algorithms to a problem the student has not seen before. In physics students use mechanistic reasoning to explain how the parts make up the properties of the whole (Hung and Jonassen, 2006) and in chemistry use multiple molecular representations (Avargil and Piorko, 2022). Similarly, an athlete will have to respond to competition situations using algorithmic and mechanistic reasoning. What can keep an athlete grounded in their conviction to succeed is previous experience and positive practice scenarios. Duncan et al. (2017) recommend reducing anxiety by simulating a competition during practice time. It has been shown that math anxiety can be lowered by tutoring lessens (Supekar et al., 2015), supplementary exercises that enhance math strategies (Passolunghi et al., 2020), or an intensive digital training (Ng et al., 2022).

Positive role models and identity

Positive role models have been identified as an important factor in increasing and/or maintaining physical activity in adolescence (Young et al., 2015). Lack of positive roles models in sport for adolescent females has been recognized in a number of countries, including Canada, as a barrier to sport participation (e.g., Casey et al., 2009; Bélanger et al., 2011). A positive role model in sport for an adolescent female is most likely associated to the gender the student identifies with Young et al. (2015) and who models a sport-based PYD model. From this validated link between role models and sport participation (Young et al., 2015) and the current research within STEM fields that indicates there are too few positive role models for adolescent females (Steinke et al., 2008; Cheryan et al., 2011, 2015) we can assume that increasing role models will be key to engagement of females in STEM.

Both environment and role models influence students' identity. In sport, feeling that you belong in the environment and seeing other girls and women participate in the sport contribute to perceptions that girls play sports. This visible connection is not overt in school classrooms. Although researchers have found that general academic achievement influences identity (Matthews et al., 2014), and that individual identity can by precluded by the identity expected by their social groups at school (Islam, 2014). Kim et al. (2018) argues that a STEM identity is "socially based identity grounded in the extent to which individuals see themselves and are accepted as a member of a STEM discipline or field" (Kim et al., 2018). The classroom environment does not consistently promote positive STEM identity and many classroom environments lack diversity, role modeling and teacher preparedness which are needed for building STEM identity. In team sport, a collective identity can emerge and these identities can "influence expectations for success" (Eccles, 2009) and these collective identities are especially important to underrepresented groups (Malorni et al., 2023). Similarly, research shows female students find that a personal connection to what they perceive as a STEM "community" helps them develop the perception "they belong" in STEM (Saville et al., 2023) and this belonging leads to positive affect (Alivernini et al., 2023). Young women who have a strong STEM identity attribute their positive STEM beliefs from having connections with instructors and finding a culture where they feel they belong (Saville et al., 2023). Peer groups who are supportive of STEM positively influence STEM career interest (Robnett and Leaper, 2013) and the personal interactions [with instructors] has a greater effect on STEM self-efficacy than actual performance levels (Skipper and Leman, 2017).

Motivation and mastery

It was identified that adolescent females with low self-esteem might identify easier with female coaches and more readily internalize their positive talk compared to male coaches (Coatsworth and Conroy, 2006). This identification is important since girls normally show lower ratings of self-esteem and self-concept than boys in middle and high school (Mahaffy, 2004). A study on motivational climate found that gender of a coach was a predictor of an athlete's perception of motivational climate, where female coaches were more greatly associated with mastery of motivational climate compared with male coaches (Vazou, 2010). This study also noted that female athletes tend to perceive more mastery involving cues compared to males possibly due to difference in measures of competence and socialization found between genders (Vazou, 2010). Mastery goals are those that focus on skill development. The student's aim is to improve their skill rather than the outcome of an exam. Performance goals lead to better achievement of simple tasks, whereas mastery goals facilitate attainment on challenging tasks (Senko, 2019). This is important for STEM because of the algorithmic reasoning needed to successfully work through STEM exam problems. A mastery-oriented classroom is created by the nature of the tasks (mastery focus), involving students in decision making, types of evaluation, and classroom climate" (Furner and Gonzalez-DeHass, 2011). A mastery climate creates higher levels of engagement (Curran et al., 2015) which is necessary for girls to be interested in STEM and can have "a buffering effect on stereotype threat" (Deemer, 2004).

Sport coaches can impact youth positively and negatively depending on their created motivational climate (Schaillée et al., 2017; Cronin et al., 2022). A sport coach who facilitates mastery motivational climate elicits PYD by encouraging factors such as effort and individual improvement (Schaillée et al., 2017). A sport coach who facilitates performance can elicit negative effects by encouraging factors such as social comparison (Schaillée et al., 2017). Parallels of positive and negative engagement were also observed in science classrooms. Shumow and Schmidt (2013) reported that in science classrooms where students had two types of goals, mastery goal orientation or performance approach goal orientation, these were largely determined by the teacher's goal orientation approach that they used with their students.

Peers and mastery climate

Peer motivational climate likely has a stronger influence on athletes' personal approach to development than coaches or parents due to the reduced power imbalance among peers compared to coaches and parents (Smith et al., 2010). It has been reported that peer performance motivational climate is associated with burnout in sport (Smith et al., 2010) and that peer mastery motivational climate is associated with positive character and support for teammates (Agans et al., 2018). Jõesaar et al. (2012) found that peer mastery motivational climate can be enhanced by having autonomy support from coaches whereby athletes perceive their coach understands their perspective and provides them choices in decision making. Therefore, coaches who promote peer mastery motivational climate with autonomy support increase motivation (Cronin et al., 2022). Applied to STEM, teachers who promote peer mastery climate with autonomy support may increase female students' intrinsic motivation for STEM as seen in sport (Jõesaar et al., 2012).

Students also learn mastery focus when they are able to use skills in applied situations. For example, Bressler et al. (2022) gave one group traditional instruction and a second group a game design task. The game design group focused more on learning goals and were mastery-oriented while the group receiving traditional instruction remained performance-oriented (Bressler et al., 2022). The cross application from sport is convincing (Meece et al., 2006; Curran et al., 2015), if STEM teachers promote mastery motivational climate, more female students may feel in control of their learning and thereby have increased confidence and determination.

Discussion

Implications for practitioners

To create a more positive climate in STEM environments, educators can adopt aspects from sports-based PYD programs by focusing on mastery and creating an opportunity for girls to participate in a community of learning. Applying positive aspects of sport to STEM classrooms will help foster strong STEM identities in young adolescent girls (Saville et al., 2023). We recommend the development of STEM curriculum and classroom conditions that integrate aspects of PYD that focus on mastery, reduce anxiety by exposure, role models and supportive peer environments.

A focus on mastery can be done by emphasizing effort as well as individual and team progress when assessing assignments and preparing for tests and examinations. Students might be more accepting of assessment outcomes when they conceptualize using maximum effort that identifies effort placed within and learning achieved on the students part, within realization of outcome marks relative to competencies or rubrics. This might contribute to utilization of skill development in learning to accept error as part of academic learning and advancement. The research strongly suggests that creating peer support by working in teams and providing role-models positively influences adolescent girls' STEM identity (Cheryan et al., 2011; Young et al., 2015). Which is why we recommend including more team-based assignments that require multiple iterations so that trial and error are expected. This will also reduce anxiety by exposure to STEM by practice and build test taking strategies. Utilizing exploratory and fun ways to practice STEM concepts in addition to traditional learning methods will also increase exposure to STEM by practice. Practice could include STEM video games such as an augmented reality of chemical structures (Tarng et al., 2022). Finally, fostering a welcoming and inclusive environment by creating spaces that reflect more of the girls' interests (Saville et al., 2023) will be important to create a sense of belonging in STEM.

Implications for future research

Future research on these aspects of a PYD sports model needs to focus on which practice for performance strategies are most effective and how best to structure group activities and projects to promote mastery. For example, the effectiveness of using video games to learn mastery can be tested against or simultaneously with traditional instruction. Future research can also assess how well role models can implement autonomous coaching strategy in STEM settings. Finally, researchers need to look at the efficacy of interventions to create a sense of belonging in STEM for girls/women and other under-represented persons in STEM and determine if changes to the STEM learning environment can increase a sense of positive STEM identity.

Author contributions

CC conceptualized and lead the writing process. JJ, HT-S, and SC conceptualized the sport and STEM interaction and

contributed to the writing process. All authors contributed to manuscript revision.

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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.

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A systemic transformation of an arts and sciences curriculum to nurture inclusive excellence of all students through course-based research experiences

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Introduction: We describe herein a large-scale, multidisciplinary course-based undergraduate research experience program (CRE) developed at Lawrence Technological University (LTU). In our program, all students enrolled in CRE classes participate in authentic research experiences within the framework of the curriculum, eliminating self-selection processes and other barriers to traditional extracurricular research experiences.

Methods: Since 2014, we have designed and implemented more than 40 CRE courses in our College of Arts and Sciences involving more than 30 instructors from computer science, mathematics, physics, biology, chemistry, English composition, literature, philosophy, media communication, nursing, and psychology.

Results: Assessment survey data indicates that students who participate in CRE courses have an enhanced attitude towards research and discovery, as well as increased self-efficacy. This intervention is particularly relevant for non-traditional students, such as students who commute and/or have significant work or childcare commitments, who often experience limited access to research activities.

Discussion: Herein we highlight the importance of a systemic institutional change that has made this intervention sustainable and likely to outlast the external funding phase. Systemic change can emerge from a combination of conditions, including: (1) developing a critical mass of CRE courses by providing instructors with both incentives and training; (2) developing general principles on which instructors can base their CRE activities; (3) securing and maintaining institutional support to promote policy changes towards a more inclusive institution; and (4) diversifying the range of the intervention, both in terms of initiatives and disciplines involved.

KEYWORDS

problem-based and cooperative learning, diversity equity and inclusion, inclusivity in higher education, mixed methods < research methodology, course-based undergraduate research experience

Introduction

This article describes the incorporation of course-based research experiences (CRE) in a large number of courses across diverse disciplines within the College of Arts and Sciences at Lawrence Technological University, a primarily undergraduate private institution in the Detroit, MI metropolitan area. The scope of integrating CRE in the Arts and Sciences curriculum was to promote inclusivity and guarantee accessibility to research activities to all categories of students, especially those historically underrepresented in STEM education and the STEM workforce in the United States.

Undergraduate research experience in the United States

Undergraduate research experiences (UREs) are a well-known pedagogical strategy for attracting and retaining students in science, technology, engineering, and mathematics (STEM). Specifically, UREs improve students' learning experience (Lopatto, 2004, 2007; Seymour et al., 2004; Kinkel and Henke, 2006; Hunter et al., 2007), increase student interest and success in postgraduate studies and careers in science (Hathaway et al., 2002; Lopatto, 2004; Hunter et al., 2007; Russell et al., 2007), enhance examination performance (Barlow and Villarejo, 2004; Freeman et al., 2014; Ward et al., 2014), and promote retention in STEM disciplines (Nagda et al., 1998; Barlow and Villarejo, 2004; Braxton et al., 2004; Kinkel and Henke, 2006; Summers and Hrabowski, 2006; Gilmer, 2007; Carter et al., 2009; Olson and Riordan, 2012). Importantly, UREs are also an effective strategy to improve the recruitment and retention of underrepresented minority students in STEM disciplines (Barlow and Villarejo, 2004; Summers and Hrabowski, 2006; Tsui, 2007; Villarejo et al., 2008; CUGESEWP, 2011). Traditionally, students participate in UREs by individually joining a research group and working closely with a faculty member on an assigned research topic. Such an approach, supported, for example, by the National Science Foundation *Research Experiences for Undergraduates* (REU) program and by the National Institutes of Health *Research Training Initiative for Student Enhancement* (RISE) program, has been broadly adopted in the United States. While there is evidence that these single-student examples of the UREs may be especially beneficial for underrepresented students (Rorrer et al., 2018), there are significant limitations, including: (1) Scalability: funding, faculty member availability, and the relatively small number of students that can benefit from this URE model (Beninson et al., 2011; Ramirez et al., 2015); (2) Time of intervention: first-year students rarely benefit from this URE model because students are typically selected for these summer experiences as rising juniors or seniors; (3) Inclusion: underrepresented minority students may have limited exposure to URE programs due to college selection, geographical limitations, and other barriers to engagement in URE (Walpole, 2003).

Course-based research experiences

In recent years, the concept of course-based research experiences (CRE, also known as course-based undergraduate research experiences, CURE) has grown in popularity in institutions of higher education in the United States. In this article, we use the acronym CRE instead of CURE because the intervention described herein includes several graduate courses, while CURE specifically refers to undergraduate curricular interventions. CRE consists of embedding authentic research experiences within regular class activities. This pedagogical approach has been applied to a variety of disciplines, including general education, STEM, and even music education courses (Boomer et al., 2002; Elwess and Latourelle, 2004; Brodl, 2005; Howard and Miskowski, 2005; Hanauer et al., 2006; Hatfull et al., 2006; Drew and Triplett, 2008; Lopatto et al., 2008; Caruso et al., 2009; Ronsheim et al., 2009; Shaffer et al., 2010; Harrison et al., 2011; Corwin et al., 2015; Dvorak and Hernandez-Ruiz, 2019; Hernandez-Ruiz and Dvorak, 2020). CRE courses overcome some limitations of the individualized approach to UREs described above, including: (1) Scalability: CRE facilitates the simultaneous exposure of a higher number of students to research because it is embedded in a course; (2) time of intervention: CRE interventions can be offered early and often throughout a student's academic journey, often impacting student success starting in the freshman year; (3) inclusion: CRE provides more opportunities for underrepresented minority students to engage in research experiences because this intervention eliminates self-selection.

In CRE interventions, the research activity is part of a regular course, meaning that all enrolled students are included in the intervention. Moreover, research activities can be conducted during regular classroom hours, and can be designed to include research endeavors conducted at home in some cases. Hence, CRE does not require that students spend long hours engaged in research activities outside of the class, making it ideal for commuter students, working students, or students with childcare or other significant non-academic responsibilities.

A notable example of CRE is the SEA-PHAGES program,[1] a large-scale multi-institutional program supported by the Howard Hughes Medical Institute (HHMI) that provides authentic biology research experiences to undergraduate students at diverse institutions at an early stage in their degree programs, leading them to experience discoveries and participate in student-authored publications (Caruso et al., 2009; Asai, 2013; Jordan et al., 2014; Pope and Hatfull, 2015). The parallel involvement of a multitude of institutions in a streamlined research paradigm facilitates a very effective and well-organized research experience in which students are more likely to publish their results because the protocols are well established and the possibility of discovery is higher. In contrast to the discipline-specific approach of the SEA-PHAGES program, we have implemented an inclusive initiative to promote and expand course-based research experiences across all disciplines within our diverse College of Arts and Sciences (Shamir et al., 2019).

Active learning environments, such as CRE programs, achieve positive academic outcomes (Lopatto, 2007; Russell et al., 2007; Shaffer et al., 2014) through multiple elements that impact academic belonging, which has been defined as "the extent to which individuals feel like a valued, accepted and a legitimate member in their academic domain" (Lewis et al., 2016). Numerous studies have shown the beneficial impact of CRE on student diversity and equitable access, including increased positive attitudes towards research (Osborne et al., 2003; Harrison et al., 2011; Brabec et al., 2018), enhanced self-efficacy (Chemers et al., 2011; Auchincloss et al., 2014; Carpi et al., 2017; Martin et al., 2021), the development of teamwork skills (Kapp, 2009; Hanauer and Hatfull, 2015; Dewey et al., 2022), and increased cultural sensitivity by introducing students of varying backgrounds to research regardless of their race or gender (Micari et al., 2007; Bangera and Brownell, 2014; Collins et al., 2019). The student experience survey employed to help measure the impact of our intervention includes an assessment of the association between these factors and participation in CRE courses.

CRE at LTU: a description of the initiative

A multidisciplinary intervention

Beginning in 2014, we began pursuing the goal of incorporating research experiences into our curriculum by transforming several traditional courses into CRE courses. With the support of internal and external funding, we designed a sustainable framework that has involved the transformation of dozens of diverse courses in the College of Arts and Sciences at LTU in addition to adopting strategies to ensure the long-term sustainability of the intervention (Shamir et al., 2019; Weinstein et al., 2019; Delogu, 2020).

Our initiative succeeded in promoting an enhanced research culture in our college, creating excitement around including students in research endeavors. While we differ in our involvement of many non-traditional CRE disciplines in a single coordinated program, the focus of our CRE intervention is well aligned with other CRE initiatives in the United States, with our goals being to: (1) Improve students' persistence and success in STEM degree programs, (2) Make research accessible to a larger and more diverse group of students, (3) Positively influence students' educational and career trajectories, and (4) Encourage students to pursue graduate education and research-related career paths (Dolan, 2016). Many CRE activities are often limited to the personal initiative of informed instructors and administrators, and rarely take the shape of a broad-scale institutional intervention involving many courses, disciplines, and departments. In contrast, we achieved a broad-scale implementation of CRE with the ultimate goal of promoting a systemic multidisciplinary intervention capable of changing the pedagogical vision of an entire college.

The most distinctive aspects of our program are the large scale and the heterogeneity of the CRE implementation. To date, our initiative has developed more than 40 CRE courses involving over 30 instructors in all disciplines within the College of Arts and Sciences, including biology, chemistry, physics, mathematics, computer science, psychology, art, literature, English composition, philosophy, and nursing. A typical CRE course at LTU includes research practices embedded in the regular coursework, in which students investigate questions with unknown answers using leading-edge practices and methods specific to the discipline. CRE practices promote student agency and ownership of the discovery process. The time and resources allocated to CRE in a course vary according to the discipline and specific course. Our intervention includes courses exclusively devoted to CRE for the entirety of the semester, courses substantially devoted to CRE in which research activities are conducted during at least the 50% of the classes, and sometimes courses in which a CRE module takes only one class period.

Conceptual model: framework, principles, and related initiatives

A CRE-related paradigm shift at LTU is being institutionalized as more faculty participate, and more research experiences are created. The number of faculty participating in CRE has grown from 22 in spring 2017 to 32 in spring 2022. During this time frame, the number of CRE courses has also grown steadily. Recognizing that our program is large and heterogeneous, and respecting the specificity of intervention in each field of investigation, we developed a set of principles that we call "Pillars of CRE at LTU" to which every CRE course adheres to. The process used to create this set of standards and theoretical principles was iterative and dynamic during the initial years of intervention. These "pillars" helped to establish and clarify the structure of CRE courses at LTU to help ensure authenticity and sustainability.

Herein we present the three fundamental principles of CRE at LTU, which constitute the "pillars" on which we base our intervention in every course (see Figure 1).

1 seaphages.org

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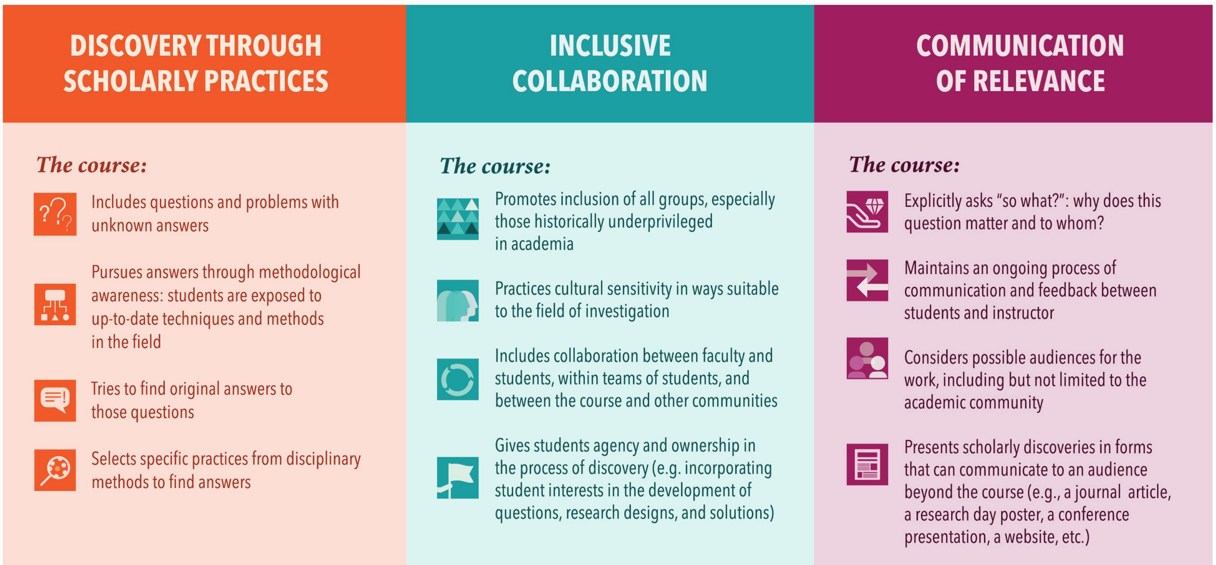

FIGURE 1
Pillars of CRE at LTU. This infographic describes the general principles and practices shared by all CRE instructors teaching CRE courses at Lawrence Technological University.

In support of the CRE pedagogical transformation, we developed the following related initiatives to foster a culture of institutional collaboration and sustainability:

a. Culturally-responsive teaching: CRE courses at LTU promote the inclusion of all students, especially those who have been historically underrepresented in STEM fields. Moreover, cultural sensitivity is explicitly addressed as a topic in many courses by emphasizing how cultural, social, and economic differences have shaped and continue to shape the process of scholarly discovery. Students are encouraged to critically examine current practices in their selected professions from inclusivity perspectives. Whenever possible, student interests are integrated in the research activities.
b. A CRE teaching and learning community: A core feature of the intervention is the creation of a cohesive community of faculty and administrators who are champions and active participants in the project. All community members are encouraged to participate in training events, journal clubs, regular meetings, and joint CRE-related dissemination initiatives, such as conference presentations and writing manuscripts for peer-reviewed publications.
c. High school and community college dual enrollment programs: There are very few reports of CRE interventions in high schools and two-year colleges (Dolan, 2016). In order to broaden accessibility to CREs, we developed a network of collaborations and agreements with high schools and community colleges in metro Detroit. Within this network, LTU professors teach CRE courses and students from high schools and community colleges can attend CRE courses at LTU. CRE faculty also organize activities such as workshops, seminars, summer camps, and guest lectures to expose high school students to CRE-focused activities. Such initiatives take place both at LTU and at host institutions.
d. Multi-institution collaborations: The grants that have supported LTU's CRE initiatives over the years strongly encouraged multi-institution collaborations. For example, peer implementation clusters (PICs) are communities of HHMI-funded institutions linked by regional proximity that are encouraged to collaborate and share ideas on topics related to inclusive excellence. Sabbatical exchanges have also been used to start collaborations with other institutions interested in using research to broaden participation and success in STEM degrees.
e. Seminar series on topics of diversity, equity, and inclusion: The LTU CRE community uses an "Idea Factory" seminar series[2] as an opportunity to discuss topics related to student research, diversity, inclusivity, and equity in academia and society. Seminars are open to the general public.
f. Substantial involvement of non-STEM disciplines: Our intervention includes redesigning courses in non-STEM disciplines such as literature, English composition, art, philosophy, communication, and psychology. CRE projects in the humanities and social sciences often include cross-disciplinary bridges between methods, approaches, and bodies of knowledge on a specific subject of investigation, encouraging interdisciplinary collaborations. This inclusive multidisciplinary/interdisciplinary aspect of our intervention is distinctive, as CRE programs are often designed for, and target, STEM fields exclusively.
g. Extracurricular CRE student researcher awards: CRE projects may be continued outside the classroom environment through our student researcher award program. This initiative allows students to help faculty members develop, test, and/or refine a protocol that will be implemented in a CRE course or may help a faculty member

2 https://www.ltu.edu/idea-factory

to finish or analyze the results of a CRE module that has already been implemented in a CRE course. Student researcher awards have increased the participation of students in research by providing funding for student stipends as well as a classroom platform to test ideas. This program also includes funding for undergraduate student travel to facilitate the dissemination of CRE projects to a broader audience beyond our campus community. More than three dozen student researcher awards have been awarded across a diverse array of disciplines over the five-year grant period.

CRE disciplines, course structure, and content at LTU

All CRE courses promote an inclusive learning environment in which the instructor facilitates a culturally sensitive classroom environment. CRE also promotes collaboration on several levels: between faculty and students, among and within teams of students, and, whenever possible, between the course and other communities (e.g., the campus, the city, similar courses at other universities, etc.). Whenever possible, student interests and personal initiatives are encouraged in the development of a question, problem, and/or experimental design. Scholarly discoveries are often reported to an audience beyond the course, such as an external community (a scientific article or conference presentation) or the campus community (presentation or written report at a university-wide, college, or department research event).

Figure 2 presents an example of a general overview of CRE activities within a CRE course at LTU. CRE courses are usually organized into four modules.

During module 1 (weeks 1–2), students explore questions and problems with unknown answers. In this first module, instructors also provide training about the importance of diversity, equity, and inclusion (DEI) in education and research in general as well as how research in the particular discipline and topic of the course relates to DEI. During module 2 (weeks 3–4), students acquire methodological awareness of current techniques and methods in the field. During module 3 (weeks 5–12), students engage in empirical research and generate results. Finally, during module 4 (weeks 13–16), students write a final report and disseminate results as term papers, posters, and oral presentations in class and also sometimes at internal or external conferences. This general structure and the time dedicated to each block of activities can substantially vary among instructors, disciplines, and research topics. Some instructors, for example, dedicate the entire semester to CRE while others blend CRE modules with traditional lectures.

In Table 1, we list examples of how CRE was implemented at LTU in many disciplines from 2014 to 2023. Since the program is currently active and new CRE projects are developed and implemented every semester, this list is necessarily incomplete. Thus, its purpose is merely to provide examples to instructors in specific fields interested in CRE implementation. Details on course implementation, research topics, and timelines of CRE activities are provided in Appendix 1.

The following sections include an assessment of the impact of the CRE Inclusive Excellence program on student success, student experience, and the faculty perception of the sustainability of the intervention at LTU. Our analysis includes institutional data about student academic achievement, survey data addressing students' experience, and survey data from faculty about the sustainability of the CRE intervention. We used a mixed-methods approach involving both qualitative and quantitative methods of analysis.

Methods: assessment of CRE impact

We have been assessing the outcomes of our intervention since we began implementing CRE in 2016. Our evolving assessment efforts include measures of academic achievement, as well as self-reported data. In this study, we report the initial assessment of our first large-scale intervention (2016–2017), supported by the American Association of Colleges and Universities (AAC&U) *Teaching to Increase Diversity and Equity in STEM* (TIDES) program and an HHMI Inclusive Excellence grant.

The primary question we aimed to assess was the impact of CRE pedagogy at LTU as it relates to student success, the student experience, and the faculty perception of the sustainability of the intervention. We collected institutional data related to student academic achievement, survey data related to students' experience, and survey data from faculty related to the sustainability of the CRE intervention.

Participants

All students enrolled in a CRE course in the fall 2016 or spring 2017 semesters were invited to complete a pre-post survey. A total of 484 CRE students completed at least one of the two surveys. After matching pre- and post-course survey responses, a total of 372 surveys (two per student, one before and one after the CRE course) were included in the final analysis. The final sample of CRE students was 186 students (110 male, 59%; 73 female, 39%; 3 undeclared, 2%). Thirty-seven students (20%) were freshman, 40 (21%) were sophomores, 37 (20%) were juniors, and 72 (39%) were seniors.

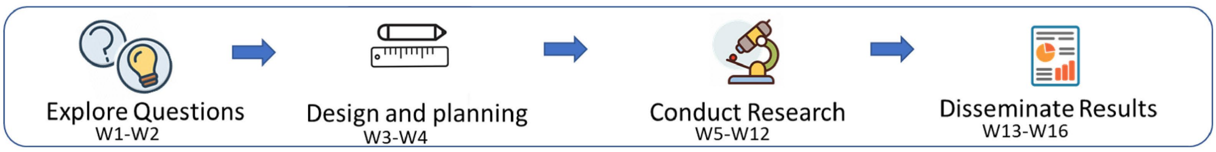

FIGURE 2
Example of the organization of CRE activities within a 16-week CRE course. The number following the "W" indicates the week of the semester.

TABLE 1 Examples of CRE courses at LTU organized by discipline.

Course	Discipline	Description	Year
BIO 2321: Microbiology Laboratory	Biology	Investigation of the impact of human activity on the soil microbiome, including skills related to aseptic technique, microbial staining, and biochemical characterization.	Sophomore
BIO 3201: Anatomy and Physiology Laboratory	Biology	The use of wearable technology to collect and analyze biometric and environmental data about topics of students' choice.	Junior
BIO 4812: Cell Biology Laboratory	Biology	Examination of potential endocrine disrupting effect of environmental chemicals using *in vitro* cell cultures and *C. elegans* models.	Junior/Senior
HRM 3023: Human Resource Management	Business	Empirical research on engagement and retention among Gen Z employees.	Junior
CHM 1213: University Chemistry 1	Chemistry	Exploration of how lone-pair electrons affect the molecular structure of small molecules.	Freshman
CHM 2321: Organic Chemistry 2 Laboratory	Chemistry	Synthesis, purification, characterization, and medicinal testing of novel aspirin analogs.	Sophomore
CHM 3452: Advanced Synthesis Laboratory	Chemistry	Synthesis, purification, and characterization of a new diamagnetic organometallic complex of a first-row transition metal.	Junior
COM 1001: Pathways to Research Careers	Communication	Use of research methods, study design, cultural sensitivity, inclusiveness, and entrepreneurial mindset to investigate career paths after graduation.	Freshman
COM 1103: Honors College Composition	Communication	Research, design, and testing of innovative methods and activities for teaching academic writing to STEM majors, with an emphasis on collaborative writing.	Freshman
MCO 4073: Topics in Television, Video, and Film: Emotional Outlaws	Communication	Interdisciplinary research on emotion and media following an introduction to feminist and anti-racist affect theory.	Junior
MCS 2513: Software Engineering I	Computer Science	Students explore, measure and discuss the implications of 'radio' interferences usually suffered by software & electronic devices.	Sophomore
MCS 2613: Software Engineering II	Computer Science	Identification of an open-ended question related to the concepts, practices, or methodologies learned in the field of software engineering leading to a research project with an emphasis on inclusivity.	Sophomore
MCS 2534: Data Structures and Algorithms	Computer Science	Students carry out research in identifying the 'realities' behind contemporary data structures, libraries and algorithms for handling Big Data. Further discussions on Hadoop, google services, SQL, AWS (and other cloud data banks)	Sophomore
MCS 4993: Text Mining	Computer Science	Students work in tandem on a relevant text mining problem, which culminates in a research paper while adhering to ACM or IEEE publication guidelines.	Senior
MCS 4993: Topics in Computer Science	Computer Science	Development of self-drive software for by-wire electric vehicles. Tasks include the development of vehicle summon system, following a human, 4-way stop coordination, and IGVC self-drive competition.	Senior
LLT 1213: World Literature and Culture 1	Humanities	Students change the number structural stages of epics, create new storylines, and measure the reception of the new epics and write an essay on the process and reception.	Freshman
LLT 1213: World Literature and Culture 1	Humanities	Interpretation of art using digital humanities algorithms.	Freshman
LLT 4513: Seminar in Literature: Cultural Representations of Violence	Humanities	Completion of interdisciplinary research on a violent event or cultural artifact. Past projects include studies of gun use in hard-boiled fiction, forensic architecture, true crime podcasts, and graphic novels.	Senior
SSC 3313: History and Philosophy of Science	Humanities	Analysis of the mistakes responsible for the replication crisis in the social sciences.	Junior
SSC 4513: Science Gender and Race	Humanities	Critically examined stories of chemists, such the one narrated in the *Women Untold* movie (https://youtu.be/T5196ZW9s-g) and engaged in immersive learning in which students were required to write, direct and produce 5-min narrative films as a final CRE project.	Junior/Senior
MCS 1414: Calculus1	Mathematics	Investigation of how calculus was discovered from the perspective of someone living in the 18th century, focusing on the definition of a limit and a derivative.	Freshman
MCS 2414: Calculus 2	Mathematics	Use of mathematical software to solve real-life problems through teamwork, composition of a research report, and presentation of projects to the class and/or at LTU Research Day.	Sophomore

(Continued)

TABLE 1 (Continued)

Course	Discipline	Description	Year
MCS 2423: Differential Equations	Mathematics	Use of 3D printing of mathematical models and virtual reality to visualize mathematical concepts.	Sophomore
MCS 2423: Differential Equations	Mathematics	Modeling of real-world scenarios of students' choice using differential equations (e.g., pollution in Lake St. Clair, aspirin metabolism, COVID-19 spread).	Sophomore
MCS 3863: Linear Algebra	Mathematics	Use of COVID-19 infection case data and linear regression to measure and compare the initial disease growth rate in different locations around the world.	Junior
NUR 4105: Population Health and Epidemiology	Nursing	Application of the concepts of epidemiology when caring for populations while incorporating social determinates of health and caring science in scholarly writing and exploration.	Senior
PHY 2432: University Physics 2	Physics	Application of computational thinking to understand phenomena in physics, including the creation of computational essays to describe their experience with problem-based active collaborative learning.	Sophomore
PSC 1161: Physical Science Seminar	Physics	Design of experiments by students with the only requirement being that data must be measured and analyzed. Past experiments include Schlieren imaging, acoustic levitation, measuring the speed of a shockwave, and payload testing a superconductor.	Freshman
PSY 2393: Sport Psychology	Psychology	Analysis of methods to improve overall quality of life beyond the classroom through sports.	Freshman
PSY 3173: Sensation and Perception	Psychology	Analysis of perceptual discriminability of sugar-sweetened beverages from artificially-sweetened beverages.	Junior
PSY 3713: Topics in Psychology - The Psychology of Language	Psychology	Testing of linguistic materials that vary in their figurative meaning with the goal of creating a database of items for future use in psycholinguistic research.	Junior

Institutional data regarding academic achievement

We gathered institutional data on participants to compare the academic achievement of CRE students ($N=186$) and the general population of all College of Arts and Sciences students during the fall 2016 and spring 2017 semesters ($N=623$). Academic achievement was assessed by comparing the yearly grade point average (GPA) and final grades of students enrolled in CRE courses with the general population of all students enrolled in any course within the College of Arts and Sciences. Independent sample T-tests were conducted to compare the mean GPA and final grades of CRE students compared to all College of Arts and Sciences students.

Survey regarding students' experience

We developed an original survey to assess several aspects of the CRE experience of students in different disciplines. We used a new questionnaire instead of an existing one because previous instruments used to assess CURE (Lopatto, 2004) are specifically designed to assess STEM courses, while our CRE intervention includes both STEM and non-STEM courses. The survey included 15 items scored along a five-point Likert scale (see Appendix 2), as well as six demographic questions. The 15 questions focused on six main topics: attitude towards research, self-efficacy, teamwork, cultural sensitivity, gender issues, and race issues. Responses related to the same topic were collapsed and averaged together. A series of 6 ANOVA analyses, one for each topic, were conducted with the academic discipline (biology and chemistry, literature, mathematics and physics, philosophy, psychology) and gender (female vs. male) as between-subject factors and CRE experience (pre- vs. post-course) as within-subject factors. We could not include race as a factor in the main analysis because the low number of non-white students in the sample (12 African Americans, 17 Asians, 9 Hispanics, 2 Biracial versus 146 Whites) prevented the inclusion of the race factor in the main design. A separate series of ANOVA analyses were conducted to evaluate the influence of race on the six dependent measures. In this supplementary analysis, the between-subject factor race was paired with the within-subject factor CRE-experience in order to verify the influence of race on the CRE intervention.

Survey regarding faculty perspectives on the sustainability of CRE at LTU

Thirty faculty currently involved in our CRE pedagogical initiative were asked to complete a brief survey during a faculty CRE retreat in August 2021. The purpose of the survey was to obtain self-reported measures of how likely the CRE faculty team was willing to use course-based research experience pedagogy in the future, in absence of monetary rewards. To maintain anonymity, we avoided asking questions that could be used to trace the identity of the respondents. From the demographic data of attendance at the retreat, we can report that the sample was composed of a total of 30 participants, including 13 female faculty (43%), 2 adjunct faculty (0.06%), 7 non-tenure-track full-time faculty (23%), 11 tenure-track assistant professors (36%), and 10 tenured professors (33%) with 24 faculty from STEM fields (80%) and 6 from non-STEM disciplines (20%).

The survey included the following main question: *"How likely are you to use course-based research experience pedagogy in the future, even if you will not be paid for any future CRE activities?"* followed by three additional questions to assess faculty opinions on the sustainability of the three pillars of CRE:

How likely are you to use course-based research experience in the future in order to:

1. Promote original discovery in the classroom
2. Require inclusive collaboration

3. Facilitate communication of course discoveries

To verify possible associations between the amount of CRE experience and the willingness of faculty to continue using CRE pedagogy, we asked participants to report how many distinct CRE courses and sections of courses they had taught at LTU. Finally, we asked participants to share any comments, ideas, and challenges about the use of CRE in their future pedagogical plans.

Results

Academic achievement

Independent sample *T*-tests were conducted to compare the grade point average (GPA) of CRE students to the GPA of students in the general student population in the College of Arts and Sciences during the targeted semesters. We also compared the final grades of students enrolled in CRE courses to the final grades of all students enrolled in courses in the College of Arts and Sciences. Prior to the analysis, the normality of GPA and final grades in CRE and all students was estimated using skewness and kurtosis. The criteria for the normality of the academic achievement data were met as skewness and kurtosis <2 (Asai, 2013). Accordingly, GPA and final grades were assumed to be normally distributed.

Independent sample *T*-test results on student GPAs ($T = 2.68$, $df = 804$, $p = 0.007$, Cohen's $d = 0.225$), indicated that the GPA of students enrolled in CRE courses ($M = 3.30$, $SEM = 0.04$) was significantly higher than the GPA of the general student population in the College of Arts and Sciences ($M = 3.16$, $SEM = 0.03$). The *T*-test results ($T = 4.14$, $df = 795$, $p < 0.001$, *Cohen's* $d = 0.349$) also indicated that CRE students ($M = 86.33$, $SEM = 1.23$) obtained higher final course grades than the general population of College of Arts and Sciences students as a whole ($M = 79.93$, $SEM = 0.76$).

While these differences between CRE students and the general student population were significant, we could not control for demographic covariates since CRE and non-CRE student populations partially overlapped. Specifically, CRE students are also part of the general college population. Also, a large portion of CRE students have taken part in more than one CRE class. In spite of these limitations, two main considerations lead us to postulate that the two populations are comparable: (1) The heterogeneity of CRE courses well represent the variety of disciplines in the College of Arts and Sciences. In fact, CRE courses are distributed among the three departments of natural sciences, mathematics and computer science, and humanities, social sciences and communication, which include STEM, non-STEM, and social science courses in similar proportions. (2) When students decided which courses to take at the beginning of a semester, they did not know if they were going to participate in a CRE experience or not. In this way, we avoided the self-selection of historically high-achieving students that could lead to potential sampling biases and, likely, to systematic higher achievements in CRE students unrelated to the actual CRE experience.

The student experience

Normality of the survey data were assessed prior to analysis *via* skewness and kurtosis; criteria for normality of the data were met as skewness and kurtosis <2 (Asai, 2013). Below we report the results of the ANOVA analyses measuring the impact of CRE and the influence of academic discipline and gender on students' attitude towards research, self-efficacy, teamwork, cultural sensitivity, gender issues, and race issues. Descriptive statistics of this analysis is provided in Table 2.

Attitude towards research

The main effect of CRE was significant, $F(1, 173) = 25.19$, $p < 0.001$, $\eta^2_p = 0.13$. Participants rated their attitude towards research more positively after CRE ($M = 2.77$, $SE = 0.04$) than before CRE ($M = 2.56$, $SE = 0.04$). The main effect of discipline was also significant, $F(4, 173) = 3.33$, $p = 0.012$, $\eta^2_p = 0.07$. Tukey post-hoc analysis found biology & chemistry students reported significantly higher research attitude than students in other fields (see Table 2). The main effect of gender was not significant, $F(1, 173) = 0.87$, $p = 0.34$ suggesting the positive effect of CRE on students' attitude towards research is inclusive across students regardless of gender. All the other interactions between main factors were not significant.

Academic self-efficacy

The main effect of CRE was significant, $F(1, 173) = 5.14$, $p = 0.025$, $\eta^2_p = 0.029$. Participants provided higher ratings of academic self-efficacy after CRE ($M = 3.29$, $SE = 0.06$) than before CRE ($M = 3.17$, $SE = 0.05$). The main effects of discipline, $F(4, 173) = 0.47$, $p = 0.76$, gender, $F(1, 173) = 0.05$, $p = 0.831$ and all the interactions between factors were not significant.

Teamwork

The main effect of CRE, $F(1, 173) = 0.78$, $p = 0.378$, gender, $F(1, 173) = 0.64$, $p = 0.424$, and all the interactions between factors were not significant. The main effect of discipline was significant, $F(1, 173) = 2.62$, $p = 0.037$, $\eta^2_p = 0.057$, with Tukey post-hoc analysis finding biology & chemistry students reported significantly higher teamwork attitude than students in other fields (see Table 2).

Cultural sensitivity

The main effect of CRE, $F(1, 167) = 0.34$, $p = 0.56$, discipline, $F(4, 167) = 0.5$, $p = 0.736$, gender, $F(1, 167) = 1.94$, $p = 0.166$, and all the interactions between factors were not significant.

Gender issues

The main effect of CRE, $F(1, 170) = 0.01$, $p = 0.925$, gender, $F(1, 170) = 2.17$, $p = 0.143$, and all the interactions between factors were not significant. The main effect of discipline was significant, $F(4, 170) = 2.74$, $p = 0.031$, $\eta^2_p = 0.06$.

Race issues

The main effects of CRE, $F(1, 168) = 0.67$, $p = 0.413$, discipline, $F(4, 168) = 2.25$, $p = 0.066$, gender, $F(1, 168) = 2.32$, $p = 0.197$, and all the interactions between factors were not significant. However, results do suggest the race factor may be relevant in CRE courses with regards to attitude towards research, $F(1, 181) = 8.33$, $p = 0.004$, $\eta^2_p = 0.04$. Tukey post-hoc analysis indicated African-American students declared a more positive attitude towards original research ($M = 2.96$) than White students ($M = 2.63$, $p = 0.15$). The race factor also had a significant influence on the race issue measurement, $F(4, 176) = 4.04$, $p = 0.004$, $\eta^2_p = 0.08$. Tukey post-hoc analysis indicated that Asian

TABLE 2 Pre- and post-CRE mean (SEM) across student experience topics and disciplines.

	All disciplines		Biology and Chemistry (n = 36)		Literature (n = 18)		Math and Physics (n = 57)		Philosophy (n = 29)		Psychology (n = 46)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Research attitude	2.56 (0.04)	2.77 (0.04)*	2.70 (0.08)	3.01 (0.10)[d]	2.78 (0.11)	2.87 (0.14)	2.48 (0.07)	2.74 (0.08)	2.34 (0.09)	2.65 (0.08)	2.60 (0.08)	2.67 (0.08)
Self-efficacy	3.17 (0.05)	3.29 (0.06)*	3.34 (0.12)	3.29 (0.13)	3.28 (0.15)	3.42 (0.19)	3.03 (0.10)	3.26 (0.11)	3.31 (0.11)	3.29 (0.14)	3.09 (0.10)	3.29 (0.11)
Teamwork attitude	2.63 (0.07)	2.52 (0.07)	2.97 (0.13)	2.88 (0.17)[d]	2.25 (0.22)	2.17 (0.24)	2.58 (0.13)	2.49 (0.10)	2.53 (0.21)	2.48 (0.19)	2.65 (0.13)	2.46 (0.13)
Cultural sensitivity	3.30 (0.07)	3.26 (0.07)	3.38 (0.12)	3.36 (0.14)	3.56 (0.15)	3.12 (0.28)	3.30 (0.14)	3.33 (0.14)	3.03 (0.20)	3.10 (0.19)	3.33 (0.12)	3.26 (0.14)
Gender issues	0.88 (0.07)	0.89 (0.07)	0.86 (0.14)	0.75 (0.15)	1.33 (0.24)	1.28 (0.20)	0.59 (0.08)	0.67 (0.11)	1.07 (0.21)	1.24 (0.19)	0.93 (0.13)	0.91 (0.14)
Race issues	0.95 (0.07)	0.90 (0.08)	0.86 (0.15)	0.83 (0.17)	1.39 (0.29)	1.28 (0.24)	0.65 (0.10)	0.68 (0.12)	1.26 (0.22)	1.28 (0.19)	1.04 (0.15)	0.84 (0.17)

n indicates the sample size in each discipline. *$p < 0.05$ pre-post difference according to paired samples T-test; [d]$p < 0.05$ highest mean student experience topic according to Tukey *post hoc* test.

students perceived more racial discrimination in their classes ($M = 1.66$) than White students ($M = 0.88$, $p = 0.006$) and Hispanic students ($M = 0.39$, $p < 0.004$). The influence of race on all the other dependent measures, namely, academic self-efficacy, $F(4, 181) = 0.41$, $p = 0.803$, teamwork, $F(4, 181) = 1.76$, $p = 0.14$, cultural sensitivity, $F(4, 175) = 1.99$, $p = 0.098$, and gender issues, $F(4, 178) = 1.69$, $p = 0.154$, was not significant.

Faculty perspectives regarding sustainability

As detailed in the methods, 29 CRE faculty completed a brief survey during a faculty CRE retreat. The survey was aimed at exploring how likely the CRE faculty team was willing to use course-based research experience pedagogy in future semesters following the end of the grant period.

The CRE faculty who took part in the survey (29 out of 30) expressed a very strong intention to continue using CRE pedagogy in spite of the end of financial incentives. The average answer to the question "*How likely are you to use course-based research experience pedagogy in the future, even if you will not be paid for any future CRE activities*?" was significantly greater than a neutral value of 4 (see Table 2 for further details). Also, participants expressed a strong intention to continue using all the three pillars of CRE in their pedagogy. Specifically, participants' self-reported likelihood to *promote original discovery in the classroom*, *require inclusive collaboration*, and *facilitate communication of course discoveries* were all very high and significantly different from a neutral response (see Table 2).

We also calculated the correlation between CRE expertise with respect to the number of courses taught at LTU and the responses to the four questions about sustainability. Results show that none of the sample's answers to the sustainability question correlated with CRE expertise (see Table 3). This finding indicates that a high level of faculty commitment to CRE pedagogy, even in absence of financial support, is shared by all faculty involved in the project, regardless of the amount of previous experience within the CRE program.

Lastly, included in the survey was an open-ended question to gain direct feedback from faculty participants. While the response to the open-ended question was not mandatory, the majority of the sample population (65%) decided to provide additional feedback pertaining to their future use of CRE in their pedagogical practices, which included the pillars of CRE as the framework. Participants offered general comments (40%), challenges (30%) and ideas (30%) while also describing their interests and support for sustaining CRE pedagogy as an ongoing teaching practice. In addition, a thematic analysis was conducted to identify key themes from faculty experiences and their perspectives related to pedagogical commitments beyond the grant funding period (Yin, 2015). Patterned codes were analyzed to help determine if faculty found value in CRE as a sustainable practice.

The overall summative responses support the future use of CRE pedagogy and sustainability beyond the grant funding period by noting that the benefits of incorporating CRE pedagogy outweigh the costs. Faculty described the strengths and challenges related to the idea of continuing to develop and teach course-based research courses. Emergent themes were identified and reported: 1. CRE is an inclusive teaching practice that strengthens the credibility of learning and its academic content; 2. CRE offers an enhanced academic learning environment to both students and instructors; and 3. CRE teaching and learning goes beyond a stipend despite its challenges.

Faculty shared their view that CRE pedagogy is an inclusive teaching practice that strengthens faculty pedagogy, offers significant benefits to the classroom environment, and positively engages everyone involved. One faculty member described how "*using CRE helps students learn much better and I really love it.*" These descriptions align with faculty being satisfied with the learning process of their students. The academic benefits of CRE pedagogy are widely viewed as invaluable. One faculty member was encouraged by the program and shared that *"course-based research allowed my students to explore the content as it provided them an avenue to learn and retain it."* As noted, CREs cultivate a richer learning environment that incentivizes

TABLE 3 Average responses to sustainability questions.

	Average response (SD)	*T*-test	Correlation with CRE expertise
How likely are you to use course-based research experience pedagogy in the future, even if you will not be paid for any future CRE activities?	6.69	$t(28) = 21.9, p < 0.001$	$r(27) = 0.15, p = 0.42$
Promote original discovery in the classroom	6.48	$t(28) = 13.6, p < 0.001$	$r(27) = 0.11, p = 0.57$
Require inclusive collaboration	6.69	$t(28) = 26.7, p < 0.001$	$r(27) = 0.10, p = 0.60$
Facilitate communication of course discoveries	6.55	$t(28) = 18.7, p < 0.001$	$r(27) = 0.05, p = 0.79$

Responses are based on a 7-point Likert scale. *T*-tests compare average responses to a neutral value (4).

faculty and students to engage in active research and deepens student learning. Therefore, faculty see the value in both the instructor and learner having positive experiences in an engaged and active classroom.

Survey data also confirmed faculty are motivated to engage in this pedagogical practice beyond the grant stipend period, thus confirming it can be sustained. Faculty noted that while the stipend helped to offset the time required for course development, it is not a necessary precursor to implement CREs. An instructor shared, "*I did not need to teach over the summer because of the CRE stipend, however, CRE has allowed me to implement and promote more original discovery and in different ways – it has and will continue to do so even after funding*." Another faculty reflected, "*financial and institutional support might not be necessary for me to teach CRE, but it would encourage me to teach more CRE courses, and incorporate the CRE pedagogy more thoroughly*." While faculty acknowledged the importance of the financial benefits, most of them expressed the opinion that the stipend is not a necessary requirement for CRE sustainability. In a theory of change theoretical framework (Reinholz and Andrews, 2020), we can argue that it is likely that financial support was important to overcome faculty's initial resistance to change. Specifically, as the adoption of CRE pedagogy requires changes of course content, methods, and classroom dynamics that are necessarily costly in terms of time and effort, a financial reward is a great motivation to change from traditional lecturing methods to CRE. However, at the end of the financial incentives, the estimation of costs and benefits may have been changed permanently, with costs not as high as when starting and benefits that grow with CRE experience and expertise. This hypothesis is in line with the expectancy theory of motivation (Vroom and Yetton, 1973) and can be empirically tested in future studies.

Other experiences and challenges were also noted to understand a broader view of the workload and faculty expectations related to CRE. Some faculty expressed that the incorporation of original research in their discipline, which is one of the three pillars of CRE, was challenging. For example, two faculty shared the difficulty of promoting original discovery as a challenge. One said: "*The largest challenge I have found in implementing course-based research or projects in mathematics courses is that often the most applicable course material occurs very late in the semester, after systematically building the course up over several months. It is challenging to have the student effectively define and analyze problems based on course material with which they are not yet familiar*."

Other faculty expressed concerns related to producing original research in their respective fields, they said, "*Ensuring original discovery at a level acceptable to the scientific community in my field is next to impossible*." Furthermore, these challenges imply the need for faculty to continue to develop creative teaching strategies to further promote and facilitate inclusive course-based research practices in their academic content area in order to support and strengthen the credibility and authenticity of the program.

Discussion

The CRE program at LTU engages undergraduate students in authentic research experiences. Consistent with previous research that URE enhances academic performance (Barlow and Villarejo, 2004; Freeman et al., 2014; Ward et al., 2014), we determined that the course grades and GPA of students enrolled in CRE courses were significantly higher than the grades of the general population of students in the College of Arts and Sciences. We believe that the increased academic performance of CRE students is likely to be related to both the pedagogical characteristics of CRE and the subjective experience of students in CRE classrooms. While grades, examination scores, and failure rates in CRE and non-CRE courses are frequently compared to assess the efficacy of CRE pedagogy (Freeman et al., 2014; Ing et al., 2021 for a large meta-analysis), there are reasons to believe that such a measure is incomplete. In fact, CRE and non-CRE courses most likely have different instructors, are taught in different semesters to different students, utilize different pedagogical methods that emphasize different topics, and use different assessment tools and metrics. Therefore, we believe that using grades as the main method to measure the impact of CRE pedagogy highlights the challenges of controls and must be necessarily supported by other indicators, such as, for example, the assessment of the experience of CRE students and instructors.

Regarding student experiences in CRE courses, in line with previous findings (Harrison et al., 2011; Brabec et al., 2018), students' attitude towards research was more positive after CRE than before it. This effect was not dependent on gender, highlighting the inclusive nature of CRE in improving students' attitude towards research. We did find that biology and chemistry students rated their attitude towards research and teamwork more positively than students in other disciplines. We believe that such differences can be explained by student expectations of the educational research activities and teamwork in biology and chemistry laboratory courses. The main positive effect of CRE on research attitude underscores the strength of CRE in fostering a positive attitude towards research in all students, including those in disciplines that do not traditionally involve research in the classroom.

There is evidence that CRE can boost self-efficacy in students (Brownell et al., 2012). The results of our survey confirm this finding. In fact, students indicate that their academic self-efficacy was positively influenced by CRE, with students expressing a higher confidence in their academic abilities and potential following CRE interventions.

One of the most compelling aspects of our program is the heterogeneity of the intervention. Students in the LTU College of Arts and Sciences take multiple CRE courses during their undergraduate degree program, including both STEM and non-STEM disciplines. All students graduating from the College of Arts and Sciences in the past 5 years experienced CREs in more than one discipline. Such a vast and diverse range of fields creates a fertile environment in which creativity, problem-solving, and research methodologies in one field can be translated to another field. It is important to note that, since many of our CRE courses are part of LTU's core curriculum, students from other academic colleges (Engineering, Architecture and Design, and Business and Information Technology) also benefit from this initiative. Our CRE model already counts several instances of direct cross-disciplinary integration incomputer science and art, psychology and philosophy, and English composition and design, for example. We are interested in understanding if the heterogeneity of the CRE intervention can provide additional benefits to CREs (Latham, 2018). However, more data is necessary to support the hypothesis that students who experience CRE in multiple courses develop an enhanced sense of methodological self-reflection and that the comprehensive nature of the CRE intervention at LTU develops a positive transfer of ideas. We are currently using focus groups and interviews to assess this hypothesis. Our preliminary results are in contrast with Brabec and colleagues, who found that first year students in a CRE biology laboratory course did not show an increased interest in research (Brabec et al., 2018).

According to the results of our surveys, students did not feel racial and gender discrimination in their classrooms. We are aware that such results could be biased by the fact that the vast majority of the students in the sample were White. Interestingly, the discipline in which CRE took place influenced the awareness of gender discrimination in the academic environment, with a greater awareness in literature and philosophy than in biology and chemistry. This is an intriguing result because it suggests that non-STEM disciplines can perhaps encourage cultural sensitivity more than STEM disciplines, resulting in a greater awareness of possible gender and racial issues. Therefore, interventions in non-STEM disciplines can be a crucial factor in the promotion of systemic institutional change that aims to develop an inclusive research environment for all students. Concerning the influence of race on students' opinions and attitudes, results indicate that African American participants shared a more positive attitude towards original research than White and Asian participants. This finding confirms previous results showing that CRE interventions are particularly effective for underrepresented minority students, resulting in improved learning gains (Lopatto, 2007). Finally, the race of students had a significant influence on the perception of racial discrimination. Specifically, Asian participants perceived more racial discrimination in their classes than White, African American, and Hispanic participants. While racial discrimination towards Asian American students has previously been documented (Sue et al., 2009), our results are in contrast with previous findings that African American and Hispanic students report higher rates of microaggression incidents than Asian students (Torres-Harding and Turner, 2014; Forrest-Bank and Jenson, 2015). The difference is likely related to our small sample size or the different structure of surveys, with ours including a few general questions about ethnic, racial, and gender discrimination in the classroom while Forrest-Bank and Jenson's and Torres-Harding and Turner's findings were acquired using the racial and ethnic microaggressions scale developed by Nadal (2011).

While peer-reviewed publication is not an indispensable condition for a successful CRE (Dolan, 2016), it is definitely an aspect that can add value to the experience, improving a student's sense of ownership, academic self-efficacy, and sense of belonging to the scientific or academic community (Asai, 2013). CRE can also be beneficial for faculty productivity in certain contexts (Gibson et al., 1996; Morales et al., 2017).

As a result of our CRE intervention, several peer-reviewed journal articles have resulted from CRE courses. Examples of CRE studies resulting in peer-reviewed articles with at least one undergraduate student in the list of authors include publications in computer science (Kuminski and Shamir, 2016; Chung and Kocherovsky, 2018; Paul et al., 2018; Shamir et al., 2019; Pleune et al., 2020), psychology (Delogu et al., 2016, 2020a,b; Delogu and Lilla, 2017; Delogu, 2020), and chemistry (Willbur et al., 2016; Zhou and Zhou, 2020; Large et al., 2023). In our experience, not all the students involved in a given CRE course are included in the list of authors for several reasons. In many cases, the CRE course is a pilot phase of a research project that requires more time than one semester to be completed. In other cases, CREs can be reiterated several times in different semesters. While only a fraction of CRE experiences can likely culminate in a peer-reviewed publication, most CRE students have the opportunity to present their work to audiences external to their classrooms.

In addition to peer-reviewed publications, students at LTU routinely present their CRE projects at national and international conferences. Some examples include physics (Houck and Bhattacharya, 2021), computer science (Shamir et al., 2019), and psychology (Delogu and Lilla, 2017). Finally, in the past 5 years, hundreds of CRE students also had the opportunity to present their work at regional conferences such as the Michigan Academy of Science, Arts, and Letters (MASAL) annual conference and at LTU Research Day, a yearly symposium dedicated to showcasing scholarly projects by students and faculty. The completion of the research cycle has several important beneficial consequences, such as the improvement of communication skills, the development of a sense of autonomy and research ownership, and a sense of self-efficacy (Spronken-Smith et al., 2013).

Faculty commitment is a crucial aspect of the sustainability of any systematic curricular transformation. In this regard, our CRE faculty expressed a very strong intention to continue using CRE pedagogy in spite of the end of financial incentives. Such self-reported commitment is shown by all the participants in CRE, regardless of the amount of previous experience within the program. While faculty acknowledged the importance of the financial benefits, most instructors shared that the stipend is not a necessary requirement for CRE sustainability. In a theory of change theoretical framework, we can argue that it is likely that financial support was important to overcoming faculty's initial resistance to change. Specifically, as the adoption of CRE pedagogy requires changes of course content, methods, and classroom dynamics that are necessarily costly in terms of time and effort, a financial reward is a great motivation to change from more traditional teaching methods to CRE. However, at the end of the financial incentives, the estimation of costs and benefits may have been changed permanently, with costs not as high as when starting and benefits that grow with CRE experience and expertise. Such a hypothesis is in line with the expectancy theory of motivation at work (Jones and Vroom, 1964) and can be empirically tested in future studies.

Considerations and future research

As a result of several years of practice, we believe that our CRE intervention produced a second order institutional change that promotes the inclusive access of all students to authentic research experiences that nurture students' self-efficacy and academic potential. Several conditions facilitated the emergence of a sustainable systemic change that is likely to outlast the external funding phase of the project: (1) we created a critical mass of CRE courses and instructors by providing both incentives and training to overcome resistance to change; (2) we developed a cohesive community of instructors who share common general principles and practices; (3) our program has the support of the university administration; (4) we diversified the range of intervention by facilitating an understanding of the concepts of scholarship, research, and discovery in diverse disciplines and by developing conceptual intersections between multiple CRE experiences in different fields; and (5) we integrated the intervention with partners that share similar goals or practices; for example, with internal institutions such as the Center for Teaching and Learning and the Office of Diversity, Equity, and Inclusion, student organizations, and external collaborators and networks. (6) we strengthened our inclusivity mission with the practice of culturally-responsive teaching and the development of a teaching and learning community, multi-institution collaborations, the development of a dedicated seminar series, the substantial involvement of non-STEM disciplines, and student researcher awards.

We believe that our program is an excellent option for the instructors interested in implementing a problem-based learning (PBL) approach in their teaching practices. In fact, CRE includes all PBL main features, such as self-directed learning, the independent use of resources, peer collaboration, data collection, flexibility in learning outcomes, the development of problem-solving skills, and the promotion of intrinsic motivation (Wood, 2003; Hmelo-Silver, 2004). In addition to PBL advantages, CRE also includes a clear orientation to original research, in which students and instructors collaborate to solve problems with unknown solutions. This aspect of originality invigorates students' sense of ownership, promoting a sense of academic self-efficacy and intrinsic motivation.

While undoubtedly positive and formative, our experience also presented challenges, which were expressed by faculty and students in their open-ended reports and discussions. We summarize the main points of concern as follows, together, when possible, with strategies to mitigate them: (1) Embedding CRE in a regular course takes time away from the traditional curriculum that must be compressed and/or reduced to provide time for research activities. Some courses, especially the ones in which the curriculum must necessarily cover basic concepts in STEM, did not have the required time flexibility to allow any CRE insertion or limited CRE to a small number of class periods. The solution we adopted is to allow the time dedicated to CRE as much flexible as possible; for example, some CREs required just a few class sessions, while others involved the entire semester; (2) as students did not decide whether to participate in CRE (i.e., no self-selection), a small number of them manifested frustration with the additional work, creativity, and problem-solving processes often required to perform original research. A strategy to reduce these frustrations is to explicitly engage these students in the ownership of the CRE project through collaboration, as well as present students with the potential advantages of CRE for their academic preparation and career paths; (3) teamwork in CRE is fundamental, but can be challenging. Survey data indicates that many students are frustrated by the unequal distribution of work and/or by sharing parts of their grade with other students. This is particularly true for successful high-achieving students who often claim to have worked more than their teammates. Possible strategies include fun and engaging team-building activities, dividing work into very small groups to mitigate "hiding," encouraging team member engagement (e.g., teams of 2–3 students focus on a very precise task), asking for anonymous and evidence-based evaluations of the work of teammates, inviting team members to complete a team participation contract, and encouraging team members to emerge as leaders and take an active role in facilitating project completion.

As we continue investigating the effects of CRE implementation at LTU, we are interested in studying a variety of factors. For example, given more opportunities (and requirements) for students to participate in CRE remotely, we could investigate the differences in CRE delivery remotely versus in person. As we increase faculty participation in teaching CRE courses, we could investigate the gender effects of instructors within and between disciplines. We are also exploring additional constructs to measure through student surveys, such as self-awareness, critical thinking, and reflective skills.

Conclusion

In this study, we described a large-scale multidisciplinary CRE program at LTU, and assessed its impact on student success and the student experience as well as faculty perceptions pertaining to the sustainability of the program following the grant period. In our transformative program, a large portion of College of Arts and Sciences faculty actively promote and facilitate the three pillars of CRE, namely (a) discovery through scholarly practice, (b) inclusive collaboration, and (c) communication of relevance. Our assessment data indicates that students have positive experiences, and tend to do better academically when they are engaged in course-based research practices. Importantly, faculty involved in CRE pedagogy fully support the mission and values of the CRE community and intend to continue to implement CREs in absence of external financial support. Our experience and data supports the idea that CRE has become an integral part of the LTU core curriculum teaching practice and is now considered an important part of the fabric and culture of LTU as an institution.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by LTU's Institutional Review Board Director - MC - Lawrence Technological University. The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because the surveys were parts of CRE activities and they involved minimal risk and privacy concern for the participants. The study was considered exempt category 2 which covers survey procedures and use of educational tasks in such a manner that the identity of participants cannot be readily ascertained.

Author contributions

FD wrote the manuscript. FD and MC performed the statistical analysis. FD, MN, ST, MW, BB, PJ, MA-H, HA-A, OA, LA, WB, CC, C-JC, SuC, MC, SiC, TF, MG, CH, MJ, VK, JK, AK, PL, TL, EM, KM-P, JM, GM, IM, PN, BP, JS, RS, DS, FS, MZ, JZ-V, NY, and H-PM contributed to the research with their CRE activities and drafted the description of their CRE courses and revised the initial draft. All authors contributed to the article and approved the submitted version.

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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.

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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.2023.1142572/full#supplementary-material

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Improving persistence of underrepresented racial minority science majors: where to begin

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Many colleges and universities are interested in implementing effective strategies to support broaden participation and persistence of undergraduates, and especially underrepresented students, in Science, Technology, Engineering, and Mathematics (STEM) majors. While there are programs and models that have proven successful in this arena, many of these models are extremely resource intensive. This Perspective provides a distillation of key aspects of successful programs that institutions could consider implementing as a starting point when thinking about how to design programs to support students in STEM.

KEYWORDS

STEM persistence, underrepresented and minority groups, graduation and persistence rates, peer mentoring, cohort program, retention

1. Introduction

There is an awakening taking place nationally about the decline in the number of undergraduate students completing majors in Science, Technology, Engineering, and Mathematics (STEM) and embarking on careers in STEM fields. While this decline is a widespread phenomenon, attrition among underrepresented minority (which include African American, Latino/a, Chicano/a, Native American, and Pacific Islander students) students is particularly noteworthy. URM students plan to study in STEM fields at the same rate as majority students but do not graduate at the same rate. According to a report from the National Center for Education Statistics, about 35% (range 32%–52%) of students who enter college in STEM majors leave those majors within 3 years (Figure 1), and for Black/African American students, the rate is 65% due to students dropping out of college or switching majors (Chen, 2013; Leu, 2017). Studies have shown that the difference in persistence rates between URM students and their majority peers cannot be wholly attributed to pre-college academic preparation (Wright et al., 2011; Riegle-Crumb et al., 2019). In fact, more academically accomplished URM students are more likely to leave STEM majors (Rodriguez, 1997; Grandy, 1998; Chang et al., 2011; Hatfield et al., 2022).

There is a need and indeed room for more interventions aimed at closing the gap in URM student persistence in the sciences and capitalizing on the increased awareness that is being generated by the renewed interest in addressing issues of inequity and disparity in various arenas, including in higher education. Instead of creating brand new programs on a blank slate however, an approach that has been put forward by a committee of experts in URM education is to "build on what works," i.e., study and learn from programs that are known, through rigorous assessment, to be succeeding in this area (Estrada et al., 2016; Burt et al., 2023). This approach would reduce unintentional waste of time, effort, and resources.

As a naturalized US citizen and immigrant from Nigeria, my experience as a college student in the sciences was probably very different from those of many of my peers who were US-born and racial/ethnic minorities. My perspective was largely that of an outsider, which tacitly excluded me from many conversations about diversity and inclusion in the sciences as it relates to race and

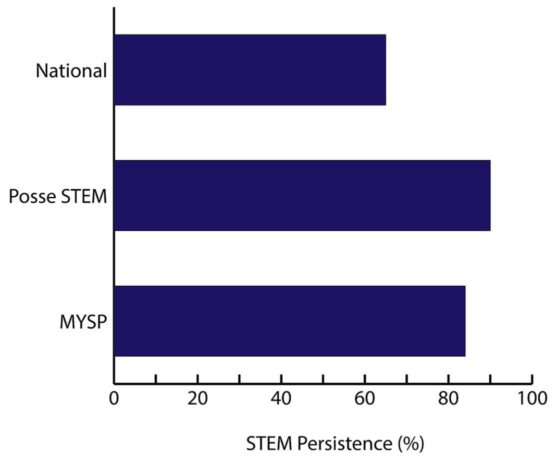

FIGURE 1
Persistence rates of undergraduate STEM majors. National 3-year persistence rate for STEM majors compared to Posse STEM and Meyerhoff Scholars Program (MYSP) graduation rates.

ethnicity in the United States. Additionally, attending a women's college provided some shelter from experiencing many obstacles related to gender. However, as I continued my studies at various predominantly white institutions, I became a witness to and, in some instances, a subject of forces that can contribute to departure from STEM fields, including isolation and poor mentoring (Lee et al., 2020). Now, as a faculty member, I am aware of some of the barriers that impede persistence of undergraduate students of diverse backgrounds on one hand and practices that stimulate persistence on the other. I am committed to contributing to the change that is needed in the ways we support and educate students of all backgrounds in STEM by continuing to engage in activities that enable me to be a better teacher and mentor and that help me be a more informed advocate for program initiatives and conversations within my institution, Northeastern University. This commitment is what led me to propose and pursue this project.

2. Lessons learned from the Posse and the Meyerhoff Scholars Programs

During the summer and fall of 2020, I explored four different institutions that have subscribed to effective models of change. Brandeis University, Wellesley College, Pomona College, and the University of Maryland, Baltimore County (UMBC). My goals were (1) to try to pinpoint the fundamental considerations that contribute to the success of any new program that aims to address the issue of **persistence** of URM students in the sciences, and (2) to offer actionable items that an institution with boundless will but limited resources can implement.

Brandeis, Wellesley, and Pomona are Posse STEM partners. The Posse Program (The Posse Foundation, n.d.) recruits a cohort (Posse) of students from the same geographical location who matriculate together to the same selective college or university. The program provides a robust peer and mentor network that supports the Scholars and enables them to thrive and excel in their studies and as leaders in their institutions. While the flagship Posse Program includes Scholars with interests across all academic areas of study, the Posse STEM Program focuses on students who aspire to studies and careers in STEM fields. As of Fall 2019, 11 institutions, including Brandeis, Wellesley, and Pomona, participated in the Posse STEM Program. I specifically chose Brandeis, Wellesley, and Pomona so that I could observe how a program, Posse STEM, that has unified goals and a defined structure is implemented at different institutions and how elements of the program are adapted to fit the population, culture, and mission of each institution. Brandeis University is an R1 (2018 Carnegie Classification) private institution (similar to Northeastern University), Wellesley is a private, four-year liberal arts, women's college, and Pomona is a private, four-year liberal arts, co-ed college. From 2007 to 2018, the Posse STEM program selected 594 Scholars (73% URM and 54% first-generation students). The current graduation rate for Posse STEM Scholars is 90% (Figure 1), with close to 80% of the program's 105 alumni having graduated with a degree in a STEM field (The Posse Foundation, 2018).

The University of Maryland, Baltimore County (UMBC), a medium size, R2, public institution, is the home of the renowned Meyerhoff Scholars Program (MYSP) (n.d.). MYSP is a long-running program focused on advancing retention and academic excellence of high-achieving URM students in STEM and preparation of the Scholars for graduate and professional studies. Over the 30 years of the program, MYSP (which includes 70.8% URM students) has had an average graduation rate of 84% for STEM majors (Figure 1).

At each institution, I spoke with program directors, faculty affiliates, and program mentors to learn about their experiences—what worked, what did not, and common themes. In the following sections, I describe the findings of my exploration and my recommendations based on those findings.

The Posse Foundation has the following stated goals (The Posse Foundation, 2018):

1. To expand the pool from which top colleges and universities can recruit outstanding young leaders from diverse backgrounds.
2. To help these institutions build more interactive campus environments so that they can be more welcoming for people from all backgrounds.
3. To ensure that Posse Scholars persist in their academic studies and graduate so they can take on leadership positions in the workforce.

The Posse STEM program, which began as a pilot program at Brandeis University, aims to improve retention of underrepresented students in STEM fields by further providing support that addresses some of the unique challenges and goals of students in the sciences. Posse STEM Scholars originate from the same city and matriculate as a cohort, with each cohort consisting of 10 Scholars. Posse provides pre-collegiate training from a strengths-based perspective with no science remediation over the 8 months preceding matriculation and Scholars receive four-year full tuition funded by the institution. The college or university organizes a 10- to 14-day summer immersion program that provides some exposure to college-level work, jump-starts acculturation to the college life at the institution, and fosters a sense of cohesion among cohort members. On campus, each cohort is guided by a mentor, a faculty member or a senior graduate student or postdoctoral fellow. During the first two years, scholars meet with the mentor as a group once every week and individually every 2 weeks. Beginning in their first year, Scholars have the opportunity to participate in academic-year or summer research. The Program identifies faculty, secures these opportunities, and provides funding for Scholars who choose to participate in research. Scholars, faculty, administrators, and

"Posse-Plussers," a small number of non-Posse students invited by Scholars, gather to discuss an important social, cultural, or political issue chosen by Scholars at an annual weekend-long PossePlus Retreat.

In addition to the obvious and tangible benefits to the students and the institution, the impact of the Posse program is far reaching. First, Posse Scholars often transfer what they learn through pre-matriculation training and campus programming to their peers, helping and providing valuable insight to other science students as they navigate the experience of being a science major. Second, the increased visibility and critical mass of underrepresented students is often self-perpetuating—the more diverse the student body, the more diverse the student body will become. Third, exposing faculty and students to more than a token number of high-achieving URM students changes hearts and minds faster than any single diversity training workshop could and contributes to creating a climate of respect that can have implications beyond the institution. To address the question of exclusivity and scale, it is important to point out that, in addition to Posse STEM, all three institutions have other success programs aimed at supporting STEM students that predated or were modeled after Posse STEM.

The Meyerhoff Scholars Program (MYSP) at UMBC is a long-running program focused on advancing retention and academic excellence of high-achieving URM students in STEM and preparation of the Scholars for graduate and professional studies. Over the 30 years of the program, MYSP (which includes 70.8% URM students) has had an average graduation rate of 84% for STEM majors. According to the 2019 Survey of Earned Doctorates from the National Center for Science and Education Statistics (National Center for Science and Engineering Statistics, 2019), UMBC ranks third in the United States for the number of Black or African American undergraduates who go on to complete a Ph.D. and first nationally for Black or African American undergraduates who complete an engineering Ph.D. MYSP has now been replicated at two institutions that are quite different from UMBC—University of North Carolina at Chapel Hill and Pennsylvania State University at University Park—with remarkably similar graduation rate results to UMBC. One of the hallmarks of the MYSP is the strong sense of community and belonging that it provides and encourages Scholars to uphold. Meyerhoff Scholars view their participation with deep and enduring pride and a sense of responsibility for other Scholars. Group work is an integral part of the program. The trajectory of the MYSP at UMBC also speaks to the importance of critical mass and visibility. The more high-achieving URM students were present, the more students *and* faculty recognized that being a member of a racial minority group was not antithetical to high achievement in STEM, the more welcoming the climate felt for URM students, and the more URM students were attracted to and thrived at UMBC.

3. Recommendations for improving STEM persistence

The premise of this project is that persistence and excellence go hand in hand. An equity-driven culture within the sciences—fostered by faculty *and* students—is a critical factor in the performance and retention of all undergraduate students, but particularly for students from traditionally underrepresented groups (Wilson et al., 2012; Dagley et al., 2016; Crawford et al., 2018; Burt et al., 2023; Lytle and Shin, 2023). I was able to distill out some key recommendations that, if implemented with deliberate, collective, and sustained effort, could enable an institution to make significant improvements in its culture, which in turn should translate to an improvement in our retention rates. The five key recommendations are:

1. Increase representation of URM students to achieve critical mass.
2. Improve access to and mentoring by faculty.
3. Improve access to collaborative learning and social connection within a positive supportive peer group.
4. Provide more opportunities to conduct scientific research as early as possible.
5. Conduct a thorough and impartial analysis and revamp, as needed, gateway courses to lower the barriers that students currently perceive or experience.

The question of how to achieve critical mass and increased representation is probably one that is slightly beyond the scope of this perspective but critical to the success of any effort aimed at addressing the retention issue by directly targeting the problem of isolation and stereotype threat that leads many URM students to exit the sciences. The constitution and learning environment at many Historically Black Colleges and Universities (HBCUs) and Minority Serving Institutions address at least the first three of the aforementioned recommendations (Chang et al., 2008; White et al., 2019). Scholars Programs, like Posse, MYSP, or similar highly resourced cohort programs are excellent opportunities that would go a long way to addressing at least the first four recommendations at PWIs while also serving to bolster a sense of science self-identity that is critical to persistence in STEM (Wilson et al., 2012; Dagley et al., 2016; Crawford et al., 2018; Thompson and Jensen-Ryan, 2018; Chen et al., 2021).

With fewer resources, a "Science Scholars" program with clearly defined goals, expectations, potential benefits, and robust oversight—that inherently targets minority, first generation, and lower socioeconomic status students, but could be open to any student, should be considered. Such a program would be presented as an honor to participants. The aspiring scientists who are selected for this Science Scholars program would be

- provided with financial support in the form of tuition, course credit, research stipends, or combinations thereof;
- assigned to fixed cohorts;
- required to attend a summer bootcamp that is not focused on academic remediation but on building familiarity, community, and insight into life as a STEM major;
- mentored by faculty or experienced graduate students or postdoctoral fellows who are dedicated, trained, and incentivized;
- provided with (maybe guaranteed) opportunities for first year/second semester introduction to research to start developing their scientific identity and to be visible to faculty. This could be an impetus for teaching faculty to incorporate more course-based research assignments and projects into their courses.

With even fewer resources, two potentially high-impact interventions can take advantage of existing expertise, resources, and framework, and bolster current efforts to make the culture of learning and excellence in the institution more inclusive and equitable.

1. **Foster an inclusive learning climate among students**. The impact of an inclusive learning climate on retention in STEM undergraduate courses, especially foundational courses, has

been noted (Haak et al., 2011; Tanner, 2013; Audette et al., 2023). Creating an inclusive climate should involve bolstering students' awareness of their role in contributing to achieving this goal. Some students are often not aware of challenges that some of their peers might be enduring and may say or do things (or *not* say or do things) that inadvertently exacerbate the negative experiences of their peers. To help foster an increased awareness of the importance of an inclusive learning culture among students, I propose, among other things, a mobile-building workshop for **students**, similar to that offered in Northeastern University's erstwhile HHMI NU-SCI Inclusive Teaching Program (Howard Hughes Medical Institute, 2017) for faculty, to encourage awareness of and an honest discussion of privilege and assets. This workshop is a hands-on single-session activity that highlights the potential impact of access to resources (or lack thereof) and how one's background and self-perception can shape one's experience (Tanner, 2013; University of Chicago Race and Pedagogy Working Group, 2019). The activity helps participants appreciate subtle, non-traditional, but high impact, factors that can contribute to academic success, e.g., asking for help.

2. **A peer mentoring and study group program.** In almost every conversation I had with faculty, staff, and students for this project, the importance of a positive, supportive peer study group arose. Indeed, studies have shown that quality peer mentoring can contribute to increased persistence of URM STEM students (Kiyama and Luca, 2013; Brown et al., 2023). Interestingly, the positive impact of these peer groups extends beyond the students who join the groups. Students who do not participate witness that their peers are resilient, diligently working together, supporting each other, and excelling, and may become aware of their own behaviors or beliefs surrounding ability, meritocracy, and equity. At the same time, faculty members witness that more experienced URM students are willing and able to serve as effective mentors to younger students, which can help perpetuate a cycle of encouragement and recognition (from faculty) and achievement (from students). Because presence and visibility can be immensely impactful, the peer mentors should aim to visit first-year classes as a group at the beginning of the semester to make an announcement and get students in the course excited about the resource. This peer support program would be designed in such a way that it is seen as an honor to participate as a mentor and is attractive to the student who would otherwise take another job, not consider being a peer mentor, or traditionally not get asked to be a peer mentor. The program would need dedicated space where students can meet either for study or social activities and some financial support to pay the peer mentors and purchase refreshments as needed. Peer mentors would be carefully selected by targeting (to secure a meaningfully diverse group of peer mentors) and through an open application process. To be rigorous, adaptable, and sustainable, this program would likely require oversight and administration by a dedicated part-time or full-time employee with a Ph.D. in the sciences, a passion for mentoring undergraduates, and who identifies/is identified as a racial minority in the US, specifically Black, Latino, Native American, or Pacific Islander.

4. Summary

The aim of this project was to learn from non-minority-serving institutions that have high rates of participation, persistence, and graduation of URM students in STEM through the implementation of excellence programs, including Posse STEM and the Meyerhoff Scholars Program. The specific goal of the project was to explore the common characteristics of the programs that contribute to student success and what other colleges could learn from these programs to begin to address the disparities in retention and graduation rates of our URM undergraduate students. The conclusion of the project is that the key contributors to persistence in STEM include significant representation of URM students to achieve critical mass, a supportive community, and early immersion in scientific research, and that this process can begin with a low-resource intensive strategy like a robust peer mentoring and study program featuring a high number of URM students.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

OO: Conceptualization, Funding acquisition, Investigation, Writing – original draft, Writing – review & editing.

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Conflict of interest

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

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Improving strategic learning and self-regulation skills among underrepresented minority students in a summer research education training program

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Introduction: This study examines the effect of educational interventions on strategic learning and self-regulation variables of underrepresented minority students (URMs) who participated in the NIH R25 Research education program.

Methods: The LASSI instrument was administered to 21 URMs who participated in the intervention over 2 years. We collected pre- and post-intervention data before and after the educational intervention.

Results: There was a significant improvement (p < 0.001) in all strategic learning and self-regulation parameters including attitude, concentration, information processing, motivation, selecting main ideas, self-testing, test strategies, and time management for the pre and post-assessments.

Conclusion: The results of this study indicate that self-regulated learning strategies in research education programs are important to help URM's chances of advancing along scientific and educational pathways.

KEYWORDS

NIH R25, LASSI, strategic learning, self-regulation, study strategies

1. Introduction

Increasing the representation of racial and ethnic minorities in the biomedical workforce is one of the top priorities for the National Institutes of Health (NIH). For example, the National Institute of Aging (NIA) is leading efforts aimed at increasing the number of underrepresented minority students (URMs) in the area of biomedical research. In line with the NIA's efforts and based on a systems analysis approach, the Research Education Program (REP) of the NIH R25 program was implemented in 2022 to provide opportunities for URMs among universities in South Carolina. The REP program was established to address the lack of well-trained minority Biomedical scientists in South Carolina and has been continuously funded by the NIH and NIA. The framework of the program is summarized in Figure 1. The program's implementation in 2022 expanded the program by initiating a partnership program between the University of South Carolina School of Medicine Greenville and seven other Universities in South Carolina. In addition, the program was expanded to include all the non-historically and historically black colleges and universities (HBCUs) in South Carolina, Anderson University, Benedict College, Claflin University, Clemson University, University of South Carolina Upstate, and North Greenville University. A significant component of the program is the provision of educational intervention activities, including learning strategies such as selecting main ideas, focusing or

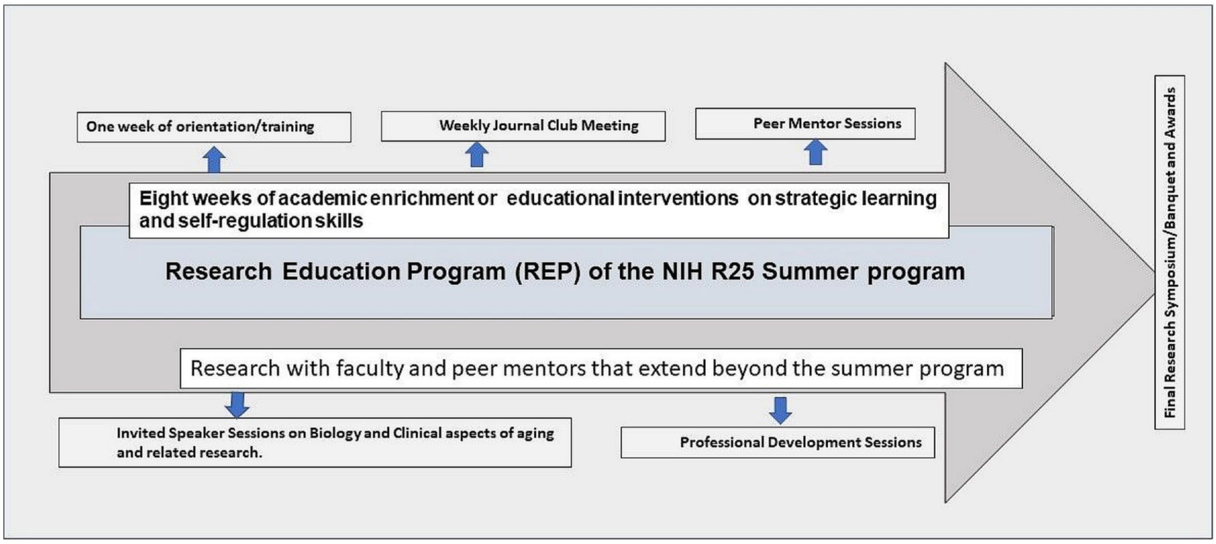

FIGURE 1
The framework of the research education program (REP) of the NIH R25 Summer program NIH R25 program is to increase post-baccalaureate opportunities in biomedical sciences. The goal is to encourage individuals from diverse backgrounds, including those from groups underrepresented in the biomedical and behavioral sciences, to pursue further studies or careers in research and foster a better understanding of biomedical, behavioral, and clinical research and its implications.

concentrating, time management skills, test-taking techniques, availability of resources, and thought processes related to identifying, acquiring, and constructing meaning for important new information. The lack of these self-regulated learning(SRL) strategies has been reported to contribute to the poor representation of URMs in STEM programs (Lukes et al., 2020). A key element of strategic learning is the will, skill, and self-regulatory ability of the individual URMs to explore different learning strategies including cognitive and behavioral strategies. According to Zimmerman (2008), SRL learning strategies are the actions and processes used to acquire information or skills that involve purpose including the instrumentality perceptions of learners. While all learners use regulatory processes to some degree, SRL learners are aware of the strategic relations between regulatory processes and they use these strategies to achieve their academic goals (Brenner, 2022). The systematic use of metacognitions, and motivational and behavioral strategies are the key features of SRLs (Ha et al., 2023). Because SRL includes the cognitive, metacognitive, behavioral, motivational, and emotional/affective aspects of learning (Panadero, 2017), it represents the strategy that allows a considerable number of variables such as self-efficacy and cognitive strategies that influence learning to be studied in a holistic approach. Therefore, providing education interventions that enhance strategic learning skills such as attitude, and motivational levels of the students, and self-regulation skills such as concentration, time management, self-testing, and using academic resources can help remove barriers and lift URM's interests, commitment, and ability to persist in STEM fields.

1.1. Learning and study strategies

Previous studies have documented the use of Learning and Study Strategies (LASS) in different learning contexts to achieve the intended learning outcomes in different study programs such as medical education (Khalil et al., 2018; Nabizadeh et al., 2019), effective learning strategies (Geller et al., 2018), and predictors of undergraduates' emotional engagement (Abulela et al., 2023). A popularly used model of LASS was proposed and revised by Weinstein and Palmer (1987). Based on the revised model, LASS is described as the behaviors and beliefs employed by students during learning and studying (Abulela et al., 2023). This model includes 10 strategies or sub-scales: information processing, selecting main ideas, test strategies, anxiety, attitude, motivation, concentration, self-testing, study aids, and time management (Abulela and Davenport, 2020). Therefore, LASS is a tool that can be used to collect noncognitive information to inform appropriate interventions evaluate learning strategies interventions, and predict students' success (Sisa et al., 2023). The LASS 10-scale items or strategies include three major components of strategic learning: skill, will, and self-regulation (Prevatt et al., 2006). While information processing, selecting main ideas, and test strategies are within the skill component of strategic learning, the will component of strategic learning includes attitude, motivation, and anxiety (Prevatt et al., 2006). The self-regulation component is concentration, time management, self-testing, and study aids (Weinstein and Palmer, 1987; Khalil et al., 2017). The LASS sub-scales associated with the skill variable of strategic learning include information processing, selecting main ideas, and test strategies (Khalil et al., 2017). In the current study, these scales assess URMs' learning strategies, skills, and thought processes associated with identification, acquiring, and constructing meaning for important new information, ideas, and procedures, and how they prepare for and demonstrate their new knowledge on tests or other evaluative procedures. The LASS sub-scales associated with the will variable of strategic learning include attitude, motivation, and anxiety. These scales examine URMs' receptivity to learning new information, their attitudes and interest in STEM programs in graduate school, their self-discipline, and their willingness to apply the effort necessary to complete academic requirements. The LASS sub-scales related to the self-regulation component of strategic learning include concentration; time management; self-testing and study aids. These sub-scales examine how students manage, or self-regulate and control, their learning process by using their time effectively, focusing their attention and maintaining their concentration over time, and using study supports such as review sessions, tutors, or available resources. Evaluating the different LASS sub-scales provides an appraisal of how receptive the URMs are to learning new information and an understanding of the importance of their college experience (Plener et al., 2017; Isik et al., 2018). It also indicates self-discipline, the desire to put extra effort into meeting their academic goals, and the degree to which they are concerned about their academic self-efficacy (Wilson et al., 2015). In addition, measuring self-regulation by focusing on concentration, time management, and self-testing provides insight into URM's level of self-control, how well they manage their time, their ability to stay focused, and how well they can successfully meet their academic learning demands (Abulela and Davenport, 2020). Therefore, all strategic learning and self-regulation components interact to create effective and efficient learning.

One of the key promises of the NIH R25 is to encourage URMs in STEM to pursue different careers in STEM research, which requires self-awareness of how they learn and study. Strategic learners have the skill, will, and self-regulation needed to be effective and efficient learners in varied educational environments. While various definitions have been used to describe self-regulated and strategic learning, we focus on the degree to which students are metacognitively, motivationally, and behaviorally active participants in their learning process (Zimmerman, 2001). This approach allows us to implement academic intervention activities that will enable URMs to take a proactive role in monitoring their learning, maintaining motivation, and engaging in behaviors that lead to success in their research, poster developments, poster presentations, conferences, and manuscript development and submission during the summer program.

1.2. Study rationale

One widely implemented approach to increase URMs' interest in STEM programs is providing a comprehensive summer bridge experience. Such programs aim to help students transition from college to graduate programs with an interest in the STEM fields. In addition, the program offers supplementary instruction for key introductory courses, financial aid, early involvement in undergraduate research, peer and faculty mentoring, and social activities. Although these systemic programs have recorded significant improvements (Beasley and Fischer, 2012; Richter et al., 2016; Kricorian et al., 2020), most did not include education intervention to provide strategic learning and self-regulated skills, including the right attitude, managing examination-related anxiety, motivation, concentration, information processing, test and studying strategies and using academic resources skills. Moreover, the body of research on URMs' poor representation in STEM programs also benefits from a broader investigation of how education interventions on strategic learning and self-regulation can be implemented to enhance engagement and higher academic skills among URMs in STEM programs (Allen et al., 2015). Therefore, it is important to provide academic skills to lift URM's interests, commitment, and ability to persist in STEM fields (Estrada et al., 2016). Given the lack of education interventions on strategic learning and self-regulation in many funded URMs summer programs (Estrada et al., 2016), the overall research goal of this study is to identify the academic support needs of URMs in a summer research education program for the planning and implementation of learner-specific interventions to improve their academic skills. Specifically, the study examines the differences in the 10 LASS subscale scores for the pre assessments of URMs in a summer research education program to identify gaps in learning and study strategy skills that require intervention to address areas that need improvement. The study was guided by a research question.

Are there statistically significant differences in the 10 LASS subscale scores between the pre- and post-assessment after the intervention?

> *Hypothesis*: There are statistically significant differences in the 10 LASS subscale scores between the pre- and post-assessment which indicates the effect of the intervention in improving the 10 LASS subscale scores.

In this study, we focused on implementing education interventions to improve strategic learning to guide URMs to an awareness of their strengths and areas of improvement in how they learn and study what they have learned. To examine the effect of educational interventions on strategic learning and self-regulation variables, we collected pre- and post-intervention data using the LASS before and after the educational intervention. Using LASS allows us to determine areas of improvement while simultaneously implementing educational interventions specific to those needs. Since URM's academic experiences affect their chances of advancing along STEM career pathways (Estrada et al., 2016; Murphrey et al., 2022), it is important to provide necessary academic skills and use educational resources to aid in developing effective learning and studying strategies. When URMs can access resources essential to their success, they will be able to employ them with limited interferences to increase their participation rate in STEM programs.

2. Methods

2.1. Participants

During the 2-year implementation of the LASS Learning and Study Strategies, there was a total of 26 students who took the LASS pre-assessment. Of the 26, only 21 of the students completed the post-assessment. Therefore, only the data of the 21 students who completed both assessments are included in the results. Four students completed the pre- and post-assessment during the summer of 2021, and the remaining 17 URMs completed the evaluations during the summer of 2022. The demographics of the 21 URMs are presented in Table 1. The table presents information on race, gender, class classification, and location of Universities for the recruitment of students. The age range was 18–24 years. For the recruitment process, applicants were required to have a grade point average of 3.0 or higher. In addition to personal identification information, the application requests a personal statement on career goals, interest(s) in STEM, and reasons for participating in the program. Applicants were also asked to provide

TABLE 1 Demographics of URMs ($n = 21$) that completed the LASSI assessment as a part of the NIH R25.

Parameters	Characteristics	Frequency	Percentage
Race			
	African American	16	76.19%
	Asian	1	4.76%
	Socioeconomically Disadvantaged	3	14.29%
	Hispanic	1	4.76%
Gender			
	Male	2	9.52%
	Female	19	90.48%
Classification			
Parameters	Sophomore	8	38.1%
	Junior	7	33.3%
	Senior	6	28.57%
Location of University			
	Clemson	3	14.29%
	Columbia	5	23.815%
	Greenville	5	23.815%
	Charleston	2	9.52%
	Greenwood	1	4.76%
	Orangeburg	2	9.52%
	Anderson	2	9.52%
	Spartanburg	1	4.76%

Information on race/ethnicity, gender, class classification, and universities that URMs were recruited for the program. The age range was between 18 and 24 years.

TABLE 2 The description of the LASS 10-subscale instrument used in this study for the three major components of strategic learning including skill, will, and self-regulation.

LASS sub-scale	Descriptions
Anxiety (ANX)	The extent in which worry is placed on school and academic performance.
Attitude (ATT)	Attitudes and interests in regard to doing well academically.
Concentration (CON)	The ability to direct and maintain attention on academic tasks.
Information Processing (INP)	The extent in which imagery, verbal explanation, organization skills, and reasoning skills are used to learn.
Motivation (MOT)	Diligence combined with self-discipline and the willingness to put effort in completing academic requirements.
Self-Testing (SFT)	The extent in which review and comprehension strategies are used to gain understanding.
Selecting Main Ideas (SMI)	The ability to distinguish between important information and less important or supporting details.
Time Management (TMT)	The extent in which time management principles are used in academic situations.
Test Strategies (TST)	The extent in which test preparation and test taking strategies are implemented.
Using Academic Resources (UAR)	The extent in which support and resources are used to learn and retain information.

Information processing, selecting main ideas, and test strategies are variables in the skill component of strategic learning. The will variable of strategic learning includes attitude, motivation, and anxiety, while the self-regulation variables are concentration, time management, self-testing, and academic resource use.

their GPA, college transcript, and two letters of recommendation. Applications were reviewed, selected candidates were interviewed, and finalists were determined and accepted to the program.

2.2. Instrument

The LASS, 3rd Edition (Weinstein et al., 2016), was used for the assessment in this study. LASS comprises 60 items that are depicted using a 10-scale system of evaluation used for the pre and post-assessment. In response to greater emphasis on student-initiated help-seeking, a new scale was created. The Using Academic Resources (UAR) Scale was created to replace the Study Aids Scale, and this fits with our current research in self-regulated learning and student learning assistance. Table 2 presents the LASS 10-subscales descriptions for the assessment of URMs' awareness and implementation of learning and study strategies. In addition, the table describes how LASS was used to collect noncognitive information to identify the characteristics of URMs, their support needs, and the planning and implementation of learner-specific interventions for URMs. As shown in Table 2, the LASS scale used in this study consists of items for each of the following subscales: (1) Anxiety, (2) Attitude, (3) Concentration, (4) Information Processing, (5) Motivation, (6) Selecting Main Ideas, (7) Self-Testing, (8) Test Strategies, (9) Time Management, (10) Using Academic Resources (Weinstein and Lane, 2016). Each statement has a response that includes a five-part Likert that consists of (a) Not at all typical of me, (b) not very typical of me, (c) somewhat typical of me, (d) fairly typical of me, very much typical of me (Weinstein and Lane, 2016). In their response, for the pre-and post-assessment, URMs are expected to rank the statements according to how each statement represents how they think, behave, or process information. Through the assessment, an understanding of how the learning and study strategies of an individual relate to their aptitude, determination, and self-regulation that make up strategic learning was determined. Understanding this relationship allowed us to implement educational interventions to change and increase positive knowledge and study strategies. Administration of LASS was implemented during the pre- and post-assessment of the inventory, which measures initial and final thoughts, behaviors, attitudes, beliefs, and growth over time. Scores for each subscale are produced automatically. All scores are computed and made available immediately once the assessment has been submitted online.

2.3. Procedure for the implementation of the intervention

An orientation to the importance of learning and study strategies was facilitated at the beginning of the NIH R25 summer programs. The conclusion of the orientation included online instructions on how to assess the inventory. URMs who participated in the NIH R25 program were required to take the LASSI pre-assessment within a week of the orientation during both years. LASS was administered online, including instructions to the students on accessing the assessment, the student's unique key to take in the evaluation, and a LASSI profile report once the review has been completed. The student profile provides a rationale for how to interpret their LASS scores for each subscale. Within a week after the administration of the LASS, a 30-min meeting was scheduled with all students. The meeting provided the opportunity to address the 10-LASS scores that are less than 50%. The one-on-one session was scheduled to discuss the results, followed by intervention to address areas that need improvement. The intervention focuses on how to plan and implement specific measures to improve learning and study strategy skills. Therefore, the education intervention's core was focused on identifying the weaknesses of each URM and then developing strategies unique to each URM's needs. For example, we focused on examination-taking strategies that can help prevent mistakes in reading and understanding examination questions, time management such as blocking distractions, creating a daily planner, organizing, prioritizing, and coordinating tasks. In addition, we provided strategies to improve concentration, focus on the classroom and manage examination-related anxiety or nervousness before taking the examination. We provided different studying strategies to prevent the memorization of concepts for better information processing. The education intervention also included identifying various school resources, including the library, counseling, and other resources to help the URMs, and using a variety of student-active teaching activities to increase motivation. These education interventions were tailored to each student's needs. An expert in academic enrichment and education intervention led the activities.

The URMs combined the knowledge and learned information from the orientation, assessment, and intervention with their weekly reflections and mentoring to implement a plan for remediation and improvement in areas of weaknesses following the intervention. Students had the opportunity to implement some of the improvements in the different activities of the program, including organizing, prioritizing, and coordinating tasks during their research activities. They also worked on identifying resources, creating a daily planner, reading and processing materials during journal club, and developing interactive activities during their research, poster development, poster presentations, conferences, and manuscript development. They also had the opportunity to use their Individual Development Plans (IDP) to identify educational activities that will allow them to improve further and practice their desired learning and study strategies. A LASS post-assessment was conducted during the last week of the summer program during both years. The post-assessment was also completed online.

2.4. Data analysis

Data from the LASS pre- and post-assessment was analyzed using Statistical Package for Social Sciences v 26.0 for Windows (SPSS, Chicago, IL). All data were tested for normality using the Shapiro–Wilk test to assess the data for homogeneity. The Shapiro–Wilk statistic associated with the data was $W = 0.890$, indicating that no significant deviations from normality were detected ($p = 0.74$) in our data which allows the use of parametric tests in our analysis. Descriptive statistics were calculated for each assessment. The results were presented as all variables' mean and standard error. Student's *t*-test paired sample analysis was used to compare differences in anxiety, attitude, concentration, information processing, motivation, selecting main ideas, self-testing, test strategies, and time management between pre and post-test following the intervention. This allows us to compare all the parameters for strategic learning and self-regulation before and after the intervention for each URM. Statistical significance was established at $p < 0.05$. In our power analysis, we used a single-group design to test whether the mean (μ) is different from 0 (H0: $\mu = 0$ versus H1: $\mu \neq 0$). The comparison was made using a two-sided, one-sample *Z*-test, with a Type I error rate (α) of 0.05. To detect a mean of $\mu 1 = 1$ (or $\delta 1 = \mu 1 - \mu 0 = 1$), with a current sample size of 21, and with a current *Z*-test statistic of 0, the conditional power was 0.99313. The predictive power of our sample size of 21 was 0.7612, and the futility index was 0.00687. The power was computed using PASS 2023, version 23.0.2. The effect size was calculated for all statistically significant values using Cohen's d value to quantify the effect of size between pre and post intervention. In interpreting the effect size, we used the commonly used interpretation in referring to effect sizes as small ($d = 0.2$), medium ($d = 0.5$), and large ($d = 0.8$) based on benchmarks suggested by Cohen (2013). Since each variable in the pre and post intervention has a different standard deviation, we also computed the glass's delta values.

3. Results

Table 3 presents the results for the 10 parameters for strategic learning and self-regulation, including, attitude, concentration, anxiety, information processing, motivation, selecting main ideas, self-testing, test strategies, and time management. There was a significant difference ($p < 0.001$) in all strategic learning and self-regulation parameters categories for the pre and post-assessments. As shown in the table, all parameters including, attitude, concentration, information processing, motivation, self-testing, selecting main ideas, anxiety, time management, test strategies, and using academic resources, significantly improved after the intervention. Moreover, URMs' performance following the intervention was above 50th percentile in all the 10 sub-scale scores, indicating that our intervention improves all the 10 sub-scale scores of LASS including reducing anxiety. Self-testing is a key component of an individual's ability to self-regulate, and showed the largest increase from the preassessment to the post-assessment, followed by using academic resources, information processing, anxiety, concentration, test strategies, selecting main ideas, motivation, and time management, while attitude recorded the lowest increase. The result indicates that using LASS and educational interventions helps to improve anxiety, attitude, concentration, information processing, self-testing, test strategies, and use of academic resources skills of URMs. The effect size reflect a large size ($d > 0.8$), for all LASS sub-class and was larger than Cohen's d value for large size effect ($d = 0.8$), revealing the stronger relationship between our pre and post assessments, indicating the practical significance of our results.

TABLE 3 The result for the parameters for strategic learning and self-regulation.

Variables	LASSI Pre-assessment Mean + SD (N = 21)	LASSI Post-assessment Mean + SD (N = 21)	T-Stat	P-value	Cohen's D values	Glass's delta values
ANX	41.43 ± 6.12	61.43 ± 5.30	4.91	<0.001**	3.494	3.267
ATT	62.57 ± 5.22	71.81 ± 4.55	4.74	<0.001**	1.887	1.770
CON	53.38 ± 5.45	73.38 ± 4.68	4.58	<0.001**	3.937	3.670
INP	53.58 ± 6.36	73.76 ± 4.58	4.63	<0.001**	3.641	3.173
MOT	62.86 ± 4.94	76.71 ± 3.88	3.21	<0.001**	3.118	2.804
SFT	45.71 ± 5.87	73.81 ± 5.92	3.15	<0.001**	4.767	4.787
SMI	47.62 ± 6.13	61.57 ± 6.13	3.31	<0.001**	2.276	2.275
TMT	58.1 ± 6.07	71.9 ± 4.59	3.35	<0.001**	2.565	2.734
TST	55.29 ± 6.67	71.67 ± 3.09	3.03	<0.001**	3.151	2.456
UAR	44.38 ± 7.35	64.57 ± 5.35	3.13	<0.001**	3.141	2.747

Mean ± SD, p-values were determined using a Student's t-test, and the effect size was calculated for all statistically significant values using Cohen's d value to quantify the effect of size between pre- and post-intervention test. Since each of the variables in the pre and post intervention has a different standard deviation, we also computed the glass's delta values using only the standard deviation of the pre-intervention variables. ANX, anxiety; ATT, attitude; CON, concentration; INP, information processing; MOT, motivation; SFT, self-testing; SMI, selecting main ideas; TMT, time management; TST, test strategies; UAR, using academic resources, *p < 0.05; **p < 0.01 (two-tailed); SD, deviation.

4. Discussion

For over a decade, the self-regulated and strategic learning framework has been used to examine study activities and academic success across various levels of education (Hayat et al., 2020; Xu et al., 2022a,b, 2023). Educational interventions have been reported to have a significant positive relationship between strategic learning, self-regulated strategies, student understanding, retention, and attitudes toward STEM programs (Sandi-Urena et al., 2011; Biwer et al., 2022; Edwards et al., 2023). However, few investigations have focused on these strategies among URMs and academic success in STEM programs. We focused on this critical line of inquiry by investigating the effect of an educational intervention to promote strategic learning and self-regulation skills among URMs in an NIH R25 summer program. We analyzed pre and post-intervention data for URMs, including anxiety, attitude, concentration, information processing, motivation, selecting main ideas, self-testing, test strategies, and time management. In our results, we observed a significant improvement in all strategic learning and self-regulation parameters in the post-assessment following the intervention. Our results indicate the importance of providing academic intervention to promote strategic learning, including the right attitude, motivation, and reduced anxiety to improve URM's development of effective learning and studying strategies. The goal of the education intervention component of the summer NIH R25 program was to improve academic skills by providing tools to guide URMs to an awareness of their strengths and areas of improvement in how they learn and study what they have learned. The intervention focused on the students' covert and overt thoughts, behaviors, attitudes, motivations, and beliefs to identify strategies to help them thrive in undergraduate and graduate environments and STEM programs. This allowed us to provide more effective learning and studying strategies using appropriate interventions that motivate and encourage URMs.

The improvement in strategic education and self-regulation parameters in the post-assessment following the intervention indicated that URMs benefited from the interventions administered to improve areas of weakness in their academic skills. After the intervention, we observed that attitude, concentration, information processing, self-testing, test strategies, and use of educational resources significantly improved. Strategic learning is grounded in the student's attitude, and motivational levels, and our interventions positively impact these skills among URMs (Hattie and Donoghue, 2016; Riestra et al., 2019; Hsu and Goldsmith, 2021). Self-regulation is identifiable in concentration, time management, self-testing, and using academic resources subscales (Jouhari et al., 2016; Evans, 2021). These parameters significantly increased after our education intervention. This result indicates that the intervention successfully helped URMs increase their self-control, manage their time, stay focused, and successfully meet their academic learning demands during their research, poster development, poster presentations, conferences, and manuscript development.

An essential component of our education intervention program is providing URMs the opportunity to monitor their learning, maintain motivation, reduce anxiety and engage in behaviors that lead to success in their research, poster developments, poster presentations, conferences, and manuscript development and publication. Therefore, our education intervention activities allowed URMs to take responsibility for their learning by participating in various self-regulated learning strategies, such as reviewing their learning strategies and peer knowledge to develop their metacognitive plan to solve problems in their research and other educational activities during the summer program.

Our intervention provides different learning strategies to prevent memorization of concepts for better processing of information during preparation for journal presentations. URMs interacted among themselves socially and during research using a variety of student-active learning activities to increase motivation. Our URMs identify different resources to implement their research by collecting, analyzing, and submitting scientific data to high-profile journals. Most of the submitted articles have been accepted and published. Our result indicates the importance of implementing a self-regulated learning framework to enhance academic success among ethnically diverse students and academic success in science.

4.1. Limitations

Despite the significance of our study, this study's result must be interpreted considering a few limitations. Twenty-one URMs participated in the program. The small sample size may affect the generalization of our findings. Due to the challenges of recruiting male URMs to the summer program, male and female participants were not equally represented in the sample collection. The educational intervention activities were implemented only during the summer period. Therefore, we could not follow up to track the long-term effect of our education intervention to promote learning strategies and self-regulation in their different institutions. There is a tendency for bias in the self-reported data from LASS. For future research, an increase in the number of participants per year and a combined analysis of the total number of participants over the five-year course of the NIH R25 program will be evaluated. An emphasis on recruiting more male URMs in the program will be implemented during the recruitment process. In addition, the educational intervention activities will be included within the short-term and long-term goals developed by the URMs so that there will be a more extended implementation and area for growth.

5. Conclusion

URMs are disproportionately represented in the biomedical sciences due to the lack of educational interventions in funded grants to improve their strategic learning and self-regulation skills. The implementation of educational interventions in a summer REP NIH R25 program resulted in a significant improvement in all strategic learning and self-regulation parameters in the post-assessment following the intervention.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

All experimental protocols were approved by the institutional review board of the University of South Carolina for ethics (approval number: Pro00113174). All methods were carried out in accordance with the Declaration of Helsinki for the conduct of scientific research.

Author contributions

NE: Formal analysis, Investigation, Writing – original draft, Writing – review & editing. MK: Formal analysis, Methodology, Writing – review & editing. RG: Conceptualization, Investigation, Writing – review & editing. TN: Conceptualization, Funding acquisition, Investigation, Methodology, Supervision, Writing – original draft.

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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.

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Recognizing and addressing environmental microaggressions, know-your-place aggression, peer mediocrity, and code-switching in STEMM

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Diversity, equity, and inclusion (DEI) initiatives are critical for fostering growth, innovation, and collaboration in science, technology, engineering, mathematics, and medicine (STEMM). This article focuses on four key topics that have impacted many Black individuals in STEMM: know-your-place aggression, environmental microaggressions, peer mediocrity, and code-switching. We provide a comprehensive background on these issues, discuss current statistics, and provide references that support their existence, as well as offer solutions to recognize and address these problems in the STEMM which can be expanded to all historically underrepresented individuals.

KEYWORDS

know-your-place aggression, environmental microaggressions, white/peer mediocrity, code-switching, diversity equity and inclusion

Introduction

There are over 19 million individuals[1] employed in science, technology, engineering, mathematics, and medicine (STEMM) fields, representing over 20% of the US workforce (Okrent and Burke, 2021). Despite being one of the fastest expanding job markets in the US, STEMM consistently lags behind other industries in terms of gender and racial diversity, with underrepresented minorities (URMs) facing various forms of systemic bias and discrimination (Fry et al., 2021). Additionally, URMs are underrepresented in STEMM leadership, accounting

1 https://www.pewresearch.org/science/2021/04/01/stem-jobs-see-uneven-progress-in-increasing-gender-racial-and-ethnic-diversity/

for only 28% of full-time faculty positions in STEMM, despite accounting for 32% of the U.S. population[2].

Broadening participation in STEMM and promoting an equitable distribution of management/leadership roles promises a stronger and more innovative STEMM workforce. However, several institutional and interpersonal barriers exist that make recruitment and retention of URMs in STEMM fields difficult. In this paper, we characterize a few important social barriers such as environmental microaggressions, know-your-place aggression, peer mediocrity, and code-switching. We then present evidence-based, actionable strategies that can be implemented at the institutional level to help break down these barriers for URMs in STEMM.

Environmental microaggressions

Microaggressions are typically discussed within the context of acts perpetuated by an individual against an individual (Marshall et al., 2021). On the other hand, environmental microaggressions (or systemic microaggressions) are defined as microaggressions that URMs experience as a result of their environment in the form of policies, laws, built environment, and more (Sue et al., 2007). Environmental microaggressions are subtle, often unintentional, acts of discrimination that can create a hostile environment for URMs in higher education, in the laboratory, and the workplace (Sue et al., 2007; McAndrews et al., 2017). These microaggressions can even be amplified among URM with different sexualities (Woodford et al., 2017). Though environmental microaggressions have no individual offenders, they communicate to people who experience them that they are unwelcome and must conform to the majority group to fit in. This racial exclusion can lead to anxiety, depression, and contribute to feelings of isolation (Peterson et al., 2020). A recent qualitative study by Mills (2020) among Black students, many of whom were pursuing STEMM majors, at a predominantly white institution demonstrated that most students experienced segregation, limited representation on campus, and tokenism among several others. Though a small study, these findings among Black students corroborate the lived experiences of URMs in general, who frequently endure the use of gendered language, absence of accessible facilities, tokenism, segregation, and biased hiring practices. Taken together, these serve to greatly disadvantage URM groups in STEMM (Mills, 2020). To date, there are no studies that have documented or characterized the experiences of trainees and faculty from URM groups in STEMM fields specifically. Further qualitative studies are needed so that institutions can characterize how environmental microaggressions are being experienced by URM groups in STEMM fields and address them.

Know-your-place aggression

Know-your-place aggression has been defined as comments and/or public judgments upon people from URM groups that seek to undermine their achievements and bring about aggression, rather than praise (Mitchell, 2018). This aggression, both literal and figurative, states "*know your place*," through action and words. Though know-your-place aggression has grown to affect other URM groups, it was originally borne out of historic marginalization, dehumanization, and control of Black people in the United States. A prominent example of know-your-place aggression in recent US history was the #blacklivesmatter protests in 2020 following the murder of George Floyd. Protests were organized in response to differential treatment, brutality, and often unjust incarceration of Black people by police forces. The successful organization of, often peaceful, protests by young people rallying under the movement was usually met with swift and aggressive force, many times at the hands of lay citizens: A symbolic act of know-your-place aggression.

In STEMM, know-your-place aggression is more subtle, and can be difficult to identify. However, when formally studied, it is more commonplace than originally thought. A 2018 study by the National Academy of Sciences revealed that women in STEMM are often targets of know-your-place aggression, with 63% reporting experiences of harassment and discrimination based on race or ethnicity (Johnson et al., 2018). In STEMM, we observe know-your-place aggression manifesting in lay-conversation such as when majority individuals say, "keep your head down until you build a good reputation," "do not speak in meetings," and/or "let me take the lead as they know me better." A major barrier to dismantling know-your-place aggression is the institutionalization of the concept. Black people and several other URM groups are often portrayed by the media as inferior to white races (e.g., promotion of white beauty standards/hair styles, must speak white standard English, etc.) (Liu et al., 2017). Furthermore, URM groups are often not represented in positions of power, further perpetuating know-your-place aggression. Within healthcare, this can manifest in especially sexist ways. While there is roughly an equal number of men and women medical graduates, patients associate men as doctors and prefer them if given a preference (Himmelstein and Sanchez, 2016). We observe women physicians frequently face the "you are a doctor? No, bring the real doctor in." The subtle promotion of white superiority and lack of representation of URMs in positions of power harm URMs in STEMM and can create a hostile environment. Addressing this takes activism to challenge racial stereotypes and normalize URM thought/culture. Re-evaluation of cultural stereotypes at an institutional level can help make the STEMM workplace a more inviting space for URMs.

Peer mediocrity

White mediocrity is the idea that society inherently values the voices of white individuals while simultaneously suppressing and greatly undervaluing the voices of URMs (Mitchell, 2018). This is a pervasive problem that is accompanied by a belief that "White is Right" and divergence from this standard signifies a problem, eerily harkening back to white superiority as mentioned earlier. While white mediocrity can occur between White individuals to minority individuals, we believe that this is a pervasive issue where peers, regardless of their identities, can suppress the voices of URMs while promoting themselves despite mediocrity. In STEMM, this frequently dissuades many URMs from accessing upper-level management positions. In fact, a recent report on STEMM workforce diversity by the National Science Foundation revealed that only 28% of full-time faculty positions in STEMM were held by underrepresented

2 https://ncses.nsf.gov/pubs/nsf23315/report

minorities, despite accounting for 32% of the U.S. population (See footnote 2). The American Association of Medical Colleges revealed that less than 4% of full-time faculty positions were filled by Black individuals in US allopathic medical schools.[3] Furthermore, among the healthcare workforce, only 5% of physicians identify as Black.[4] In the academic sphere, current data suggests that people of color are underrepresented in leadership positions, with only 13% of university department chairs in STEMM being people of color (Gibbs et al., 2016). White applicants are more likely to get hired and promoted due to falsely perceived superiority (Gibbs et al., 2016). While the total number of underrepresented racial/ethnic populations in Dean-level positions at medical schools have doubled since 1993, this number remains at only 12%.[5] Though a part of the lack of diversity in leadership occurs due to inadequate recruitment efforts, implicit bias in leadership can impair the upward mobility of underrepresented minorities (Neikirk et al., 2023). Beyond this, questioning URM qualifications when novel ideas are presented or selectively ignoring ideas unless presented by a White coworker can feed into know-your-place aggression and fuel the promotion of White individuals (Mitchell, 2018), resulting in a continuous loop of poor recruitment and lack of promotions of URMs at the institution-level.

Code switching

Code-switching refers to the practice of adjusting one's behavior, language, or appearance, either consciously or unconsciously, to fit in with a particular group or environment, such as a workplace. It is commonly employed by URMs in professional settings, such as the STEMM field, to navigate and cope with the challenges presented by environmental microaggressions, know-your-place aggression, and peer mediocrity. By adjusting behavior to conform to the dominant culture's norms and expectations, URMs seek to avoid negative biases, invalidate negative stereotypes, and combat discrimination (Gay, 2018). Code-switching can serve as both a survival strategy for URMs (Brown, 2021) and, in our experience, as a means to gain upward mobility in the workplace. However, it is crucial to acknowledge the physical and psychological toll that code-switching can have on URMs, and address how it can propagate systemic biases and inequities (Rolle et al., 2021). Continuously adapting and suppressing one's authentic behavior and personality can lead to increased burnout, stress, anxiety, and perpetuate a sense of alienation (Molinsky, 2007). Moreover, the pressure to code-switch may inadvertently reinforce the idea that the dominant culture's norms and values are superior, further marginalizing URM groups and preserving the vicious cycle of know-your-place aggression and white superiority.

3 see https://www.aamc.org/data-reports/workforce/data/figure-15-percentage-full-time-us-medical-school-faculty-race/ethnicity-2018#:~:text=Diversity%20in%20Medicine%3A%20Facts%20and%20Figures%202019,-Diversity%20in%20Medicine&text=The%20largest%20proportions%20of%20faculty,with%20another%20race%2Fethnicity, accessed July 31st 2023.

4 https://www.aamc.org/data-reports/workforce/data/figure-18-percentage-all-active-physicians-race/ethnicity-2018, accessed July 31st 2023.

5 see https://www.aamc.org/data-reports/faculty-institutions/data/us-medical-school-deans-trends-type-and-race-ethnicity, accessed July 31st 2023.

Often, professionalism may be used to exclude non-dominant cultural behaviors, however, this can communicate a sense of exclusion for individuals from URM groups. In the context of STEMM culture, this belief can become internalized by URM students, laboratory staff, and other professionals, suggesting that they must set aside their cultural identities when entering the laboratory space.

Solutions and recognition strategies

At present, URM minorities face remarkable systemic barriers when trying to enter and stay in STEMM fields. These obstacles are exacerbated by discrimination embedded at both institutional and personal levels such as environmental microaggressions, know-your-place aggression, peer mediocrity, and code-switching. To address these challenges, it is crucial for STEMM leadership in both workplace and academic settings to heed the concerns and opinions of URMs with cultural humility and show equal dedication to accommodating their needs. Cultural humility is an important element of the dialogue (Murray et al., 2022). It emphasizes actively striving to learn and respect the beliefs and values of URM individuals and relies heavily on being open to recognizing one's own cultural limitations and biases. All of this is required in order to help reduce power imbalances in intercultural interactions (Murray et al., 2022). With this in mind, we present a short list of proposed solutions to addressing each of these barriers in Table 1 and elaborate on them below.

Institutions can address environmental microaggressions by offering training on unconscious or implicit biases (Hagiwara et al., 2020) and microaggressions to all employees and ensuring that the work environment is accessible for individuals with disabilities (Crabtree et al., 2022). Perspectives of URM employees should be sought out with cultural humility regarding workplace/academic culture and policies (Fleischmann et al., 2009; Morrison and Grbic, 2015). Environmental microaggressions should also be considered when designing and naming symbols, buildings, or groups. Examples of environmental microaggressions include naming buildings exclusively after White donors or using Native symbols or icons as mascots or names (e.g., Washington Redskins) (Steinfeldt et al., 2018). Thus, surveys for open and anonymous feedback are imperative to allow individuals to have honest conversations about these microaggressions. These surveys must be accompanied by close follow-up from individuals who are willing and able to make

TABLE 1 Strategies for organizations to create an inclusive and supportive environment where underrepresented individuals feel comfortable being their authentic selves.

1. Foster a culture of openness and respect, by including more intentional intercultural dialogues (e.g., roundtable discussions, DEI lectures given by diverse faculty) where diverse perspectives and backgrounds are valued and celebrated.
2. Provide DEI training for all employees, emphasizing the importance of understanding and appreciating cultural differences.
3. Establish employee resource groups to create safe spaces where underrepresented employees can connect, share experiences, and support each other.
4. Incorporate diverse cultural events and celebrations into the workplace to promote understanding and appreciation of different cultures.

actionable changes. Rather than frequently highlighting Christian, White, and Male accomplishments, institutions can increase the representation of URMs by showcasing URM accomplishments and contributions, while emphasizing that, despite systematic barriers, URM individuals are managing to succeed.

Foster a culture of openness and respect

Leaders can actively promote intentional intercultural dialogues to foster a culture of openness and respect among faculty, staff, and students in institutions of higher learning. Diverse lived experiences and perspectives, especially at the leadership level (Ruiz et al., 2022), must be heard in order to promote an adoption of interventions that reduce barriers for URMs (Fleischmann et al., 2009; Morrison and Grbic, 2015; National Academies of Sciences, Engineering, and Medicine; Division of Behavioral and Social Sciences and Education; Board on Behavioral, Cognitive, and Sensory Sciences; Committee on Advancing Antiracism, Diversity, Equity, and Inclusion in STEM Organizations et al., 2023). These dialogues serve as platforms for meaningful discussions, learning, and celebrating diverse perspectives and backgrounds. They can be organized as roundtable discussions or DEI workshops led by diverse speakers, bringing together individuals from various cultural backgrounds to engage in open and honest conversations about relevant topics, experiences, and challenges to bring into their careers and classrooms (O'Leary et al., 2020). Encouraging participants to share their perspectives fosters empathy and raises awareness of the challenges faced by underrepresented individuals (National Academies of Sciences, Engineering, and Medicine; Division of Behavioral and Social Sciences and Education; Board on Behavioral, Cognitive, and Sensory Sciences; Committee on Advancing Antiracism, Diversity, Equity, and Inclusion in STEM Organizations et al., 2023). Such impactful and respectful dialogues contribute to a more inclusive and understanding community.

Provide DEI training for all employees

Institutions can effectively address environmental microaggressions by mandating training for all employees on unconscious bias, microaggressions, cultural humility, and cultural sensitivity (Murray et al., 2022). Generally, DEI training is widely supported by employees (Enders et al., 2021), with frameworks to adapt this training for a range of career fields (Dali et al., 2021; Wang et al., 2023). Simply put, DEI training aims to facilitate positive intergroup interaction, and create expectations for inclusive behavior from everyone in the organization to create a positive learning and working environment. Providing uniform training on implicit bias and cultural humility showcases the institution's dedication to diversity and inclusion (Neikirk et al., 2023), thereby enhancing its reputation among potential employees, students, and partners. To foster inclusivity, institutions should actively seek out perspectives from URM employees, approaching them with cultural humility. This includes considering workplace and academic culture and policies from their unique vantage point.

Establish employee resource groups

In the absence of or in tandem with DEI offices, employees can initiate changes through the formation of Employee Resource Groups (ERGs). These groups can foster community building, offering mentorship, leadership, and professional development opportunities independently of institutional support (Green, 2018). Past studies have shown that ERGs have tangible effects through reductions in employee turnover (Dutton, 2018) and elevated work engagement via cultivating inclusivity, feelings of connectedness, and a sense of belonging (Cenkci et al., 2019). In the context of STEMM, groups similar to ERGs can be formed including minority writing accountability groups (Spencer et al., 2022), which offer a safe space to write grants and manuscripts. Moreover, leadership should collaborate closely with ERGs and DEI offices to dispel the myth that DEI initiatives are solely for racial and ethnic minorities.

To address both peer mediocrity and code-switching, mentorship, sponsorship, and professional development programs should be established to uplift URM professionals and foster an inclusive and accountable culture. Celebrating the achievements of individuals ensures they are not overlooked in favor of lesser achievements by their well-represented counterparts. Additionally, institutions can allocate funds for hosting employee group activities, encouraging a sense of belonging and engagement within the workplace. Critically, ERGs should encompass both well-represented and underrepresented employees, planning activities, and recognizing talent in an inclusive manner that promotes allyship. Allyship plays a vital role in this solution, as it involves sponsoring URM staff for positions and opportunities (Uddin and De Los Reyes, 2021).

Incorporate diverse cultural events and celebrations

To foster understanding and appreciation of diverse cultures, institutions can arrange intercultural events and celebrations that highlight various traditions, holidays, and practices (Klak and Martin, 2003; Davis et al., 2023). These events serve to educate the community about different cultures and also provide opportunities for people to come together and celebrate diversity, thus improving student outcomes to appreciate cultural differences (Klak and Martin, 2003). Additionally, there are various organizations dedicated to promoting diversity, equity, and inclusion, such as DEI committees. These groups can host events, workshops, and discussions, amplifying the voices of underrepresented communities and contributing to a more inclusive environment (Davis et al., 2023). While these can be effective for faculty, past frameworks have also established comprehensive workshops for undergraduate students aimed at increasing their retention in graduate school (Marshall et al., 2022a,b,c,d; Barongan et al., 2023). While these workshops are typically aimed at URM students, they also offer a prime avenue to introduce content regarding diverse cultures at the undergraduate level in tandem with existing frameworks for education around mentorship and professional development. This early intervention, paired with regular events for faculty, may increase cultural humility in the long-term while improving the inclusion of individuals from diverse cultures (Marshall et al., 2023).

Additional strategies

To encourage open dialogue about microaggressions, conducting surveys for anonymous feedback becomes imperative. These surveys should be followed up with actionable change by individuals committed to making a difference. On the other hand, institutions can increase the representation of URMs by showcasing their achievements. Emphasizing URM individuals' success despite systemic barriers reinforces a more inclusive and supportive environment.

To combat know-your-place aggression, organizations should establish clear policies against discrimination and harassment, DEI and create a safe reporting mechanism for incidents. Additionally, fostering a culture of allyship, where leaders and peers advocate for the rights of persons of URM without being a member of the racial/ethnic group, can help create a supportive environment for URM professionals. At present, DEI offices across the country are being banned or having their funding slashed (Russell-Brown, 2022). This was galvanized, by the 2023 Supreme Court ruling of *Students for Fair Admissions Inc. v. President & Fellows of Harvard College* et al. (Heriot and Kirsanow, 2021) that prevents institutions of higher education to stop considering race in admissions, ostensibly presents a barrier to promoting DEI efforts in higher education and the workplace. This should, however, inspire a shift in responsibility to institutional leadership to assume key DEI roles. This requires holding supervisors and leadership accountable for their actions and implementing mechanisms where they can bring internal and external experts on DEI-related topics as speakers, share resources, and critically evaluate DEI efforts of leadership.

By combatting know-your-place aggressions, organizations can also help to confront peer mediocrity and code-switching. For example, they can create a culture where diversity of thought and background is valued, encouraging employees to bring their authentic selves to work, thus avoiding the necessity of code-switching. In addition to retention, organizations should be more rigorous about their commitment to equitable hiring and promotion practices, such as using diverse hiring panels and implementing a standardized evaluation process. It is important to streamline hiring practices as URM candidates are more likely to leave if they do not hear back within an acceptable time frame.[6]

Conclusion

Addressing environmental microaggressions, know-your-place aggression, peer mediocrity, and code-switching at the institutional and interpersonal level is crucial to promoting the recruitment and retention of URM in STEMM and promoting DEI. This requires difficult, open-table discussions, where all voices are heard, to lead to institutional change. Here we sought to bring light to these issues, as well as offered tools for implementing strategies to recognize and mitigate their effects on URMs. While many studies have discussed these issues in the context of Black individuals, in our experience that can often affect other URMs, with their prevalence and potential solutions needing further research. We hope that with more widespread recognition of these issues, organizations can create a more inclusive and supportive work environment that empowers all individuals in STEMM to succeed while retaining their unique identities in the process.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

KN: Writing – original draft, Writing – review & editing, Investigation. SS: Investigation, Writing – original draft, Writing – review & editing. VK: Writing – original draft, Writing – review & editing. AM: Writing – original draft, Writing – review & editing. ES: Writing – review & editing. MM: Writing – review & editing, Funding acquisition, Supervision, Writing – original draft. AH: Funding acquisition, Supervision, Writing – original draft, Writing – review & editing, Conceptualization.

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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.

6 see https://hbr.org/2022/07/its-time-to-streamline-the-hiring-process, Accessed August 1st 2023.

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Examining Black and Latinx STEM graduate students' laboratory rotation experiences and their impact on advisor selection

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Despite being fundamental to graduate education in the sciences, lab rotations are largely unexplored in the academic literature. The purpose of this study is to understand how the laboratory rotation process impacts Black and Latinx STEM graduate students' advisor selection process. Steeped in Critical Race Theory, this study employed a case study approach to explore the experiences of four Black and Latinx STEM graduate students enrolled at Predominantly White Institutions (PWIs). The article highlights that students who participated in lab rotations were able to gain more insights into their advisor's advising style and lab environment before making their decision. Participants felt more comfortable in labs where the advisors provided a hands-on advising style over a hands-off advising style. Ultimately, results indicated that Black and Latinx STEM graduate students benefited from participating in lab rotations prior to selecting their research advisors. This study's findings may help STEM departments, especially those within PWIs, understand the importance of consistently offering lab rotations for Black and Latinx STEM graduates prior to selecting their graduate advisor.

KEYWORDS

STEM, advisor, lab rotation, Black, Latinx, graduate students

Introduction

Historically, People of Color in the United States have faced institutional racism, including limited access to educational and professional opportunities (Gildersleeve et al., 2011). This long standing legacy of racism has significantly and negatively impacted People of Color's participation in Science, Technology, Engineering, and Mathematics (STEM) (Bullock, 2017; Martin, 2019; McGee, 2020). In 2020, Latinx, Black, and American Indian and Alaska Native students collectively earned 43% of associate's degrees, 26% of bachelor's degrees, 24% of master's degrees, and 16% of doctoral degrees in the five broad Science and Engineering fields of study (Burke et al., 2022). The underrepresentation of students of color in STEM graduate programs is a complex and multifaceted issue that arises from a combination of historical, social, economic, and systemic factors (National Academies of Sciences, Engineering, and Medicine, 2016).

One key component of increasing and retaining the number of students of color pursuing STEM graduate degrees is to better support them during their graduate experience. There are many factors that impact Black and Latinx STEM students graduate experience, such as the graduate student's research interest and alignment (Kim and Beier, 2020), the advisor-advisee relationship (Zhao et al., 2007; McCray and Joseph-Richard, 2020; Bryson and Kowalske, 2022; Wilkins-Yel et al., 2023), institutions and departments (Golde, 2005), academic performance and skills (Sinche et al., 2017; Grote et al., 2021), and collaborative research environment (Trujillo et al., 2015). Many Black and Latinx graduate students in STEM cite funding as a significant barrier to their retention and success (Ramirez, 2013). Specifically for STEM students, lab rotations can substantially impact the academic performance and overall experience of a graduate student (Rodriguez et al., 2022).

Some STEM graduate programs, particularly those specializing in the life sciences, chemical sciences, and biomedical sciences, offer lab rotations. In laboratory sciences, researchers have documented how the first year of doctoral programs is characterized by lab rotations—a process in which students navigate short-term placements in several research labs while finding an appropriate match for their training (Hirshfield, 2015; Maher et al., 2019, 2020). Lab rotations are designed to expose graduate students to a variety of research areas, methodologies, and research environments, allowing them to investigate diverse research interests and potential advisors prior to committing to a research lab and advisor (Lee, 2008; Maher et al., 2019). Lab rotations are often scheduled during the first year of a graduate program; however, this may vary based on the structure of the particular department (Lancaster et al., 2022). Lab rotations are a valuable component of many graduate STEM programs, and they offer several significant benefits to both students and academic institutions.

During each lab rotation, graduate students spend a period of time in the lab, gaining hands-on experience with ongoing research projects and connecting with prospective advisors and members of the research group. These lab rotation programs offer several advantages to both students and academic institutions. The following are the primary benefits of lab rotations: exploration of research interests (Wofford and Blaney, 2021), skill development (Cai et al., 2018), networking and collaboration (Maher et al., 2020), fostering independence (Holley, 2006), selecting the right graduate advisor (Blaney et al., 2022), early publication opportunities, and a shorter time to graduate completion.

In STEM graduate programs, lab rotations are beneficial because they provide students with a well-rounded view and ensure that students make educated choices regarding their research focus and mentoring before committing entirely to a certain research subject and advisor for their dissertation work (Hall, 2006). Graduate programs benefit from lab rotations because they provide students with a broad perspective and ensure that they make informed decisions about their research focus and mentor before committing to a specific research project and advisor for their dissertation work (Wofford and Blaney, 2021). This is a great opportunity for STEM programs to promote interdisciplinary research projects and encourage students and universities to both master disciplinary knowledge and think beyond departmental borders (Gardner et al., 2012).

In addition to developing relationships with their multiple potential advisors and research groups, lab rotations enable PhD students to expand their network within the academic community and foster future networking and collaboration (Maher et al., 2020). Many graduate students join graduate programs with a broad research interest, and lab rotations enable them to explore different research areas in order to narrow down to a particular research emphasis that matches their interests and skills (Maher et al., 2019; Du et al., 2021). In some programs such as laboratory-based disciplines, the research lab is shaped by the principal investigator (PI). One of the primary goals of lab rotations is selecting a PI and their lab, which is a critical step for graduate student success. In this process the role of the faculty members is not only advising students but also to be a model for their future professional experience. Rotating through different labs can allow students to get access to the lab to learn from PI, other graduate students and postdocs, peers and also to expand their network of colleagues, as well as to explore different types of research methods and working styles (Maher et al., 2020).

Relationships formed during rotations may lead to important collaboration, mentoring possibilities, and a larger professional network (Joy et al., 2015). According to extant research, one of the most essential aspects of graduate program effectiveness is communication between the advisor and graduate students (Ives and Rowley, 2005; Lee, 2008). Participating in lab rotations exposes students to potential advisors from diverse backgrounds, which is crucial, because having advisors who share similar experiences and backgrounds can help them find the right fit, overcome barriers, and develop academic success (Maher et al., 2019). This enables both the graduate student, the advisor, and graduate program to assess their compatibility in terms of the student's graduate work.

In some graduate programs, graduate students are required to undergo lab rotations regardless of their background. However, these initiatives can be particularly beneficial for students who identify as members of marginalized groups for several reasons. Lab rotations are great opportunities for students of color to increase socialization and be more engaged in various research labs. Lab rotations bring fresh perspectives from students from historically excluded groups who may not have had access to research opportunities during their undergraduate years due to socioeconomic or institutional barriers (Thiry and Laursen, 2011). Furthermore, engaging in lab rotations gives students from historically marginalized groups an opportunity to explore a range of research areas and demonstrate their skills and capabilities in different settings, which may lead to increased representation in disciplines where they have been historically underrepresented. Additionally, each rotation exposes graduate students to diverse cultures and management methods, which can potentially foster the growth of independence, conflict resolution, and collaboration skills (Mendoza-Denton et al., 2017).

Extensive research has been conducted on the effect of the first year of graduate school on women's participation and success in their chosen field (Golde, 1998; Sallee et al., 2011). Maher et al. (2019) found that the "student grapevine" shapes students' information networks in rotations, aligning with previous findings about the role of peer networks as a socialization mechanism (Gardner, 2007). Such a "grapevine" effect refers to the informal channels by which advanced students communicate advice to earlier-stage doctoral students. However, Maher et al. (2019) also recognized that these channels may open the "door to systemic inequity in information access" (p. 78). In fact, additional research has revealed that students' lab selection procedures vary based on their gender, race/ethnicity, and generational status (Maher et al., 2020), which may have longer-term implications for key experiences like lab mentorship (Burt, 2017). Other literature in chemistry has also explored how women and men differentially experience lab rotations, with women encountering greater competition and work–life balance conflicts than men (Hirshfield, 2015). Lab rotations foster a culture of intellectual curiosity, openness to new ideas, and the ability to collaborate across boundaries. These qualities are crucial for promoting innovation and creativity.

Despite being fundamental to graduate education in the sciences, lab rotations are largely unexplored in the academic literature. Lab rotations are not well understood, regardless of the fact that many doctorate schools consider them a "signature pedagogy" that distinguishes the first year of graduate study (Golde, 2007, page 350). This knowledge gap presents a compelling invitation for researchers and academics to delve into the multifaceted aspects of lab rotations, uncovering their impact on students' skill development, research productivity, and overall academic experience.

Theoretical framework

Ladson-Billings and Tate (1995) posited that Critical Race Theory (CRT) offers a unique lens to analyze the role of race and racism in perpetuating social disparities between dominant and marginalized racial groups. Through the application of CRT, extant research has been able to question, critique, and challenge the manner and methods in which racism, white supremacy, meritocracy, and racist ideologies have shaped and undermined institutional and systemic policies and practices (Harper et al., 2009). Black and Latinx graduate students in STEM, particularly at PWIs, have had to contend with a barrage of toxic and disenfranchising experiences that are likely contemporary manifestations of the historical legacies of racism and white supremacist practices (McGee, 2016; National Academies of Sciences, Engineering, and Medicine, 2023). By employing CRT as a frame in the current work, we explored how these white hegemonic systems in STEM, especially within lab rotations, affect Black and Latinx graduate students. Given that CRT acknowledges the shared historical conditions and collective experiences and standpoints of and for people who have been systematically oppressed (Crenshaw, 2019), it provided a frame to center those often relegated to the margins in STEM.

To further disrupt academic prose in higher education, CRT has several underpinnings that are central to the current study: (a) the concept that a shared group experience exists among marginalized people and that these experiences are unique and different instead of monolithic, (b) counter-stories and the voices of students of color are vital to understanding their differential experiences in higher education, (c) "rejection of a colorblind society," and (d) the necessity of adopting an epistemological lens for transforming higher education as part of a larger social justice agenda.

With these underpinnings in mind, the current study explored Black and Latinx STEM graduate students laboratory rotation experiences and how these experiences influenced the selection of their graduate advisor. The guiding research questions included:

1. How do lab rotations impact the advisor selection process for Black and Latinx STEM graduate students'
2. What are the benefits Black and Latinx STEM graduate students report after participating in Lab Rotations?
3. What are the challenges Black and Latinx STEM graduate students report after participating in lab rotations?

Materials and methods

The work presented here is part of a larger, longitudinal, mixed-methods study focused on identity integration among Black and Latinx STEM and Social, Behavior, and Economic Sciences (SBE) graduate students as they progressed through their doctoral programs (NSF Grant # REDACTED). A multi-site case study approach was utilized to capture a diverse range of experiences (Merriam, 2009). The research sites consisted of three PWIs located in the Midwest region of the United States. Semi-structured interviews, Likert-scale surveys, and social networking surveys were administered over 4 years to collect complete data sets on 30 Black and Latinx STEM or SBE graduate students' experiences, allowing for an in-depth look at students' persistence in their degree programs and transition into their professional communities. For the study described here, we explored the impact of lab rotations on four science graduate students, including how the rotation experience impacted the lab they joined, their perceived success in the program, and the relationship with their advisors with a particular focus on power dynamics and institutional racism. Using CRT, we were able to center our participants' voices to gain a better understanding of the lab rotation experience, their progress toward degree completion, and the relationship with their advisor over time.

Participants

Due to the broader study focusing on STEM and SBE graduate students, purposeful sampling was used to select only graduate students who participated in lab rotations for this paper. Consequently, the participants in the current study consisted of four students enrolled in science doctoral programs at one PWI in the Midwest. Participants self-identified as a Black/African American man, (n = 1), Hispanic/Latinx woman (n = 2), and Hispanic/Latinx man (n = 1). The two Hispanic/Latinx women originated from and completed their undergraduate degrees in Puerto Rico before coming to the continental United States for their graduate degrees. The Hispanic/Latinx man described himself as Mexican American.

Data collection procedures

Upon receiving approval from the PI/second author's Institutional Review Board, the PI/second author recruited doctoral students' from each institution with the assistance of the registrar's offices. The recruitment email was sent to all students who met the selection criteria: That is, they self-identified as not white or self-identified as white Hispanic, first- or second-year graduate student, and enrolled in a STEM or SBE doctoral program (as identified by the PI/second author utilizing the graduate catalog at each institution). Students were invited to complete a pre-survey after consenting to participate. The pre-survey included demographic information, identity scales adapted from Settles (2012) work on scientist identity and identity integration, and relational identity and social support scales adapted from Bouchey and Harter (2005) scales to identify who participants sought support from and what their connection was to each individual. Participants were compensated for their time with a $25 Amazon gift card after completing the survey. The demographic questions allowed participants to select any and all identities that applied to them and to further describe their identities through open-ended responses. Specific questions asked participants for their racial identity and another asked about whether they identified as Hispanic or Latino/a/x. This survey did not force a response nor limit the number of racial identities selected. In addition to allowing multiple selections, an open-response option was included and participants were prompted to provide their own identity names if they did not see theirs listed.

After the survey, participants were given the option to provide their contact information in an unlinked online form to indicate interest in the study's interview portion. All students who expressed interest in participating in the study were contacted, and interviews were scheduled. Over 3 years, each participant completed a total of six individual semi-structured interviews, two interviews per year, that were conducted by one of the five research team members. Participants were compensated with an Amazon gift card for each interview they participated in: $25 for each of the first two interviews, $50 each for the third and fourth interviews, and $100 each for the last two interviews. The increasing gift card value was designed to improve retention over the course of the study.

The semi-structured interviews were scheduled approximately every 6 months over a 3-year period from June 2015 to December 2017. Each interview included different questions, based on where participants were in their programs. For example, the first interview included questions related to how participants chose their advisor and research group. Later interviews included questions about their career plans. Some topics were consistent throughout all six interviews, including central project foci such as scientist identity, relationship with advisor, sense of belonging, and social support networks. Most interviews were conducted in-person, on-campus or near the university campuses at a location of the participants' choosing, by one of five trained researchers. Each researcher followed the same semi-structured interview protocol but probed and asked follow-up questions according to the responses given by the interviewee. Interviews were conducted by video conference if participants were unable to meet in person. The interview length varied depending on how much information was provided, ranging from 30 to 154 min.

Analytic procedures

All interviews were audio-recorded and professionally transcribed. Names and identifying information were anonymized, with pseudonyms replacing participant first names. The second author generated pseudonyms that aligned culturally with participants' given names; for example, a Latinx participant named Javier might have Juan as a pseudonym while a Latinx participant named Michael might have Matthew as a pseudonym. Transcripts were read several times and discussed by the research team prior to codes being created. Codes and definitions were then revised as more data was analyzed and discussed in an iterative process. Codes were generated from the data and were based on emergent themes in the participants' responses, regardless of the prompt or interviewer question (Saldaña, 2013; Miles et al., 2014). To ensure intercoder agreement amongst team members, the codes and definitions were created and revised several times to increase consistent usage and team members engaged in group coding exercises. Pairs of researchers coded all transcripts for their assigned codes, using Dedoose (Talanquer, 2014), a software program for collaboratively managing and coding qualitative data and regularly met to discuss findings.

The work presented here arises from the code "advisor-advisee relationship." As is common in the sciences, there are multiple terms that refer to the research advisor, and participants used the terms mentor, principal investigator (PI), boss, and advisor interchangeably. The first and second authors identified participants who were enrolled in graduate programs that utilized lab rotations as a means for assigning students to research labs. They each reviewed all six transcripts from each participant, noting how they described the lab rotation process for their program, how they selected an advisor and joined a research lab, what their initial impressions were of the lab environment and advisor, how their relationships with labmates and their advisor changed over the course of their graduate program, and their sense of success in their programs. Analysis specifically probed power dynamics between the students and faculty members in the program, specifically advisors they rotated with, their research advisor, the graduate program director, and other key personnel. As each students' experiences were unique in many ways, the first and second authors identified salient details from each participant's story to include in a brief case study and then looked at themes across participants. The first and second authors met regularly to discuss participants' stories and the emerging findings while collaboratively writing.

Findings

The findings are organized into four case studies, one for each participant, and three themes generated from the combined interview data. Each case study provides a detailed description of the participant, including their race, gender identity, program, structure of lab rotation, experience in their lab rotation, rationale for selecting their advisor, and who ultimately held power in the decision on which lab was joined. The themes will highlight the advisor selection process, benefits, and challenges that Black and Latinx STEM graduate students experienced. Theme 1, how the lab rotations impact the advisor-advisee selection process.

Theme 2, benefits from participating in a lab rotation, expectation, lab environments, and research interest exposure. Theme 2, challenges while participating in a lab rotation, limited guidance about navigating lab rotations and how power impacts their lab rotation experience.

Laura

Laura is a Puerto Rican woman in a doctoral program in the chemical sciences. She attended a 4-year public university in Puerto Rico for her undergraduate degree. Her father had a bachelor's degree and her mother completed high school. Her graduate program required her to participate in two lab rotations, each a semester long, prior to selecting her advisor. Since she also participated in a summer opportunity which required her to arrive on campus the summer prior to starting graduate school, she was able to participate in an additional lab rotation. Having the opportunity to have an additional rotation was beneficial because she selected the PI from her third lab rotation as her advisor. Prior to selecting her final rotation, Laura spoke to peers in her department to get some suggestions on labs to consider for her final rotation. When she approached the faculty member she wanted to complete her final rotation with, he encouraged her to speak with students in his lab first and attend a lab meeting. After speaking with members of his lab (one was also a Puerto Rican woman) and attending a lab meeting, Laura decided to rotate in his lab. Laura mentioned she enjoyed rotating in different labs. Participating in lab rotations allowed Laura to see how each advisor worked with their mentees. She performed well during each rotation and received good feedback from each faculty member. In fact, each faculty member invited her to join their lab.

Nicole

Nicole is a Puerto Rican woman in a life sciences doctoral program. She attended a 4-year public university in Puerto Rico for her undergraduate degree. Both her father and mother completed their bachelor's degrees. Her graduate program required her to participate in lab rotations her first year. She had the option to do two full terms with one lab each term or four half terms with one lab every 8 weeks. Nicole did two lab rotations, each for a full semester, and selected her first rotation as an advisor. Initially he told her yes, she could join his lab but after speaking with the second faculty member she rotated with, who Nicole described as "opinionated," he said she could not join his lab. Nicole expressed frustration with trying to find an advisor that was accepting students and had funding to support them. Therefore, she had to complete an additional lab rotation before selecting her advisor, which put her behind compared to other students in her cohort. Prior to selecting her third rotation, Nicole spoke to peers in her department to get some suggestions. Two peers gave positive references about the same advisor, so she approached him about rotating in his lab. She set up a meeting and learned about research projects in his lab, his mentoring approach, and his expectations. He encouraged her to talk to the people from his lab and to attend lab meetings so she was able to see the dynamics between him and the lab. Nicole decided to rotate with him and subsequently selected him as her advisor.

Nathan

Nathan is a Mexican American man in a chemical sciences doctoral program. He attended a 4-year public university for his undergraduate degree. His father completed high school and his mother completed some college. His graduate program required him to participate in three lab rotations, though he completed three rotations and he did not find the right lab for him. He enjoyed rotating in different labs because he was not sure about the research area he was interested in. After his first two rotations, Nathan found that he did not enjoy the research labs he tried and felt stuck because he was expected to join a lab. He did not feel comfortable in the first lab he tried and the second advisor he rotated with was overly hands-on. Nathan expressed the importance of finding a mentor that allowed him to be independent rather than micromanaging him. A postdoc from his first lab rotation told him he could look outside his program for an advisor, which he was not aware was an option, but it led him to his third rotation and the advisor he eventually decided to work with. Initially, he felt his third rotation was a good fit. Nathan's third rotation combined a research topic he enjoyed, a lab environment that felt comfortable, and an advisor who offered flexibility and independence. However, after 6 months in the third lab he said the advisor's mentoring style shifted to a micromanaging approach which led him to leaving the lab.

Seth

Seth is a Black man in a doctoral program in the chemical sciences. He attended a 4-year public university for his undergraduate degree. Both his father and mother completed their bachelor's degrees. His graduate program required him to participate in three lab rotations before selecting an advisor. Given that Seth had taken 2 years off after completing his baccalaureate degree, and before pursuing his graduate degree, these lab rotations allowed him to have a better understanding of his research interest. Additionally, the lab rotations provided him with a review of concepts in chemical sciences and he was able to gain hands-on experience during each rotation. Seth benefited greatly from lab rotations because he did not participate in research opportunities prior graduate school. Seth expressed the importance of identifying a mentor with a hands-off approach. He wanted to be able to be independent and not work with someone looking over his shoulder. Seth described three lab rotations with various labs as "fairly good" yet he expressed his frustration with the limited guidance he was provided with during the lab rotation experience. While participating in the lab rotations, Seth paid attention to the lab environment because it was an important factor to his decision. Especially, because he did not have a relationship with his cohort. Seth was able to select a lab with an advisor who demonstrated a hands-off approach, was conducting interesting research, and a lab environment that he preferred. It is important to note that his relationship with his lab changed as he progressed through his program for the worse.

Theme 1: advisor selection process

Lab rotations allow graduate students to join labs temporarily to get a feel for the advisor's advising style. All four participants discussed the importance of advising style and the type of mentoring relationship they wanted when considering advisors and research labs. Lab rotations allowed the participants to gain a better understanding of which advising style aligned with their personality before making a selection. The two women in this study discussed approachability and openness as an important feature of their relationships with their advisors. For example, when Laura, a Puerto Rican woman in chemical sciences, was asked about her relationship with her advisor she answered,

> The relationship with my advisor is a good one. He is an approachable person. If you want to go and talk with him, you don't need to schedule an appointment. I never have seen him angry. Well, if you are not working, then, he does get irritated, but if you had data that did not work or that is bad and he knows that you have been working, he supports you and tries to help you to see how we can resolve the problem. He is quite approachable. He's really a nice guy.

Having an advisor that was approachable and available was important to Laura. Similarly, when Nicole, a Puerto Rican woman in life sciences, was asked about her relationship with her advisor, she shared,

> It's a real open relationship in that he encourages me to let him know anything that's going on with me, either any issues or any ideas, or just things that I wanna do, anything I want to talk to him about, honestly. And he's very supportive. He tries to understand where I'm coming from. And right now, I think it's great. I can't really say anything bad about it.

During lab rotations, both Laura and Nicole were able to identify that their advisors had approachable, accessible mentoring styles. However, both men in this study desired a different approach. During their lab rotations they wanted to find an advisor that would have a more hands-off approach which would allow them to work independently. Although Nathan, a Mexican American in chemical sciences, was not impressed with his first two rotations, they did allow him to identify the mentoring style that best fits his personality. He shared,

> So, I guess, because I did the total of three rotations, and I think each rotation kind of guided me toward what I wanted in an advisor. So, the first rotation was a research area that I really liked. . .but I think the advisor and the advisor situation in terms of lab manager, dynamics and relationships with people who I would be working with were not a best fit for me. Although I did like the fact that my advisor was more of a hands off person, which allowed me to be independent, which I liked, but it was just the whole her personality was not very fitting . . .. because she has a lot of conflicts with other people in the lab, and as well as the lab manager doesn't get along with other people either, and the lab manager and the PI are best friends, so that doesn't help either.

Similarly, Seth, a Black man in chemical sciences, desired to have an advisor who was also hands-off. Seth described his relationship with his advisor, saying, "It's great. He's helpful, responds well, is nice but still allows you to figure stuff out on your own. He's not over your shoulder. He's there when you need him." Both Seth and Nathan desired a more hands-off approach while Laura and Nicole appreciated having an advisor that was accessible. Although the participants desired various advising approaches; lab rotations were critical in allowing participants to identify mentoring styles that worked for them and to figure out which advisor was the right fit.

Although lab rotations helped participants get a feel for their advisors advising style, the short term rotation did not allow them to develop a relationship and see how they would mesh with the advisor and research group over time. Short-term lab rotations meant everyone was on their "best behavior" and there was excitement and newness that had not yet worn off. For instance, although Laura initially spoke highly of her relationship with her advisor, as she progressed through her program she was very candid about the need to be independent as he would not solve her problems for her and was not someone she went to for help with experiments. She explained, "My advisor, he's a good person. Great person. Sweet person. However, he is not going to resolve anything for you. He's not going to solve your problems." When asked about mentoring interactions and who she went to for help with research, she always talked about the postdoc in the lab. Each interview, when she was asked about who she sought out when she needed help, she answered, "When I need help, in reality I do not go directly to the PI. I go to the postdoc. The PI is like the secondary person." Similarly, Nicole initially talked about how much she liked her advisor, but that feeling started to sour as time went on. During her first interview, she said,

> So, my relationship is limited right now because I've only been with him for a month, but it's a real open relationship in that he encourages me to let him know anything that's going on with me, either any issues or any ideas, or just things that I wanna do—anything I want to talk to him about, honestly. And he's very supportive. He tries to understand where I'm coming from. And right now, I think it's great. I can't really say anything bad about it. But again, I've only been with him a month, and so I've only met with him a handful of times, and I can't really say until I guess I've gone through the ups and downs of working on a thesis project with him.

Describing her relationship with her advisor later in her program she talked about several tense spots in their relationship and how her perspective of him has changed. She said,

> I've realized in these past months that it really has to be my initiative with everything, I can't rely on my PI. He's just not a person I can rely on when it comes to my project, he's too busy, he doesn't really pay much attention to what I'm doing. And, I think I'm kind of finally passed the frustration phase and just now ready to work and get at it.

Like Laura, Nicole also sought out help and advice primarily from a more experienced researcher who was not her advisor; in Nicole's case, she relied heavily on a physician scientist conducting research in her lab. Both women found alternate mentoring relationships when they realized their advisor was not providing the guidance they needed.

Nathan also struggled to identify a lab that was a good fit for him during his first two rotations but felt more comfortable during the third rotation. He shared, "That third rotation was similar in terms of research field and as well as a PI who had a mentoring style that I liked." Initially, he felt his third rotation had an interesting research topic and hands-off advising approach. However, 6 months into the lab his feelings began to change. He shared,

> Yeah and I'm still rotating from like do I really want to be here or not kind of thing? And then she kind of, I felt like she was being more hostile toward me and I didn't know why. And I was like, is it because I'm new or whatever or because she doesn't want me there anymore does she in her words she doesn't feel like I'm committed to being there. Because she says that I should be there 10 h a day every day and that in order to be serious.

Seth always spoke highly of his relationship with his advisor but as time passed he questioned the fairness of the lab. He shared,

> For instance, I've had to fight for my publications. I had to literally write it, throw it on your desk, not throw it, place it on your desk, I had to spearhead the whole issue whereas I've seen many people whose skin do not match mine be handed publications, for lack of a better word, meaning I almost felt no, I did feel like the word publications was a bad word like it shouldn't be my goal. It should be about learning, the breadth of knowledge, and all that and I felt bad saying, I want to publish.

So, not only did Seth's relationship with his advisor change, he highlighted how publication support and opportunities differed based on race. While he had to "fight" for publications, he noticed that others whose skin differed from his own were just "handed publications." It is in this way that the advisor-advisee experience can differ for minoritized students compared to their white counterparts.

All four participants in this study spoke about the importance of the advisor-advisee relationship. The lab rotation allowed them to learn more about the advising style they preferred and gave them an opportunity to experience their advisors' advising style for a short period of time. Unfortunately, the lab rotations were not long enough for them to get a complete understanding of the advisor prior to making a permanent decision. As with all relationships, they changed over time, and for these participants, the relationships became more challenging and tense.

Theme 2: benefits of lab rotations

The participants in this study benefited from participating in lab rotations. They were able to understand expectations, lab environment, and gain exposure to research topics. For example, having clear expectations from their advisor was also important to the participants in this study, which helped them navigate their graduate programs as first generation Black and Latinx college students. For instance, Nicole, a Puerto Rican woman in life sciences, mentioned that she was able to speak with her advisor about expectations during her rotation. She shared,

> We don't have [a mentoring plan] settled, but it's things we have talked about as to what I expect from him and what he expects from me. And so we haven't formally written down a mentoring plan, which we should for some of the scholarships I'm applying to. But yeah, we've kind of talked about those things early on.

For Nicole, having an understanding, although not formalized in writing, of what her lab rotation advisor expected of her was important to her.

Another important factor when selecting a lab was the environment. Seth, a Black man in chemical sciences, shared that the lab environment was an important factor when he selected his advisor. He said, "It was really the atmosphere of the lab and how I worked with the advisor. It was just a good fit." Similarly, Nathan, a Mexican American man in chemical sciences, appreciated being able to experience the lab dynamics during his lab rotations. He recalled not selecting a lab due to the relationship he witnessed between the advisor and others in the lab. He shared that witnessing the climate and culture of the lab contributed to him feeling uncomfortable with the mentoring, lab environment, and research topic, which, in turn, influenced his decision to not select that lab.

Additionally, lab rotations were beneficial because they exposed students to research topics while gaining hands-on experience. This was critical for Nathan and Seth because they both transitioned from an undergraduate degree to a doctoral program and were not exposed to the research experience that many other students had. Participating in the rotations allowed them to gain exposure to various research topics. Nathan, shared,

> I guess, if I had been at Michigan, as a master student, I would've known that, maybe, but coming from an undergrad to a PhD, I guess I was really uninformed as far as what I could do. Because, I guess it's sort of, like a limit in myself, as far as who I get to work for, and it ended up being not really exciting that I ended up doing. So I feel like I wasted half a semester, in a lab I didn't enjoy anyways. So that was a little bit frustrating to me.

Theme 3: challenges with rotations

Participants had little information about the structure of lab rotations and limited guidance on what to look for, what questions to ask, and how to assess fit while completing their rotations. They were also expected to make an important and permanent decision about who they would work with and what research they would work on for their graduate education within a short period of time, making this a high-stakes decision. Although all four participants were at the same university, they were in different STEM programs so their lab rotations were structured differently. The number of lab rotations, how long students were expected to stay in the lab (8 weeks or full semester), and who they could rotate with all varied. Some departments also allowed students to rotate with labs outside of their departments but did not communicate this information prior to starting the rotation. So, only those who had access to this information were aware that it was an option. Nathan, a Mexican American man in chemical sciences, shared,

> My program expects me to choose a lab that I'll stay in after [the] second laboratory rotation, and after going through both of those labs, I wasn't interested in either one. I wasn't engaged in the work at all, and I found it kind of boring. I didn't like the interpretations you obtained from the results, I didn't agree with the methodology, and it wasn't exciting to me. . .. Initially, I kind of felt like I didn't want to continue anymore because I didn't want to be miserable for 4 years doing something I didn't care about, or wanted to do, or work with a PI who was kind of frustrating, and not a very person-friendly, or somebody to work with. So I felt kind of frustrated, so I was considering just dropping out after the second year, and just accepting the master's degree. But then, when I figured out you can go outside (your program), and I found the lab that I'm really engaged in and I enjoy being in. And I actually like the research, too, and the PI is very nice, and she's a very student-oriented person.

Noteworthy in Nathan's experience is how inequitable access to programmatic information (i.e., being able to complete his lab rotation outside of the department), coupled with two underwhelming lab rotations, could influence Black and Latinx graduate students' intentions to persist in their STEM PhD programs. Similarly, Seth, a Black man in chemical sciences, described experiencing a lack of guidance from his department regarding lab rotations and the classes that would be a better fit while rotating with particular labs. Seth also talked about peers who seemed to know which lab they wanted to join before they started rotations, while he was using the rotations to identify which lab he wanted to join. He explained,

> Because it was just me throwing a dart at a dartboard randomly in picking a class. I didn't know what lab I wanted to join until the rotations were over, but most people seemed [to] know exactly what they wanted to do from day one, which defeats the purpose of the rotation system, I feel. So it would be nice to have higher students or faculty to be like, well, maybe take this course which is very general which could be very helpful no matter where you go or things like that.

Both Seth and Nathan expressed a desire for more guidance on the rotation process, indicating that they felt there was insider knowledge and a hidden curriculum that they did not have access to while other students did. In alignment with Seth's suggestions, equitable access to programmatic information could be improved upon by having faculty and/or more advanced students formally share their recommendations on the classes that would complement specific lab rotations.

Funding was also an important factor when selecting an advisor. Although three of the four participants had a fellowship, it only covered their tuition and stipend for 2 years. Students were expected to join a lab that would cover their educational expenses, find an assistantship, or apply for outside funding. This brought funding to the forefront of their mind while searching for an advisor and added pressure to finish their degrees in a timely manner. Nathan, a Mexican American man in chemical sciences, who completed three rotations and ultimately ended up switching into a fourth lab, expressed being behind on his program milestones when he shared, "I'm technically behind in my preliminary exam because I was supposed to take it in May." Both Nicole and Nathan prolonged the process of joining a lab, which ultimately added pressure to finishing their degrees quickly and secure funding. Nicole shared,

> It's just in the case of the lab, it's not more funding myself, it's more funding the project and so that's when I can't do anything about it until my PI gets grant so that's why the program thinks, feels that I should consider joining a different lab because it's not gonna be anything fixed and something that we don't know when we'll get funded. And so in the long run, it might just end up hurting me more.

Students also felt pressured to select a lab quickly rather than choosing to complete an extra rotation and getting behind. Three out of four graduate students in this study had an additional rotation beyond program requirements. Laura, a Puerto Rican woman in chemical sciences, participated in a fellowship that required her to start the summer before graduate school, allowing her an extra rotation without prolonging her graduate timeline. This was beneficial because she ended up selecting her third rotation. Nicole, a Puerto Rican woman in life sciences, had the option to do two full rotations or four half rotations as part of her program. She selected two full rotations and ended up completing an additional third rotation before she selected her advisor.

Discussion

Steeped in the CRT framework (Crenshaw, 2019), the current study explored Black and Latinx STEM graduate students' laboratory rotation experiences and how these experiences influenced the advisor selection process. CRT was used to foreground the participants' lived experiences and deepen our understanding of the advisor selection process as well as the benefits and challenges of lab rotations. Several CRT underpinnings were central to this study. These included: (a) the concept that a shared group experience exists among marginalized people and that these experiences are simultaneously unique and different instead of monolithic, (b) counter-stories and the voices of students of color are vital to understanding their differential experiences in higher education, (c) "rejection of a colorblind society," and (d) the necessity of adopting an epistemological lens that centers students of color in order to transform higher education. In the subsequent paragraphs, we situate our findings within these underpinnings, the CRT frame, and the existing literature.

Extant scholars have reported that the advisor-advisee relationship is critical to the success and retention of students of color in STEM graduate programs (Bryson et al., 2023;

Wilkins-Yel et al., 2023; Womack et al., 2023). By centering the voices of students of color, a vital component of CRT, this study offered key insights into how lab rotations supported Black and Latinx graduate students in gaining a better understanding of their preferred advising style. Participants in this study repeatedly discussed the importance of identifying an advisor who demonstrated characteristics that aligned with their personalities and work style. Some participants desired an advisor who demonstrated approachability and openness while others preferred advisors who were more hands-off. By participating in lab rotations, Black and Latinx graduate students were better able to identify advisors who matched their preferred advising style.

Lab rotations also served as an avenue to expose Black and Latinx graduate students, particularly those with limited access to prior research opportunities, to different research topics and lab environments. In alignment with past research (Hall, 2006), rotating in different labs provided students with scientific knowledge, exposure to various research topics, and hands-on experience. We also found that exposure to lab environments was a determining factor in selecting a research lab. Participants felt it was important to experience the dynamics of their lab before making a permanent decision. Being able to see how the advisor worked with other students and how students worked together was an important factor in their decision-making.

While lab rotations offered several significant benefits, the challenges they posed illuminated how systemic barriers and disenfranchising practices uniquely affected Black and Latinx STEM graduate students. Although lab rotations were likely designed to level the playing field, the present study found that inequitable access to programmatic information perpetuated disparities. For example, one participant noted that only certain students in his program were aware of the opportunity to complete a lab rotation outside of the department. Being unaware of this information, coupled with two unsatisfactory lab rotations, contributed to this student's decreased intentions to persist in his STEM PhD program. With decades of valiant efforts being made to broaden participation in STEM, practices that perpetuate inequities continue to thwart efforts to achieve a diverse STEM field. Mitigating occurrences whereby only some students, namely white students, have access to insider knowledge and the hidden curriculum will require the creation of systems and structures that streamline the dissemination of information to all students.

A unique aspect of this study is that it not only offered a one-time snapshot of students' experiences in their respective lab rotations, but because of its longitudinal design, was able to explore students' experiences *after* they completed their rotations and through the advisor selection process. This longitudinal qualitative design provided unique insights into how everyone was on their "best behavior," given the short duration of the lab rotations, and how the advisor-advisee relationships evolved over time. So, as students progressed through their programs, they often mentioned experiencing differing advising experiences than the ones that motivated their interest in choosing their respectives labs in the first place. For instance, an advisor who demonstrated a hands-off approach during rotations, switched to a more micro-managing approach as time progressed. Similarly, an advisor who was open and approachable became unsupportive and critical. Notable in one participant's experience was blatant acts of racism whereby he witnessed where students whose "skin [did] not match" his were "handed publications" while he had to "fight for [his] publications." Evidently, the additional layers of race and gender compound power imbalances between students and advisors, where unconscious bias and ingrained attitudes infiltrate every interaction, particularly for cross-race and cross-gender relationships.

Many Black and Latinx graduate students in STEM cite funding as a significant barrier to their retention and success (Griffin et al., 2020). The results of the current study uniquely shed light on how the availability of funding played a key role in the selection of lab rotations and, eventually, a graduate advisor. As a way to counteract the barriers related to funding, students from historically excluded groups are often recruited to graduate programs with fellowships aimed at diversifying the student body, particularly in STEM programs. Despite their attempts at promoting equity, these fellowships are typically for a shorter timeframe than the time that it takes students to complete their STEM degrees. Thus, students are left in a precarious position to find alternate sources of funding. In the current study, we found that Black and Latinx students were concerned with being able to identify a lab that would be able to support them financially when they did not have enough fellowship funding. This was a major concern because students were expected to join a lab that would cover their educational expenses, find an assistantship, or apply for outside funding. General research funding in the lab was a concern as well, since that could stall projects and halt the research they needed to complete their degrees. These findings align with extant research such as Maher et al. (2019) who reported that money underpinned students' rotation options and experiences.

Notably, the power differences between students and prospective advisors also negatively affected Black and Latinx graduate student participants. Power differences often leave students feeling powerless and uncomfortable and this was evident in the current study when students described feeling uncomfortable talking about funding with their PIs. By not having these conversations, participants described feeling like they wasted a lab rotation because their advisor did not have funding to support them. Feelings of powerlessness and discomfort can prohibit students from asking the necessary questions to determine if their potential advisor-advisee relationship would be a good fit for them. It is in this way that rigid hegemonic hierarchical practices in STEM perpetuate stark divides between faculty and students, which perpetuates feelings of powerlessness and prevents students from asking questions pertinent to their degree completion.

Taken together, the findings of the present study contribute to, and extend the literature on, the advisor-advisee relationship through a unique examination of Black and Latinx graduate students' experiences. This study highlights the value of lab rotations while simultaneously shedding light on the ways in which systemic barriers and inequitable practices can negatively affect students' success in STEM.

Limitations

While this study provides new insights into how Black and Latinx STEM graduate students experience lab rotations, it is important to discuss several limitations. We acknowledge that our sample size is small owing to the limited number of Black and Latinx STEM graduate students enrolled in graduate programs that utilize lab rotations, yet the findings represent common experiences with lab rotations and therefore are likely to be applicable to Black and Latinx graduate students enrolled in PWI institutions across the U.S. Although this study captured lab experiences for Black and Latinx graduate students, the study did not capture the full experience for students. Some students began the study after their first lab rotation, thus the initial interaction with their lab rotation was not discussed in as much detail. A better understanding of the lab rotations could be achieved with a study starting at the beginning of their lab rotation. Additionally, if students were interviewed at the beginning and end of each rotation we would be able to capture a more in depth understanding of their experience. This research was geographically restricted and only conducted in the Midwest, at one institution, which limits the diversity of experiences represented given the overrepresentation of white students at the institutions and in the surrounding communities. While this likely highlights racial disparities and challenges that might not be as pronounced in more diverse locations, it also provides data from locations that have the most need for improvement. The use of robust qualitative data and diverse participant voices, however, lends an authenticity and relatability to the work presented here that is likely useful to both faculty and students within STEM graduate programs across the U.S.

Conclusion

Black and Latinx STEM graduate students benefit from lab rotations because they are able to make a more informed decision regarding their advisor-advisee relationship and what their preferred advising style is, which can help with their overall success in their program. Lab rotations can provide students with a broad perspective and learn about different research areas, lab cultures, and advisors before committing to a specific research project and advisor for their dissertation work. The process is not without its challenges, as our findings illustrate. Graduate students are inherently in a powerless position, as their advisor can dictate their progress toward completing their degree. This is also evident during lab rotations and the advisor selection process, as students try to impress advisors, navigate funding, and find a mentoring relationship that works for them, all with limited guidance. The lack of knowledge regarding the lab rotation and advisor selection process led three out of four participants to participate in an additional rotation before finding a lab to join, delaying their progress in the program.

The keys to improving the lab rotation experience for students include providing a clear and consistent structure for students and faculty, explicitly guiding students through the selection process, and training faculty advisors on implicit bias, mentoring relationships, and communication. The findings from this study highlight the importance of students being aware of and understanding the often unspoken expectations and rules of lab rotations and selecting an advisor. It is critical to provide students with guidance on what to consider before selecting a lab to rotate in, as well as information about who they can rotate with, who is accepting students into their labs, what type of research is happening in the lab, and what funding is available in the lab. While difficult, it is important to do away with rigid hierarchical power differences to ensure that students are comfortable engaging in potentially uncomfortable questions and having hard conversations before committing to a research lab. These suggestions highlight the importance of providing knowledge and access to students, dismantling academic hierarchy, and allowing some of the power to shift from professors toward students.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the Western Michigan University Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

TB: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review and editing. MK: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Software, Validation, Writing – original draft, Writing – review and editing. KW-Y: Conceptualization, Data curation, Formal analysis, Resources, Validation, Writing – review and editing. SA: Formal analysis, Methodology, Resources, Software, Writing – original draft, Writing – review and 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.

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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.

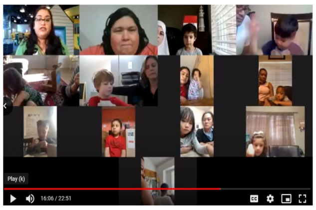
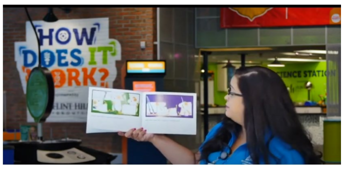
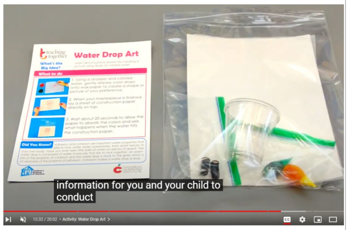
Reminders and incentives

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.

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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.

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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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Mixed reviews on diversity initiatives: toward an institutional change model for Black faculty in engineering and computing

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Introduction: Universities across the United States have implemented initiatives to enhance diversity in science, technology, engineering, and mathematics (STEM) fields, focusing on improving outcomes for racially minoritized students. While many diversity initiatives target undergraduate programs, there is a gap in support for STEM graduate students. Recognizing the persistent underrepresentation of racially diverse populations in STEM, the Biden-Harris Administration launched the "Raise the Bar: STEM Excellence for All Students" initiative, aiming to bolster STEM education nationwide. Foundations like the Sloan Foundation have developed pathways programs for STEM students, extending support into graduate school and the professoriate. The success of diversity initiatives often hinges on the participation and endorsement of underrepresented STEM faculty.

Methods: This study investigates the perspectives of twenty-nine Black engineering and computing faculty regarding diversity initiatives within their respective departments. Grounded theory methodology guided the qualitative analysis, enabling a deeper understanding of the racialized diversity management framework. Drawing on institutional racism perspectives, the study aimed to develop a theoretical framework elucidating institutional engagement with and implementation of diversity initiatives in engineering education.

Results: The participants' perspectives on diversity initiatives reflected features of organizational change. Three types of organizational environments emerged: 1) stagnant, characterized by aspirational commitments to diversity; 2) moderate, where underrepresented populations are recruited but expected to assimilate into the dominant culture; and 3) transformational, representing organizations taking significant steps towards creating equitable environments. The narratives of the study participants shed light on the varying effectiveness of efforts to increase the representation of successful Black students and faculty in engineering academia.

Discussion: The findings underscore the importance of understanding organizational contexts and dynamics in shaping the outcomes of diversity initiatives. By delineating the racialized diversity management framework, this study provides insights into the complexities of institutional engagement with diversity in engineering education. Addressing the challenges identified, particularly in environments characterized as stagnant or moderate, is crucial for advancing equity and inclusion in STEM fields. Effective diversity initiatives must go beyond recruitment efforts to create transformative, equitable environments conducive to the success of racially minoritized students and faculty in engineering academia.

KEYWORDS

higher education, diversity, faculty, STEM, institutional change, faculty of color, engineering

Introduction

Nearly four thousand higher education institutions exist in the United States, offering a broad range of degrees and programs of study (National Center for Education Statistics, 2021). Within this higher education landscape, there are efforts to counter the decline of the entry of domestic students into science, technology, engineering, and mathematics (STEM) fields (Bullock, 2017; Slovacek et al., 2019; True-Funk et al., 2021) and implement diversity initiatives aimed at increasing the representation of Black, Latinx, Indigenous, and female students and faculty (Ahmed, 2012; McGee, 2016, 2021; True-Funk et al., 2021). Diversity initiatives in STEM majors and academic careers are typically a combination of programs, policies, and activities that support the recruitment and retention of racially underrepresented students and faculty (Rincon and George-Jackson, 2016; Miriti, 2020; Miles et al., 2022). However, much of this programming ends at the undergraduate degree, offering few programs for STEM graduate students (Rincon and George-Jackson, 2016; White et al., 2023). The gross underrepresentation of racially diverse populations has gained the attention of the federal government for decades. Recently the Biden-Harris Administration launched an initiative called "Raise the Bar: STEM Excellence for All Students" to strengthen STEM education nationwide and to ensure career readiness and global competitiveness for students at all levels regardless of background. The Sloan Foundation has developed pathways programming for STEM students through graduate school and into the professoriate. Many diversity initiatives rely for their success on the participation, endorsement, and implementation of underrepresented STEM faculty (White et al., 2023).

Some describe these STEM diversity initiatives as having their basis in capitalist self-interest (Ridgeway, 2019; Rodriguez and Morrison, 2019), which values competition and individual financial and technological gain. Nonetheless, the recruitment and retention of underrepresented populations into STEM higher education and industry alike raise questions about the systems of inequity acting as barriers to access and opportunity (Briggs, 2017). Research shows that embracing cultural and racial differences create diversity in thought which in turn correlates with innovation and creativity in STEM (Whittaker and Montgomery, 2014; Slovacek et al., 2019), which leads to more competitive products. However, ambiguity around how to best implement and evaluate diversity initiatives in higher education, makes it unclear what types of changes prove effective for institutions as well as how to best support the target populations they attempt to serve (Whittaker and Montgomery, 2014).

In engineering and computing, women and people of color are poorly represented in academia, with alarmingly low statistics for Black faculty representation (Robinson et al., 2016). According to data from Yoder (2012), 48% of engineering schools have no Black tenured or tenure-track faculty members, 19% have only one, and 12% have two. The remaining 21% have more than two Black tenured or tenure-track faculty members. The representation of Black faculty is even lower in top-ranked engineering schools. A 2017 study found that only 2% of engineering faculty at the top 50 engineering schools in the United States were Black (Robinson et al., 2016). The overall percentage of Black engineering faculty is 2.6%, and these numbers are stagnant when compared to other racial and ethnic groups (American Society for Engineering Education, 2022). The percentage of Black engineering faculty in the United States is significantly lower than the proportion of Black students in engineering programs, which is about 14%. Among the 774 Black engineering faculty, 293 are full professors, 228 are associate professors, and 253 are assistant professors, making up 2.1, 2.9, and 3.4%, respectively, of all engineering faculty nationwide (American Society for Engineering Education, 2022). The few faculty that are Black in US postsecondary institutions work in settings that are White-normed and exclusionary (Whittaker and Montgomery, 2014; McGee et al., 2022).

While most institutions lack Black faculty, there are some notable exceptions. For instance, Howard University, a private historically Black institution, operates with distinct policies compared to state-supported schools (Ortiz et al., 2019). Historically, Howard University has been successful in addressing the hiring of Black faculty, while state-supported institutions may have additional requirements and procedures for faculty recruitment. Notably, Howard University, being a historically Black university, boasts a significantly higher percentage of Black faculty in the field of engineering. In 2017, 40% of the engineering faculty at Howard University were Black. Studies show that Black faculty from various disciplines report the following challenges: 1) higher levels of occupational stress due to hostile working environments, 2) higher levels of discrimination, 3) that their work is devalued or not recognized, and 4) that they receive less financial compensation in comparison to their peers (Thompson and Dey, 1998; Zambrana et al., 2017; McGee et al., 2021; Louis, 2023).

These conditions are not just experienced by Black faculty, but Black students and other Black STEM professionals experience parallel phenomena. Former STEM students and professionals speak with great agony about the various ways they were pushed out or almost pushed out of STEM (McGee and Bentley, 2017; McGee, 2021; White et al., 2023). Most reference one or more of the following reasons for leaving their chosen fields:

Demeaning racial stereotypes from STEM faculty that place them at or near the bottom of a racialized STEM hierarchy. At the top are international Asians, then international Europeans, next White people and other international students, and at the bottom are Latinx, Black, and Indigenous students, often in that order (McGee, 2021).

Too few students and faculty of color in the STEM disciplines (Palmer et al., 2011; Burt, 2020).

Difficulty with envisioning themselves as part of the STEM workforce given the racially charged academic environments they experience (Palmer et al., 2011; Whittaker and Montgomery, 2014; Burt, 2020; Miles et al., 2020; True-Funk et al., 2021).

Unwelcoming institutional climates and the "revolving door" syndrome of faculty of color (who often serve as role models to students of color); these climates influence Black faculty to leave their institutions, and sometimes academia altogether, because a doctoral degree in STEM—even from a prestigious university—does not save professors of color from stereotypes (Palmer et al., 2011; Eastman et al., 2019; McGee, 2020).

Despite this climate, some Black professors are successful as tenure-track faculty. Their view of diversity initiatives, and their need to target the challenges cited above, is critical to the implementation and outcomes of diversity programming (McGee, 2020). Black STEM individuals in higher education spaces should be aware that they are navigating racist environments that may have diversity and inclusion initiatives that are merely performative. Performative gestures cause STEM departments and institutions to usurp their equity efforts (White et al., 2023).

The outcome of this study was the development of names and descriptions characterizing the environments experienced by Black faculty in STEM departments and institutions when they engaged in reflection. The act of "naming" and labeling of environments can provide entry points into having productive conversations and responses to institutional diversity (Miles et al., 2020). Examining the narratives of Black faculty and their recollections of diversity initiatives within STEM departments and institutions offers valuable insights into implementing changes with a specific focus on the unique needs of Black faculty, who are among the most minoritized. The central question guiding this research study was: How do Black engineering and computing faculty perceive and experience diversity-initiatives in engineering education? To address this question, we employed the diversity management framework (Gilbert et al., 1999; Cao et al., 2003, 2004; Cao and McHugh, 2005), a model derived from business organizational theory, to delineate the features within an organization that contribute to creating and sustaining a diverse environment. Diversity management, defined as an organizational process fostering diversity and inclusion in the workplace, proved instrumental in comprehending how faculty experienced change by identifying and labeling environments. However, it fell short of capturing the historical and contemporary context in which Black faculty, who routinely encounter racism through the implementation of policies and practices, operate. To address this gap, we integrated the diversity management framework with the concept of institutional racism (Bonilla-Silva, 2006, 2020; McGee, 2020). This combination enhances our understanding of institutional engagement with and the implementation of diversity initiatives from the perspective of Black engineering faculty. Institutional racism refers to the policies and practices existing throughout an entire society or organization that result in and support a continued unfair advantage for some people and unfair or harmful treatment of others based on race.

Background literature

Brief overview: contextual evolution of diversity initiatives in higher education

Affirmative action, also known as Title VII of the 1964 Civil Rights Act, was introduced as federal legislation to expand employment opportunities for women and marginalized populations underrepresented in the workplace (Hall, 2016). In this context, affirmative action is defined as organizational efforts to ensure that individuals are not discriminated against based on their gender or ethnic group (Crosby et al., 2006). However, during its inception, there was a lack of a clear plan for organizations to implement and sustain equitable hiring practices, necessitating organizations to take on the responsibility of fostering inclusivity (Kelly and Dobbin, 1998; Gilbert et al., 1999; Crenshaw, 2006). In the realm of higher education, affirmative action plans may include goals set by institutions to enhance diversity in their student body, faculty, and administration (Sánchez, 2015).

In response to these limitations, organizations introduced diversity initiatives aimed at fostering more equitable working environments. These initiatives encompass a range of strategies, such as affirmative action policies, mentorship programs, diversity training, and inclusive hiring practices, all designed to promote a more diverse and inclusive workplace. According to Gilbert et al. (1999), initiatives require "major, systemic, planned change efforts," which typically differ from affirmative action plans (p. 64). The creation of positions and offices within organizations to monitor and report on institutional compliance was an early step toward institutional change (Kelly and Dobbin, 1998).

In the late 1980s and early 1990s, businesses implemented a variety of diversity initiatives, including the use of diversity training, often in response to or to resolve civil rights lawsuits. These initiatives aimed at cultivating more inclusive workplaces, fostering understanding among employees, and addressing the broader goals of diversity and equality within the organizational context. Many other professions followed suit to avoid legal complications (Vaughn, 2002). Today, many of these efforts have evolved into climate surveys, bias training, and diversity committees, but too often these efforts are spearheaded by people who do not hold effective decision-making power (Wilson, 2013). While affirmative action focused initially on human resource functions and college admission practices, over the years, assumptions about the value of diversity training have changed (McCuiston et al., 2004). Iverson (2007, 2012) examinations of various institutional diversity plans exposed a discrepancy. While institutions professed a commitment to diversity, closer scrutiny revealed that their dialog, policies, and practices often perpetuated inequitable and oppressive actions, contrary to their proclaimed objectives. In essence, what they purported to be doing in theory did not align with the reality of their actions.

Since its inception, Affirmative Action has faced scrutiny, and more recently, many states have witnessed Supreme Court decisions challenging higher education institutions' use of affirmative action, potentially disadvantaging students and faculty of color. Some states, such as Arizona, California, Florida, Michigan, Nebraska, New Hampshire, Oklahoma, and Washington, have banned public universities from considering the race of applicants (Santoro, 2022). Critics of affirmative action in university admissions argue that it excludes White women and Asian American students, creating the perception that Black, Latinx, and Indigenous students are "taking" their spots (Nelson, 2016; Long and Bateman, 2020). State ballot initiatives like California's Proposition 209 and Washington's initiative I-200 banned or limited the use of race as a consideration in hiring for public employment, including in public education (Coleman et al., 2012). However, research indicates that certain top-tier universities, which admit only a small percentage of applicants, struggle to achieve diversity in student backgrounds in the absence of affirmative action (Santoro, 2022). Contrary to the notion that White women are negatively impacted, studies reveal that White women are more likely to benefit from affirmative action than any other minoritized group (Wise, 1998; Nelson, 2016). This trend holds true across various sectors, including business, higher education, and the public sector, where White women emerge as the primary beneficiaries of affirmative action (Hall, 2016). The discontinuation of affirmative action as a factor in university admissions is anticipated to have lasting repercussions on the participation rates of Black, Latinx, and Indigenous students in certain professions.

Theoretical framework: diversity management through the lens of institutional racism

For this study, we propose to leverage the integration of two frameworks, namely the diversity management framework and the concept of institutional racism, to offer a more comprehensive understanding of the challenges faced by Black engineering faculty in the context of diversity initiatives. The diversity management framework, centered on fostering diversity and inclusion in the workplace, has proven invaluable in recognizing and categorizing environments where faculty experience change. However, it falls short in capturing the historical and contemporary context within which Black faculty navigate the impact of policies and practices rooted in racism. To bridge this gap, we have merged the diversity management framework with the concept of institutional racism (Bonilla-Silva, 2006, 2020; McGee, 2020).

Institutional racism encompasses policies and practices that permeate an entire society or organization, perpetuating unfair advantages for some and unjust or harmful treatment of others based on race (McGee, 2020). While the diversity management framework, originating from business management, aids in analyzing the perspectives of Black engineering and computing faculty on diversity initiatives in higher education, it lacks a critical race analysis that exposes how systemic racism acts as a structural impediment to diversity management initiatives.

Even with the infusion of critical perspectives (see Cao and McHugh, 2005), the framework did not fully account for racism or provide a racialized understanding of the experiences of Black Americans in the United States. Although the diversity management framework effectively labels environments based on characteristics, it is crucial to align our understanding of racism with criticality. As critical scholars of race, specifically focusing on Black individuals in STEM environments experiences, we propose augmenting the diversity framework with the critical perspective of institutional racism. This type of racism is deeply embedded in the rules and regulations of a society or organization, and its integration illuminates the socio-historic context of the systemic inequity prevalent in engineering education and practice (Eastman et al., 2019).

The diversity management framework

An organization is a social construct designed for a specific purpose, characterized by managerial elements that define the relationships and roles inherent to its structure. In this context, it's pertinent to acknowledge that departments within higher education institutions can be regarded as distinct organizations (Cao et al., 2003). The diversity management framework is a conceptual tool used to understand and analyze efforts to manage diversity within organizations, particularly in the context of workplace environments (Gilbert et al., 1999). It provides a structured approach to examining how organizations address issues related to diversity and inclusion. While specific details may vary, the framework typically involves categorizing organizations based on their approaches to diversity management (Cao and McHugh, 2005).

Cao et al. (2004) applied the diversity management framework to describe diversity efforts and institutional change in a higher education institution. They drew on Cox and Blake (1991) descriptions to categorize how institutions implement diversity initiatives:

Monolithic organizations

In this type of organization, the commitment to diversity is limited and often confined to affirmative action plans. There may be minimal efforts to go beyond basic compliance.

Plural organizations

Plural organizations actively recruit and promote individuals from diverse backgrounds. However, these individuals are often expected to assimilate into the dominant culture, and the organization may not fully embrace their unique perspectives.

Pluralistic organizations (espousing affirmative action)

These organizations emphasize affirmative action efforts but may fall short of implementing initiatives that truly integrate individuals from diverse backgrounds. The focus is on meeting specific diversity targets rather than fostering a comprehensive and inclusive environment.

Multicultural organizations

Multicultural organizations appreciate and leverage differences among their workforce as a source of competitive advantage. They aim to create inclusive environments that embrace diversity both in terms of attitudes and structural integration.

The framework serves as a lens through which researchers and practitioners can analyze the effectiveness of diversity management initiatives within organizations. It recognizes that diversity efforts go beyond mere representation and should involve creating inclusive cultures where individuals from different backgrounds feel valued and can contribute fully to organizational success.

Institutional racism in STEM higher education

In 1967, Stokely Carmichael and Charles V. Hamilton introduced the term "institutional racism" in their work "Black Power: The Liberation Politics." They highlighted that while individual racism is often overt and discernible, institutional racism operates more subtly, making it less perceptible. This form of racism, deeply embedded in the United States, operates at macro-, meso-, and micro-levels, perpetuating a racial hierarchy that privileges White individuals and marginalizes others at a larger scale systematically (Bonilla-Silva, 2006; Phillips and Lowery, 2018).

Institutional racism, drawing on critical perspectives of structurally endemic racism (Morton and Nkrumah, 2021). Within higher education, institutional racism encompasses systemic practices, policies, and structures that disproportionately disadvantage Black individuals (Branch-Brioso, 2009). It manifests in discriminatory practices, unequal opportunities, and biased policies affecting academic success, representation, and overall well-being (Sue, 2010). These manifestations include admissions processes, resource allocation, curriculum design, and campus culture, contributing to educational disparities and sustaining historical inequities (Museus et al., 2015). Effectively addressing institutional racism requires

TABLE 1 Racialized diversity management framework.

Organizational category	Description
Stagnant institution	The institution has an aspirational commitment to diversity. It has only an affirmative action plan or a diversity statement. Policy changes are minimal, or adverse. These institutions may count Black faculty without many present
Moderate institution	Underrepresented populations are recruited but are expected to assimilate into the dominant culture. These institutions attempt to maintain their structure. The retention and recruitment efforts can focus on supporting the individual without dramatic change to the institution. Black faculty are present but cannot participate as their authentic selves
Transformational institution	The institution has made significant steps toward creating an equitable environment. Differences in people are appreciated and viewed as assets. The institution reflects critically on areas that need to be changed for institutional health and for maintaining equity. Black faculty are present and feel comfortable participating as their authentic selves and are appreciated

confronting and dismantling these systemic barriers, fostering a more inclusive and equitable learning environment for Black individuals.

In the context of STEM higher education environments, institutional racism has been applied to scrutinize its presence in postsecondary STEM departments (Malcom and Malcom, 2011; Baber, 2015). Exclusionary practices continue to shape the educational experiences of Black students and faculty in STEM (Gasman et al., 2008; McGee et al., 2022), subjecting them to a racial hierarchy that upholds whiteness, masculinity, and middle-class knowledge (Leyva, 2016; Gholson and Wilkes, 2017). We have integrated the diversity management framework with a critical understanding of institutional racism, leading to the revision of organizational categories (see Table 1).

Methods

This study is part of a larger three-year research project to shed light on the barriers and opportunities facing Black engineering doctoral students, postdocs, and faculty that included qualitative interviews, focus groups, and surveys. We analyzed interview data we collected from 29 tenure-track Black engineering and computing science faculty at 15 schools of engineering who discussed diversity efforts they experienced (see Supplementary Table A1 for demographic information and pseudonyms). Interviews were semi-structured, lasting from 45 min to 2½ hours. The interviews were audio-recorded, professionally transcribed, and analyzed in Nvivo©, a computer-assisted qualitative data analysis platform licensed by QSR International©. The primary analysis team consisted of two Black faculty (one who was a postdoctoral researcher at the time of analysis), one doctoral student, all of whom identify as Black women, and a master's student who identifies as an Afro-Caribbean man. All participants were given pseudonyms for this study.

Grounded theory guided our qualitative analysis since we were gaining an understanding of the racialized diversity management framework (Charmaz, 2006). Our interview protocol focused on the underrepresentation of Black engineering faculty members, but some participants also referred to diversity efforts that target graduate student diversity as a means of diversifying the professoriate. When asked why the percentage of Black faculty in engineering remained stagnant at 2.6% in contrast to the growth shown for other underrepresented minorities, many of our participants reported a broad range of experiences with institutional engagement around diversity initiatives (i.e., personal experience of faculty and faculty hiring practices). They reported both positive and negative experiences with diversity initiatives, showing how diversity initiatives can either be supportive or rendered ineffective in engineering and computing academia. We selected this pattern for closer analysis and reviewed the 29 transcripts for participant references to diversity in engineering and computing science. We discovered two categories in our analysis: 1) Faculty referenced diversity effort, which typically had a name or label, or 2) General efforts that were not specifically titled or labeled but the faculty member could describe the characteristics of an effort.

The qualitative research method of analyzing data using a pre-defined codebook is known as closed or deductive coding (Pearse, 2019). It is a deductive method with the goal of comprehending data through theory-informed methods, in this case, the racialized diversity management framework (Table 1). Participant references to diversity initiatives were categorized as descriptions of stagnant, moderate, or transformational institutional change according to the descriptions in Table 1. For this research, we defined STEM departments as "organizations," and institutions as large organizations comprised of a collection of smaller organizations. Our closed coding analysis was successful when the data could be coded based on pre-determined codes. The authors coded data separately and met weekly to review coded data. When the data codes were not in agreement we deliberated until we had a consensus on how to proceed.

We combined our characterizations of participants' perceptions with the organizational categories that describe institutional responses to diversity initiatives. We applied one or more organizational categories to each participant's reference to a diversity initiative based on the category descriptions in our conceptual framework. To answer our research question, we explored the aspirational relationship between participants' perceptions of diversity initiatives as positive, negative, or neutral consistent with how they appeared to be categorizing institutional change as stagnant, moderate, or transformational.

Findings

In this section, we provide a synopsis of our findings along with descriptions of the three types of organizations: stagnant, moderate, and transformational. In the twenty-nine participant interviews, we identified forty-seven references to diversity initiatives. The number of references does not equal the number of participants because $n=9$ participants made multiple references to diversity initiatives in their interviews. Of these forty-seven references, $n=26$ references (55.3%) described positive participant perceptions, $n=19$ references (40.4%) described negative perceptions and $n=2$ references

(4.3%) described neutral perceptions. The Black faculty remained hopeful towards developing equitable STEM higher education environments. Participants' perceptions of diversity initiatives coordinated with certain features of organizational change towards or away from inclusion. Many of the Black faculty described working in transformational departments and institutions, however, they often juxtaposed this with previous negative and even traumatizing experiences.

When applying our deductive coding of institutional categories to the participants' references to diversity initiatives, we were able to apply the categories to $n = 40$ (85%) of the 47 references to diversity initiatives. Seven of the references were participants naming an initiative or commenting on an initiative generally in a way that did not support the application of an institutional category. For example, Dr. Benson mentioned how a diversity initiative helped expose him to more Black students in the academic pipeline but did not describe how that initiative or experience might facilitate diverse hiring practices for engineering and computing science faculty. Within the forty references to which we applied our selective coding, we identified $n = 6$ (15%) descriptions of stagnant institutions, $n = 18$ (45%) descriptions of moderate institutions, and $n = 16$ (40%) descriptions of transformational institutions.

Stagnant institutions – superficial commitments towards the inclusion of Black faculty

Six participant descriptions in the stagnant institution category describe institutional contexts where few strides have been made towards diversifying the engineering and computing science professoriate or where changes have adversely affected the recruitment of Black faculty. All participant descriptions of stagnant institutions were related to institutions or departments that were doing nothing substantively to diversify their students and faculty further racially. These institutions may have Black faculty that they rely upon, but they have collected little to no data to understand the experiences of Black faculty. For example, Dr. Appleton described a patronage system for hiring faculty that is rooted in racism and that disadvantages Black faculty.

> One of the things that we have historically [had] within organizations, [is] a hiring system that was… called the "good old boy network." And in that good old boy network, once you are in an organization, you could know a given person, tap that person, say, come on in, interview, and you can get in through that sort of system. Because of the abuses of the past, today's hiring protocols are much more rigid… [There are still not] large numbers of underrepresented minority faculty available in any pool or search.

Dr. Appleton highlighted a hiring system rooted in racism, favoring candidates with connections. Despite efforts to make protocols more rigid, the change did not facilitate the inclusion of Black faculty; instead, it perpetuated their exclusion. The institution's attempt to address diversity challenges inadvertently continued to disadvantage Black applicants due to the limited availability of underrepresented minority faculty in the candidate pool. The intended diversity enhancement through protocol shifts resulted in continued stagnation, with only a few Black faculty members remaining, while others were effectively funneled out of the applicant pool. The other five participants expressed concerns similar to Dr. Appleton's. They also pointed to the lack of underrepresented populations in the applicant pools combined with institutional hiring practices that are not intentional about attracting and interviewing them. Dr. Franks pointed to policy change during the presidency of George H.W. Bush that opened trade with China and relaxed visa requirements for Chinese students and scholars. Dr. Franks is referencing The Chinese Student Protection Act (1992) where he noticed an increase in the representation of Chinese nationals in engineering and computing sciences in the United States (Feldgoise and Zwetsloot, 2020). It had long-term effects on the engineering department at Dr. Franks' institution. He noticed that most of the faculty were Asian internationals and these faculty worked predominantly with Asian students and occasionally with African international students, but never with African American students. Dr. Frank felt this placed African American students at a disadvantage since students are required to have a faculty advisor.

These exclusionary practices make it more challenging for Black students to have a willing and equitable faculty advisor. Dr. Franks suggested that this requirement could also be contributing to the low representation of African American students at the Historically Black Institution because students had few faculty they were able to work with. Although the change in government policy did support diversity in engineering and computing science, there is much room for growth for the systematic inclusion of African Americans.

Dr. Walker shared a narrative of systematic exclusion in hiring that eroded organizational efforts toward diversity and inclusion for both faculty and students:

> The search committees and the decisions about who gets hired are not African Americans, because they are not there to begin with. And my observation is that people tend to be biased toward individuals like themselves. So, if I'm an African American, and there are two people or three, four people in a search, and one is an African American and everything else is equal, I'm more likely to choose the African American. If a White male is Department Chair and the same thing happened to him, more likely he'd choose the White male… So [when it comes to] the underrepresented student, graduate student to begin with does not get selected. And if you do extra things to bring in underrepresented students, they still have to be selected by their faculty members to be mentors and advisors. And so, if they are there and do not get selected, they'll have a hard time graduating. So sometimes… the environment for success is not there to help the student to move forward.

The six participants identified institutional lack of diversity as a limiting factor in increase diversity among engineering and computing science faculty. Dr. Walker's account underscores a systemic exclusion in hiring that contributes to the perpetuation of underrepresentation, particularly for Black faculty. His narrative reveals how the absence of diversity within search committees influences hiring decisions. In environments lacking African American representation, biases tend to favor individuals similar to the existing committee members. This perpetuates a cycle where, even when efforts are made to increase diversity, underrepresented candidates, including Black faculty, face significant hurdles in being selected. The institutional environment, as described by Dr. Walker, poses challenges for the success and advancement of underrepresented individuals, ultimately impacting the numbers of Black faculty within the institution. While the faculty perceived organizational commitments to diversity as superficial, their narratives align more closely with the stagnant category the challenges they describe reveal a systemic stagnation in diversity efforts. To truly diversify the candidate pool, institutions must move beyond minor adjustments in hiring practices.

Moderate institutions – recruitment with the goal of assimilation of Black faculty

Most of the settings participants described were consistent with what we called "moderate institutions." Respondents in such institutions saw small incremental progress toward diversity. However, these efforts did not have longevity, nor did they lead to lasting change defined as an environment where Black faculty felt comfortable participating as their full authentic selves. For example, Dr. Hewey did not describe a diverse initiative, but he did describe the lack of a sense of community in his institutional setting. He described his undergraduate HBCU as having a strong community where he felt a sense of connection. He was then able to re-create that sense of community as a doctoral student at a predominately white institution, but he leveraged student organizations and the community outside of the institution in order to receive support. As he reflected on his experience, he compared his perspective as a student to his current experience as a Black faculty member:

> In terms of faculty, I do still feel the isolation sometimes, because in terms of African American men across the three programs within one department, there are really two of us, and the other one is a senior [faculty member]… I think there's just a difference in interaction between faculty members and even how we interact with students. And I still rely on kind of [the] same, similar strategies [from my graduate school experience]. I am collegial with people in my department, I make sure that I connect with other faculty in other departments and even other colleges.

Despite strong interaction with his colleagues, Dr. Hewey feels isolated within his department. This contrasted with the faculty in our sample who are working in transformational institutions. None of them described feeling isolated even if they were the only Black person in their department. If Black faculty are present but have feelings of isolation the environment is not transformational.

Dr. Higgins believes accountability and buy-in are very important in executing effective diversity initiatives. He feels that leadership, like "deans and chairs," should be held accountable for maintaining diversity efforts that include retention and support of underrepresented faculty. He said:

> If the goal is to diversify your faculty, then you cannot afford to have any faculty of color having to go through the usual games that people play through the tenure process. So, like I say, if people ask me, "What's it like to be a tenured professor, or be on tenured track?" It's like having a job and pledging a fraternity all at the same time, where doing your job is necessary, but not totally sufficient for entrance into the club. Right? And so, for me, everything was cool and copasetic until I hit. So, what's Gandhi say? You know, first they laugh at you, then they ignore you, then they fight you, then they… then you win.

In this instance, Dr. Higgins conveyed a negative perception of being part of a diversity hiring initiative. He found himself in an environment where he perceived a lack of support for him and other underrepresented faculty members. This study revealed that 40.3% of Black faculty held unfavorable views of diversity initiatives. Despite environments that aimed to surpass mere affirmative action measures, these faculty members did not feel entirely included and often sensed the need to assimilate. They reported experiencing environments that lacked collegiality and support for underrepresented faculty members, with described efforts having minimal buy-in or support from their peers and leadership.

Transformational institutions – diversifying toward disruption and fully inclusion of Black faculty

Participants' descriptions of transformational institutions were characterized exclusively by their positive perceptions of how STEM departments and institutions can foster inclusivity. Although descriptions of transformational institutions appeared in 40% of the institutional references to diversity initiatives, only three reference described the participant's current institution. When asked what his institution is doing to foster diversity, Dr. Wright described an academic setting and a department that had commitments to inclusion which were often reinforced. Dr. Wright reported:

> Based on interactions that I've had with administrators here, I'm convinced that everyone—the decision makers—are focused on creating the right environment where you can have [diversity]. Not just in terms of faculty, but also in the student body as well. I think, I'm convinced that everyone here is focused on making it a comfortable and welcoming environment for their fresh faculty. That's certainly been my experience. Definitely… all my interactions with the Dean of the College of Engineering [have] been fantastic, supportive, diverse… and for me personally, I think from day one.

Dr. Wright expressed satisfaction with the efforts of his institution and felt immersed in an inclusive, supportive institutional context within his department and the university more broadly. Dr. Wright felt he had the ability to contribute to and see a change in his institutions. He felt able to assist in these transformations, working within his department as his authentic self while feeling validated. Dr. Wright goes on to describe how the Dean of Engineering is very supportive of cultivating a positive cultural climate, which he deemed important for him as a new faculty member. Dr. Evans echoes Dr. Wright's experience. Dr. Evans is in a department that is interested in the perceptions of Black faculty, seeking to gain their insight into the institutional climate. Although Dr. Evans's experiences are positive, he also compares it to his international positions. He states, "[The] United States is way behind in that area [of diversity]… We have faculty retreats where we talk about things like this. Like how to promote the department, make it better." Dr. Evans felt the retreats were a good way to create a space to listen to the faculty on the topic of diversity.

Dr. Davis describes his institution as a place where all the faculty are involved in many different initiatives that they feel are important for recruiting underrepresented faculty, and more importantly, retaining them by cultivating a supportive environment. However, Dr. Davis stressed the importance of the university having "flexible hiring lines that basically [go] out and recruit faculty, African American, or any member of the underrepresented groups and women." He believes that flexible hiring lines provide his institution more options to increase the diversity in their faculty.

Discussion

This study detailed three types of organizational environments 1) Stagnant institution, where the institution has an aspirational commitment to diversity which can be noted by simple affirmative action plans or generic diversity statements with little is in place to cultivate equitable environments. 2) Moderate institutions, where underrepresented populations are recruited but are expected to assimilate into the dominant culture. The institution desires to maintain its structure which has racist policies and practices. 3) Transformational institutions, which are the ideal environment to foster healthy faculty conditions, this institution has made significant steps toward creating an equitable environment. The institution reflects critically on areas that need to be changed for institutional health and for maintaining equity.

This paper provides the needed language for departments and institutions to name their environment. There is power in naming, by giving something a name it makes it real and can be communicated about. For example, at a faculty meeting, a department chair could ask, "What would be needed in our department for it to become transformational? The naming of an environment is a tool that can provide a clearer and more detailed dialog within engineering and computing departments. Efforts must move beyond counting the number of Black faculty (stagnate institution) towards accepting and working to fully include Black faculty in healthy ways (transformational).

It can be difficult to process and accept that racism will be the default operation in an institution unless it is collectively and constantly worked against. In addition to creating equitable and healthy work environments, this will also have a direct impact on the student body and ultimately produce more equity-focused engineers and computer scientists.

Conclusion

There is no doubt that the country's demographics will continue to change, but, for Black engineering and computer science faculty, this ripple effect is not guaranteed to reach higher education. To significantly increase the number of Black STEM professors in academia, change agents must address several factors and forces within the academy. To address the numerous factors that have hampered progress in diversifying the professoriate, campus leaders, consortia of institutions, and national organizations must collaborate and work independently to develop novel strategies to increase the number of transformational environments where Black faculty are engaged and valued in the transformational efforts.

This research provides a rare description of institutional efforts towards diversity in STEM departments and institutions from the perspective of Black faculty. However, this study has its limitations, primarily in fully comprehending the complexity of Black faculty members' experiences. The broader research study from which this study draws did not initially aim to investigate diversity initiatives specifically, yet these initiatives emerged within the narratives of participants. Subsequent research endeavors could explicitly explore diversity initiatives, examining their direct impact. Such research could contribute to the development of a survey tailored for departments, enabling a more comprehensive self-assessment of their respective diversity initiatives. The goal of our research was to provide descriptions for the type of institutional environments Black faculty have experienced. This research suggests that STEM departments and institutions consider using as a model the transformational organizations, as defined above, where Black faculty can thrive and not merely survive. We suggest that departments and institutions gage what type of environment they currently have. Is it stagnant and only taking diversity efforts as far as affirmative action, not accounting for unwelcoming and hostile working environments? Or is the environment more progressive and transformational? Within higher education each STEM department has its own culture. It is important to look within and across each department to ensure every area is transformational.

Data availability statement

The data analyzed in this study may not be readily available as it is in the form of qualitative interview results. Requests to access these datasets should be directed to https://www.r-rights.com/.

Ethics statement

The studies involving humans were approved by Peabody College Vanderbilt University IRB. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

MM: Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. EM: Data curation, Formal analysis, Funding acquisition, Resources, Supervision, Writing – review & editing. PB: Data curation, Formal analysis, Investigation, Software, Writing – original draft.

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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.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1324389/full#supplementary-material

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Including neurodiversity in computational thinking

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Introduction: The foundational practices of Computational Thinking (CT) present an interesting overlap with neurodiversity, specifically with differences in executive function (EF). An analysis of CT teaching and learning materials designed for differentiation and support of EF show promise to reveal problem-solving strengths of neurodivergent learners.

Methods: To examine this potential, studies were conducted using a computer-supported, inclusive, and highly interactive learning program named INFACT that was designed with the hypothesis that all students, including neurodivergent learners, will excel in problem solving when it is structured through a variety of CT activities (including games, puzzles, robotics, coding, and physical activities) and supported with EF scaffolds. The INFACT materials were used in 12 treatment classrooms in grades 3–5 for at least 10 h of implementation. Pre-post assessments of CT were administered to treatment classes as well as 12 comparison classes that used 10 h of other CT teaching and learning materials. EF screeners were also used with all classes to disaggregate student results by quartile of EF.

Findings: Students using INFACT materials showed a significant improvement in CT learning as compared to comparison classes. Students with EF scores in the lower third of the sample showed the greatest improvement.

Discussion: This study shows promising evidence that differentiated activities with EF scaffolds situated across several contexts (e.g., games, puzzles, physical activities, robotics, coding) promote effective CT learning in grades 3–5.

KEYWORDS

computational thinking, neurodiversity, executive function, inclusion, STEM problem-solving, differentiation

1 Introduction

This paper reports on a study of teaching and learning materials designed for the inclusion of neurodivergent learners in computational thinking (CT) in grades 3–8. We define an inclusive classroom as one that has at least 20% of students with individual education plans (IEPs) or equivalent alternative programming for cognitive differences. The study examines how materials supported executive function (EF) and differentiated teaching and learning, specifically in inclusive classrooms in grades 3–5.

Inclusive classrooms are typically general education classrooms where neurodivergent and neurotypical students learn together. Inclusive classrooms often do not include learners with profound needs that cannot be accommodated in a general classroom. As of 2017, in the US, approximately 65% of learners receiving special education services were spending 80% or more of the school day in inclusive classrooms (Horowitz et al., 2017; McFarland et al., 2019). While there are varying levels of severity of many of the conditions requiring special education, inclusive classrooms typically include learners who need light or moderate supports, but not those who need more intensive supports to accomplish daily tasks (Polirstok, 2015). As today's classrooms are becoming more inclusive of neurodiversity—the differences in the ways students think and learn—teachers and those designing for classroom settings need to look for new approaches to engage all learners.

The term neurodiversity refers to a growing perspective that variation in human brain activities is comparable to the natural variation in race, sexuality, and other human factors (Blume, 1998; Singer, 1998). Terms such as neurodiversity and neurodivergence are often used to steer away from labels such as autism, ADHD, and dyslexia, which come from a medical perspective. The diagnostic labels may be useful in identifying potential interventions as well as crucial for accessing potential educational resources for some learners, but they may also come with prejudice and stigmatization that ignore the talents of these learners. Focusing on strengths, and taking an asset-based approach to education, offers each learner a chance to reveal their strengths and supports equity in the classroom (Bang, 2020; Madkins et al., 2020).

Inclusive classrooms often include students who demonstrate outstanding talents in specific areas related to problem solving, while also requiring supports for EF (Asbell-Clarke, 2023). EF is the set of processes the brain uses to coordinate sensory, emotional, and cognitive aspects of learning (Antshel et al., 2014; Varvara et al., 2014; Bellman et al., 2015; Meltzer, 2018; Meltzer et al., 2018; Demetriou et al., 2019). These processes include attention, working memory, and self-regulation, which are required when organizing and prioritizing information and tasks and when conducting tasks such as setting goals and designing and implementing a plan to achieve those goals (Brown, 2006; Diamond, 2013). EF is considered essential for deeper learning and developing transferable skills for success in school, college, and one's career (Pellegrino and Hilton, 2012).

EF is rapidly being recognized as a key area of focus for education for all learners, not just those in special education (Immordino-Yang et al., 2018; Meltzer, 2018). EF is responsible for regulating attention, emotions, and impulse control, which enables persistence and motivation to achieve these goals (Meltzer et al., 2018; Semenov and Zelazo, 2018). EF can be a struggle for many neurodivergent learners, as well as learners undergoing stress, trauma, and/or anxiety (Immordino-Yang et al., 2018), all of which are on the rise in today's schools (Hawes et al., 2022; Rodriguez and Burke, 2023). Overall, supporting EF in learning activities may produce better performance which can, in turn, increase motivation, causing a positive learning cycle and improved self-efficacy (Semenov and Zelazo, 2018).

CT is an emerging area of education that may reveal the strengths of many neurodivergent learners and also support their EF. CT is a problem-solving approach that leads to generalized and replicable solutions that can be implemented by computers and information-processing systems (Shute et al., 2017), and is attracting increased attention in K–12 education, prompting calls for new models of pedagogy, instruction, and assessment, particularly in younger grades (Wing, 2008; Cuny et al., 2010; Barr and Stephenson, 2011; Grover and Pea, 2017; Shute et al., 2017). The fundamental practices of CT are also foundational to everyday problem solving (e.g., making a meal or cleaning up the classroom), as well as many school-based learning activities (e.g., solving a math problem, conducting a science experiment, or writing an essay). Foundational CT practices include *Problem Decomposition*: breaking up a complex problem into smaller, more manageable problems; *Pattern Recognition*: seeing patterns among problems that may have similar types of solutions; *Abstraction*: generalizing problems into groups by removing the specific information and finding the core design of each problem; and *Algorithmic Thinking*: thinking of problem-solutions as a set of general instructions that can be reused in different settings. Additionally, the CSTA (2017) outlines a number of dispositions or attitudes essential to CT, including confidence in dealing with complexity, persistence in working with difficult problems, tolerance for ambiguity in dealing with open-ended problems, and the ability to work in collaborative groups towards a common goal.

The practices and dispositions associated with CT present an interesting overlap with the strengths and needs of many neurodivergent learners. For example, some neurodivergent learners such as autistic learners may not demonstrate high cognitive flexibility (i.e., they are very rigid in their thinking) yet excel in recognizing patterns within complex situations and paying attention to close detail (Jolliffe and Baron-Cohen, 1997; Fugard et al., 2011). Pattern recognition has also been proposed as a primary basis for particular talents and savant behaviors in autism, such as calendar calculating, mathematics, and other specialized skills (Baron-Cohen, 2008; Mottron et al., 2009). Research also suggests that some other learners who may struggle to focus attention on details in pattern recognition (e.g., some people with ADHD) may be more open to ambiguity and collaborations than their peers, often making innovative connections between ideas and abstractions that are not seen by others (Beaty et al., 2015). Similarly, the differences in the brains of individuals with dyslexia may be beneficial for spatial reasoning, interconnectedness, and abstraction (Eide and Eide, 2012).

CT has the potential dual advantage of tapping into some of the specific cognitive strengths (e.g., pattern recognition, systematic thinking, and abstraction) associated with neurodiversity, while also structuring problems in a clear and generalizable way to assist all learners. Students who struggle with EF challenges may benefit from a problem-solving approach that emphasizes breaking up problems into smaller chunks to support working memory, and generalization of patterns in problem solutions to apply to a variety of different situations that may support cognitive flexibility. In addition, the emphasis on developing algorithms, or problem-solving tools, that can be named and re-used, is a mechanism to support metacognition and explicit reflection on the problem-solving steps (Ocak et al., 2023). A systematic review of the effects of CT interventions on children's EF (Montuori et al., 2023) showed significant effects on students' planning and core EF skills. For example, children aged 5–7 showed increased planning skills after using Code.org (an introductory coding environment) for a month. The largest effects were observed on children's problem solving and complex EFs such as planning, but significant positive effects emerge also for core EFs like cognitive inhibition and working memory.

Coding and robotics programs were shown to be effective when they addressed the various components of CT, such as problem analysis, planning, evaluating and debugging, where CT interventions that focused on just one component or on programming skills solely were less effective (Oluk and Saltan, 2015). Robotics activities have been shown to improve the inhibition in terms of speed and accuracy of information processing for a broad array young children who were categorized as having "special needs" (identified as having cognitive and behavioral differences) (Di Lieto et al., 2020).

2 Materials and methods

The challenges many neurodivergent learners face in school are often related to executive function processes in the brain, which include working memory, cognitive flexibility, and inhibitory control (which is closely related to self-regulation of attention) (Meltzer, 2018). In an effort to support a broad range of neurodivergent (and neurotypical) learners in CT, the INFACT project provides differentiated teaching and learning materials using CT in a variety of contexts and modalities with embedded supports for learners' executive function. To support and study the potential intersection between CT and EF in grades 3–5, a consortium of learning scientists and developers designed a program called *Including Neurodiversity in Foundational and Applied Computational Thinking (INFACT)*.

2.1 Overview of INFACT teaching and learning materials

The INFACT teaching and learning materials for grades 3–8 introduce CT practices such as Problem Decomposition, Pattern Recognition, Abstraction, and Algorithm Design in a variety of contexts like mazes, music, art, puzzles, and sports to provide many real-life examples of CT.

The INFACT activities are delivered in topical sequences that build foundational and applied CT knowledge through a multitude of off-line and online activities. The sequences are:

- *Sequence 1: Introduction to CT* focuses on introducing learners to CT practices such as Problem Decomposition, Pattern Recognition, Abstraction, and Algorithm Design.
- *Sequence 2: Clear Commands* focuses on clear and unambiguous communication and devising a common set of commands to give instructions for a task.
- *Sequence 3: Conditional Logic* focuses on the use of IF-THEN (and IF-THEN-ELSE) commands with the introduction of Boolean operators such as AND, OR, and NOT.
- *Sequence 4: Repeat Loops* uses REPEAT commands to group together patterns of commands to make repetitive instructions more efficient.
- *Sequence 5: Variables* focuses on the use of variables to make commands and algorithms modifiable and reusable.
- *Sequence 6: Functions* focuses on the creation and use of functions to build sets of commands into reusable algorithms.

Each INFACT learning sequence consists of a number of different possible *Activation* activities, *Foundational* activities, *Applied* activities, and *Wrap Up* activities that the teacher can choose according to their students' interests and their classroom needs. Each sequence also has a default set of activities for a quick start. *Activation* activities motivate and prepare learners for the sequence topical activities. The *Foundational* activities build conceptual knowledge associated with CT topics and practices. The *Applied* activities have students apply CT topics and practices in supported tasks. The *Wrap Up* activities allow students to reflect upon the sequence and focus on the main take-aways. These materials are available through Open Access (INFACT, 2024).

2.2 Supporting differentiated instruction in INFACT materials

For effective inclusive education, educators need to differentiate their teaching strategies to draw on the unique strengths of all learners, including neurodivergent learners, while also supporting the different EF needs of all students (Tomlinson and Strickland, 2005; Van Garderen et al., 2009; Brownell et al., 2010; Armstrong, 2012; Immordino-Yang et al., 2018). Differentiated instruction presents all learners with the same learning goal but provides students varied pathways to reach that goal and also allows students to demonstrate knowledge in different ways by adapting activities to support multiple modalities (Galiatsos et al., 2019). The Universal Design for Learning (UDL) framework (Rose, 2000) provides guidance on differentiating for neurodiversity by offering multiple means of representation, multiple means of action and expression, and multiple means of engagement. Some neurodivergent students may need additional supports with EF, as well as with navigating social interactions, sensory demands, and barriers posed by disability-related bias or social stigma (Schindler et al., 2015; Chandrasekhar, 2020; Mellifont, 2021). Students' need for differentiated learning, particularly around EF, has only grown during COVID (Myung et al., 2020). Without these supports, neurodivergent learners may "underperform" because extraneous barriers mask their problem-solving talents (Shattuck et al., 2012; Gottfried et al., 2014; Austin and Pisano, 2017; Galiatsos et al., 2019).

Differentiation strategies for inclusive classrooms that are embedded in the overall design of INFACT include:

- Clean and consistent interface design
- Activation strategies to engage and prepare learners
- Multiple entry points into an activity
- Alternate representations and modes of learning.

The INFACT activities are delivered through a teacher differentiation portal that allows teachers to select activities based upon availability of technology, student grouping (e.g., pairs or whole class), and interest area or theme. The portal also offers multiple versions of many activities allowing for different entry points and scaffolds for different learners. The INFACT themes include game-based learning, robotics, and/or coding, as well as activities that allow a more general exploration of CT. Robotics activities are designed for use with Spheros, and a guide is provided to "translate" the activities for other popular robotics systems. The game-based learning theme of INFACT focuses on *Zoombinis*, a popular and award-winning CT puzzle game that has been shown to support teaching and learning of CT practices in grades 3–8 (Asbell-Clarke et al., 2021). Unplugged activities, puzzles, and games are used to build CT concepts before (or instead of) jumping into coding activities. Many of the INFACT activities include "get up and go" embodied activities, where students physically act out a puzzle or walk through a maze. Unplugged and digital CT activities complement robotics and gameplay to help build foundational understanding of problem decomposition, pattern recognition, abstraction, and algorithm design.

2.3 Supporting executive function in INFACT materials

Robertson et al. (2020) argue that the link between EF and CT is worth exploring for two reasons. First, EF is a predictor of academic success in general, including in the development of mathematical skills and science learning (Gilmore and Cragg, 2014). Second, there is some evidence that the development of CT practice may support the improvement of EF. Castro et al. (2022) found that an 8-week CT intervention program had a favorable effect on metacognitive processes, as well as cognitive processes such as working memory. DePryck (2016) suggests that "the metacognitive abilities required for CT (including connecting new information to former knowledge, deliberately selecting thinking strategies, planning, monitoring and evaluating thinking processes, breaking down complex actions into a conditional sequence) rely on executive function." Other recent research shows that teaching coding and robotics may have an impact on students' planning abilities (Gerosa et al., 2019; Arfé et al., 2020; Di Lieto et al., 2020). This research is just emerging and generally has small study numbers, so these linkages merit further investigation.

The INFACT online and offline activities are designed with embedded supports for EF. Supports for EF that are offered alongside offline and online INFACT activities include:

- Vocabulary cards to support working memory by introducing and keeping key terms and phrases at hand during activities (Figure 1).
- CT learning checkpoints to support metacognition and foster explicit expression of understandings (Figure 2).
- "Set up for success" teaching strategies to support working memory and attention through differentiation (Figure 3).
- Prompts to support metacognition including reflection and connections to other contexts (Figure 4).

In addition, digital supports for EF that are embedded within online puzzles from the CT learning game *Zoombinis* include:

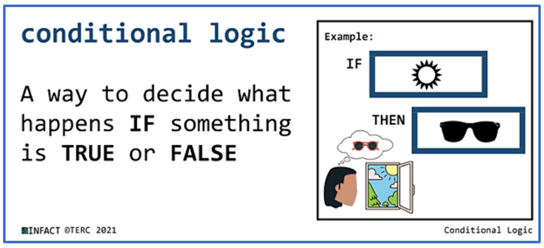

FIGURE 1
INFACT Vocabulary Cards help teachers support vocabulary in just-in-time learning.

- A flashlight tools to support attention by highlighting salient information (Figure 5).
- Graphical organizers to support working memory by enabling visual recording of information (Figure 6).
- Expression tools to support metacognition by promoting explicit expression of learning (Figure 7).

2.4 Research questions

The goal of this study was to address three research questions during the implementation of INFACT in inclusive classrooms in grades 3–5:

- *Research Question 1 (RQ1)*: To what extent does a CT program designed for inclusion (e.g., with built-in differentiation strategies and EF supports) impact foundational CT learning?
- *Research Question 2 (RQ2)*: To what extent does a CT program designed for inclusion moderate the effects of individual EF differences for learners?
- *Research Question 3 (RQ3)*: What connections between CT and EF do teachers recognize and use when implementing a CT program designed for inclusion?

2.5 Research sample

Our independent research team studied the implementation of INFACT in 12 inclusive classes in grades 3–5. Another 12 comparison classes used other CT materials for the same duration. Pre-post CT proficiency assessments and EF assessment screeners were administered to INFACT and comparison classes.

2.5.1 Student participants

In most inclusive classrooms, neurodivergent learners may receive an individual education plan (IEP) or equivalent. Our study included classrooms with at least 20% of students having an IEP. The provision of IEPs, however, is often complicated by unequal access to diagnostic resources as a function of social economic strata and cultural disparities in what behavior is considered problematic or disruptive (Rucklidge, 2010; Russell et al., 2016; Shi et al., 2021). Therefore, we use a screener test with EF tasks rather than IEP status to get a more direct and equitable, albeit limited, measure of student neurodivergence for disaggregation of our sample. We divided the student population into thirds so that we were able to compare students who demonstrated low, medium, and high levels of EF.

A total of 1,009 students (515 treatment and 494 comparison) in grades 3–8 had consent to participate in the study. We obtained full pre-and post-assessment data for 659 (307 treatment and 352 comparison) of these students. However, due to the impact of COVID on recruitment, pre-instruction assessment scores for middle school (grades 6–8) students differed too significantly between the treatment and comparison participants for rigorous comparison, so the final analytic sample consisted of matched data from 364 students (182 treatment and 182 comparison) in grades 3–5.

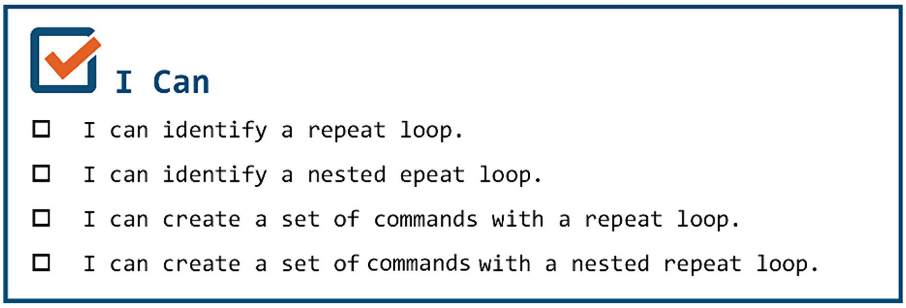

FIGURE 2
Metacognitive "I Can" Statements.

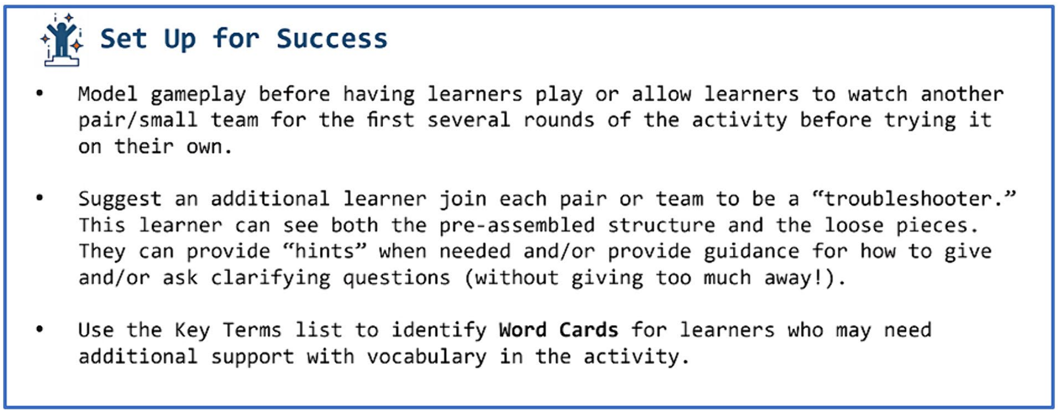

FIGURE 3
Teacher tips on when and how to use scaffolds are accompanied by suggested offline strategies for inclusive implementation of INFACT.

2.5.2 Teacher participants

To obtain the student sample, INFACT recruited individual teachers through social media and teacher mailing lists. Eligible teachers could work at any kind of school (public, private, etc.) and teach any subject, but had to confirm 20% or more of the students they typically teach had IEP/other classification or teacher/parent designation as needing learning support. Each teacher could enroll up to five grade 3–8 classes in the study.

A comparison group was recruited from teachers who were already teaching CT. For this group, we purposely selected experienced CT teachers so they had an established curriculum they considered business-as-usual for CT teaching and learning. Many of the control teachers were focusing on CT activities that related specifically to coding. These included using introductory coding activities from Code.Org (e.g., hour of code) or having students build games and animations using Scratch (scratch.mit.edu). None of the control teachers reported specific EF supports used in the other materials. The treatment group was notably less experienced in CT. To participate as part of either group, teachers needed to commit to 10 h of CT instruction (using either INFACT or their existing curriculum) during a specific 10-week time period in Fall 2021 or in Spring 2022. Across both implementation periods, a total of 14 teachers participated in the treatment condition and 13 in the comparison condition.

2.5.3 Research design

To address RQ1 (*To what extent does a CT program designed for inclusion* (e.g., *using differentiation strategies and EF supports) impact foundational CT learning?*), we examined the difference in CT proficiency of students in grades 3–5 who have had 10 instruction hours with INFACT teaching and learning materials compared to equivalent students who have had 10 instruction hours with business-as-usual CT activities.

To address RQ2 (*To what extent does a CT program designed for inclusion moderate the effects of individual EF differences for learners in grades 3–5?*), we examined the difference in CT proficiency for students who had the lowest third of EF scores in grades 3–5, comparing students who were in the INFACT program with equivalent students in the business-as-usual condition.

To address RQ3 (*What connections between CT and EF do teachers recognize and use when implementing a CT program designed for inclusion in grades 3–5?*) we studied teachers' perspectives on CT and EF through their descriptions of their experience of teaching INFACT. We included the perspectives of all 14 teachers who implemented the program for RQ3, since this question did not include a comparative element. That means that RQ3 includes the perspectives of teachers working in grades 3–8, though the samples for RQ1 and RQ2 only included students in grades 3–5.

Debrief, Reflect, and Check for Understanding

1. Ask questions such as:
   - What did you find challenging or difficult about preparing your directions?
   - What commands did you use in your final set of directions? What specific details did you use?

2. Encourage learners to share original and revised versions of their directions in whichever format(s) they chose.

3. Use the **CT Learning Checkpoints** above to review and assess understanding and progress.

4. Use the **PRADA Prompts and Strategies** below to review the computational thinking principles used to create and implement clear commands (directions) for getting from one place to another.

FIGURE 4
Prompts for reflection and connection.

Allergic Cliffs: One Value

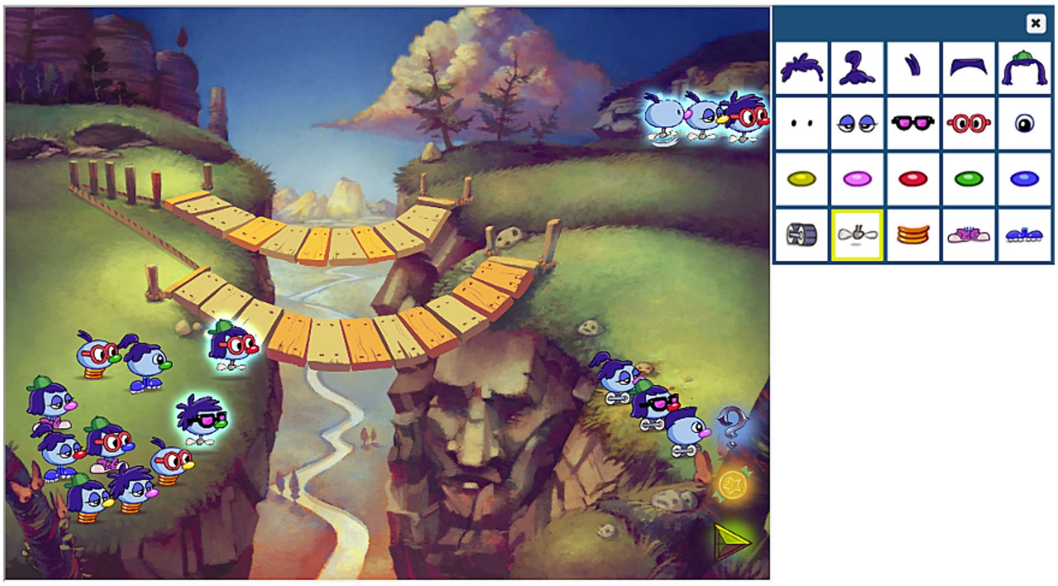

FIGURE 5
Screenshot of flashlight tool to scaffold attention in *Zoombinis* puzzle *Allergic Cliffs*.

2.6 Data sources

2.6.1 CT measures

Assessment of CT practices is challenging due to a lack of standard measures, particularly at the elementary level. Compounding that complexity is the issue that CT is a thinking process, and measuring thinking processes can be more nuanced than assessing whether a learner can demonstrate knowledge components of a concept. Measuring learners' abilities to plan, design, and solve complex problems is not done by a typical school test (Ritchhart et al., 2011). Even when CT performance is measured in a natural setting, such as in a coding environment, the final product may not reveal the CT practices or thinking processes involved in designing code (Grover and Pea, 2017). Current assessments often rely heavily on text comprehension and/or prerequisite knowledge of coding, which may preclude adequate measurement of these CT concepts (Kite et al., 2021; Rowe et al., 2021).

The Computational Thinking test (CTt) (Román-González, 2015) and Bebras Tasks (Dagienė and Futschek, 2008; Dagienė et al., 2016) have shown promise as general assessments of core CT constructs for K–12 students (Wiebe et al., 2019). At the time this research was conducted, the psychometric properties of these instruments had not been fully demonstrated, however, and most research was only conducted at the middle-school level. Also, some Bebras tasks were

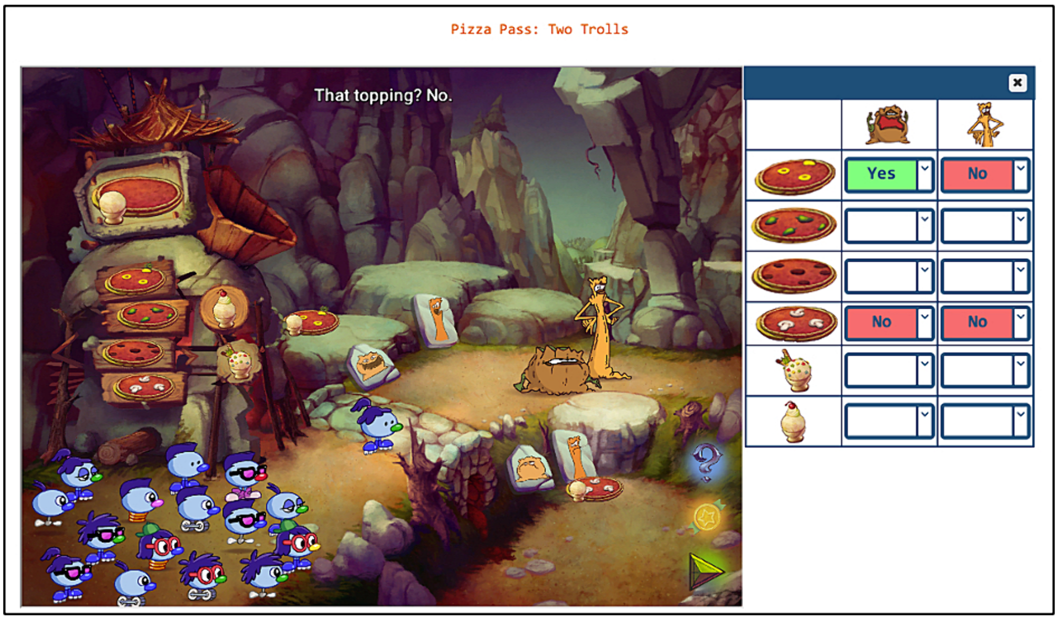

FIGURE 6
Screenshot of bookkeeping tool to scaffold working memory in *Zoombinis* puzzle called Pizza Pass.

FIGURE 7
Screenshot of expression tool to scaffold metacognition in *Zoombinis* puzzle called Allergic Cliffs.

considered too peripheral to core CT skills to stand alone as a standard assessment for CT in K–12 education (Román-González et al., 2019). Additionally, many Bebras questions are coding-centric, a common critique of many CT assessments (Huang and Looi, 2021). The CTt test is more generalizable and also has been since adapted and validated for elementary-aged students in the form of the BCTt and the cCTt (El-Hamamsy et al., 2022), but those findings were not available for this research opportunity.

Learning assessments that include irrelevant barriers such as text or other heavy symbolic notation may also create an undue cognitive load for learners, particularly for those who struggle with areas of EF including attention and working memory (Haladyna and Downing, 2004; Sireci and O'Riordan, 2020; Rowe et al., 2021). For equitable assessments of CT, assessments should be differentiated in terms of "engagement, representation, and action & expression" in line with UDL principles (Rose, 2000) so that each learner is able to learn and demonstrate knowledge on their own terms (Armstrong, 2012; Rowe et al., 2017; Murawski and Scott, 2019). For these reasons, we have used the Interactive Assessments of Computational Thinking (IACT) assessment in our study of INFACT (Figures 8–10). We developed and validated the IACT items in previous research, where they showed a strong test–retest validity and a moderate concurrent validity with select comparable Bebras items (Rowe et al., 2021). At the time of this research, the IACT items presented the best option for CT measures for grades 3–8 without many of the extraneous barriers presented by other CT assessments.

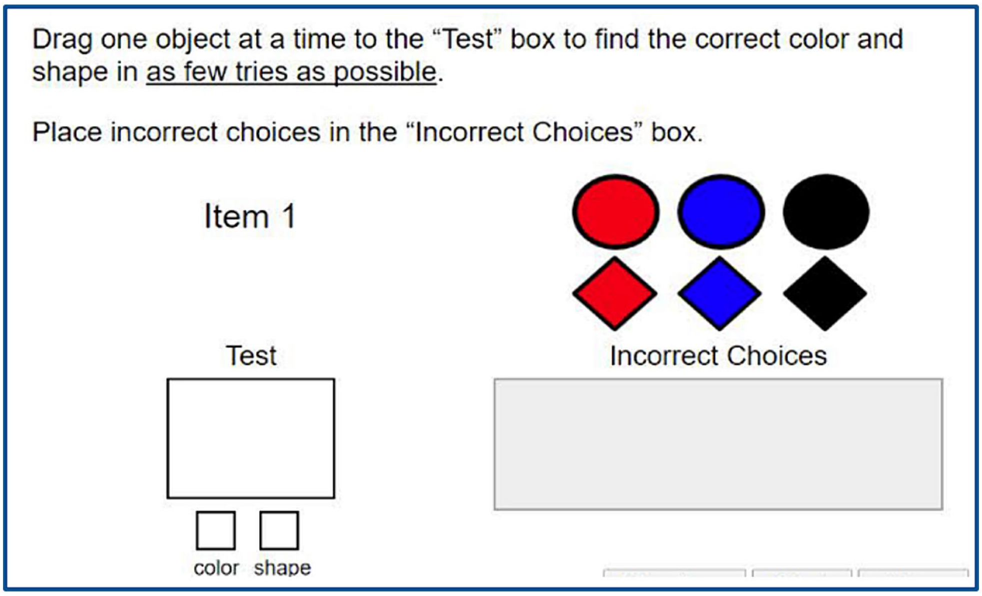

FIGURE 8
Example Problem Decomposition task in IACT assessments (Rowe et al., 2021).

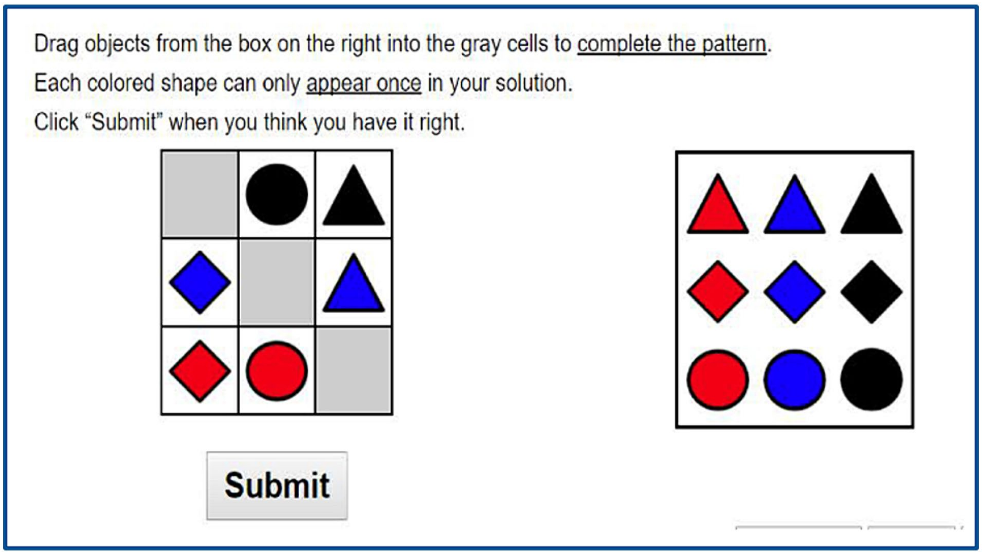

FIGURE 9
Example Abstraction task in IACT assessments (Rowe et al., 2021).

The IACT items were delivered at the beginning and end of the 10-h CT-instruction period, as a pre-and post-test of CT proficiency. IACT consists of four modules, each containing multiple logic puzzles. Because each module is scored differently, z-scores are calculated for each separately, using all data available (including from previous large studies). To prepare to use the IACT items in the INFACT research study, we conducted an initial validation study of 167 students with similar but separate participants in grades 3–8. We observed that the variation in participants' scores on the first (pattern recognition) module was much lower than for the other modules, with most scoring close to the maximum. Accordingly, we chose to use a modified IACT score based on the remaining three modules, where we observed wider variation. (Data from the first module were still collected during the research study, and they exhibited the same pattern as observed during the validation study.)

The IACT scores were computed based on the performance of participants on a set of CT-related tasks relative to a total norming sample of 4,168 students in grades 3–8 in previous research (Rowe et al., 2021). This was done so that we could place the current study in the context of the full distribution of possible IACT scores. A z-score was computed for each student on each subscale of IACT and then amalgamated into a single overall z-score. Therefore, an IACT score of zero means average performance relative to the sample, a negative score indicates below average performance in units of standard

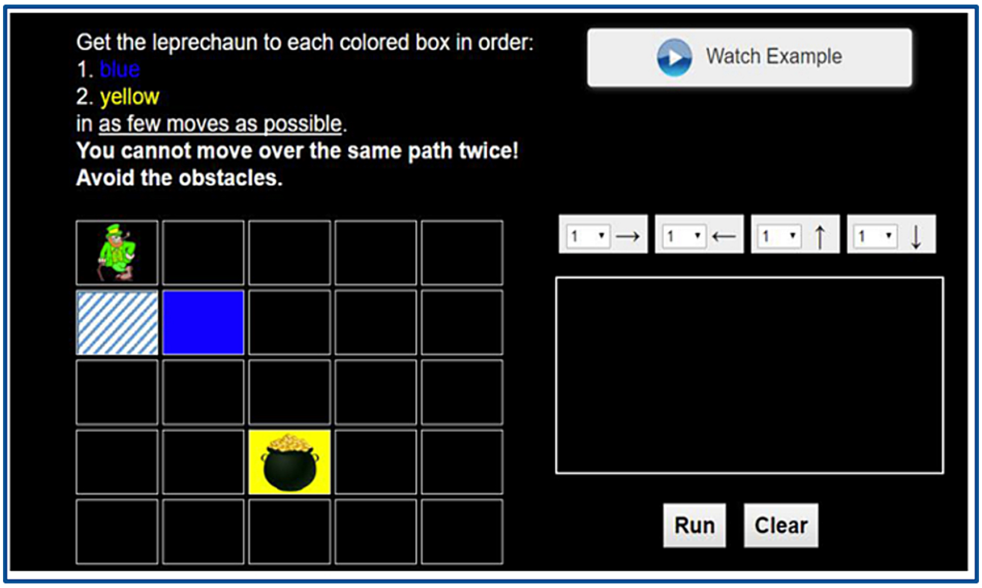

FIGURE 10
Example Algorithm Design task in IACT assessments (Rowe et al., 2021).

deviations, and a positive score indicates above average performance in units of standard deviations. One should note that students in the present sample generally scored above the overall mean score on the IACT, which may be attributable to the increase in CT in schools since the time of the data collection of the norming sample.

2.6.2 EF measures

In addition to the IACT pre-test, students completed a set of EF tasks at the beginning of the implementation period. These tasks were taken from Neuroscape's Adaptive Cognitive Evaluation (ACE), a game-like implementation of standard instruments to measure working memory, cognitive flexibility, and attention regulation (Younger et al., 2021). The tasks selected for the research study were Go/No-Go, Flanker, Task Switching, and Backwards Spatial Span. The results of scores on these four tasks were standardized and amalgamated into a single ACE score. ACE data were processed using the aceR package provided by Neuroscape, and the scoring metrics for each individual task were chosen based on the developers' recommendations (Rate Correct Score for Flanker and Task Switching, Mean Response Time for Go/No-Go, and Maximum Object Span for Backwards Spatial Span). Neuroscape does not currently provide guidance on combining scores from different modules to create a composite measure. However, since scores on each module were weakly to moderately correlated with the other modules (after normalization to account for the different scoring metrics), we used a combined measure. We tested several methods of creating this summary score, including Mahanalobis distance from a theoretical student who obtained the maximum score observed for each module and principal components analysis, but these did not significantly improve model fit over a basic mean of z-scores on the four modules. Accordingly, we proceeded with the mean score for analysis.

2.6.3 Teacher interviews

To address RQ3 and understand how teachers implemented INFACT, we interviewed each teacher in the Treatment condition 3–4 times over the course of the term. Teachers in the comparison group were not interviewed throughout the term, but did fill out a survey after their participation concluded, which included items on the types of activities used and time spent on CT, as well as open-ended items on the meaning and value of CT.

Three interviewers conducted these conversations, with each interviewer assigned to a small number of teachers for continuity. In the first interview, we asked about teachers' reasons for participating and the planning process, in addition to gathering information about the activities they had already used and their experience. In subsequent interviews, we continued to ask about their experience with the activities used to date. In the final interview, we also asked about their overall INFACT experience, including curricular connections, impact on their teaching, and impact on their students.

2.7 Data analysis

Linear mixed-effects models were used for the quantitative analysis. The models included terms to control for the fixed effects of pre-instruction IACT score, composite ACE score, and grade level. The model also controlled for teacher-and school-level random effects; that is, it accounted for the fact that students with the same teacher or in the same school might show comparable outcomes. There was only one case in which two teachers from the same school participated, and both were in the comparison condition. Meanwhile qualitative analysis began with overarching themes identified from project goals, with additional themes identified iteratively through analysis.

2.7.1 Analysis for RQ1 and RQ2

2.7.1.1 Apriori analysis

See Table 1 for the equations used to model the data for analysis of RQ1 and RQ2. Note that these models were developed apriori in anticipation of the predicted structure and potential sources of noise

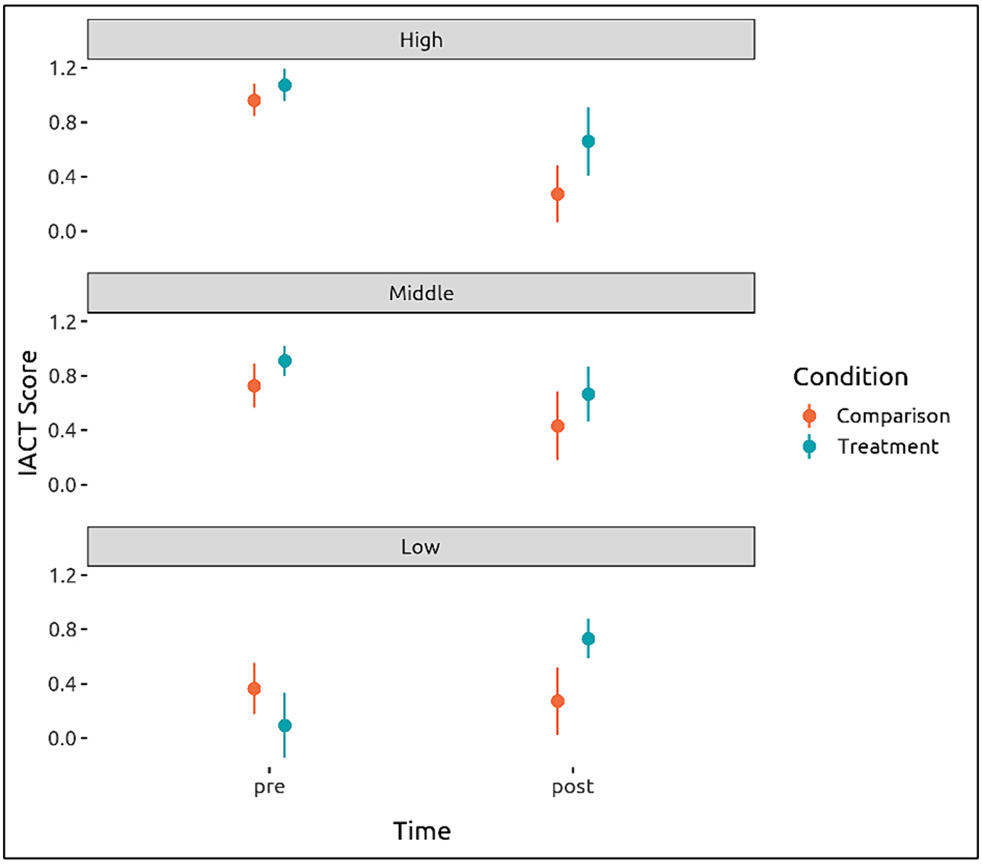

FIGURE 11
Performance on pre-and post-assessments of CT by group, for students divided by ACE thirds.

TABLE 1 Linear mixed-effects models used to analyze the full sample.

Model	Equation
Model 1	$Y_i = \beta_0 + \mu_j + \nu_k + \beta_1(Prescore) + \beta_2(ACE\,score) + \beta_3(Grade) + \beta_4(Condition) + \epsilon_i$
Model 2	$Y_i = \beta_0 + \mu_j + \nu_k + \beta_1(Prescore) + \beta_2(ACE\,score) + \beta_3(Grade) + \beta_4(Condition) + \beta_5(Condition)(ACE\,score) + \epsilon_i$

Y_i= Predicted IACT score for student i, β = Fixed component, $\propto$= Teacher j's random component, ν = School k's random component, ϵ = Residual Error.

ahead of data collection. We present the results of the pre-registered study (Attaway and Voiklis, 2022) here, with additional analyses in the next section. Model 1 provides a test for RQ1 by looking for a statistically significant impact for the treatment condition while controlling for the other factors. Model 2 addressed RQ2 and included all the same variables as Model 1 but added an interaction effect between the ACE score used as an EF screener and treatment condition.

2.7.1.2 *Post hoc* analysis

In addition to the apriori models, to address RQ2, we conducted a *post hoc* analysis to look at the impact of the intervention on students in the lowest third of ACE scores. This provided a better sense of how well INFACT worked for students who struggle the most with EF barriers. As shown in Figure 11, we grouped the data by ACE score thirds rather than continuous ACE scores because the impact of the intervention on ACE scores was not linear. We also recoded time as a binary variable rather than including IACT prescores as a fixed effect. This resulted in a new model using only those students in the lowest third of ACE scores. Table 2 includes the model used.

2.7.2 Analysis of interviews

We conducted the full qualitative analysis of the teacher interviews using nVivo. Overarching themes were identified based on project goals with additional themes developed through iteration. We treated each individual teacher as a case study in that we coded all interviews with a single teacher before moving on to the next teacher. Participating educators reviewed these portraits as a form of validation, We also considered demographic and institutional factors (e.g., grade level [s] and school type) but saw relatively little variation patterned along these lines. For portraits of each individual teacher, see Attaway and Voiklis (2022) and Barchas-Lichtenstein et al. (2023).

3 Results

3.1 RQ1: impacts of INFACT on CT proficiency

The difference in CT proficiency between students in grades 3–5 who used INFACT as compared to those who used other CT activities showed a substantial advantage to using INFACT (Table 3). Average IACT scores for students in classes using INFACT were one-third of a standard deviation (β = 0.41) higher than average scores for students in classes using other CT programs. This difference between instructional conditions appears to exceed chance occurrence ($p = 0.02$). However, because this implementation study occurred during COVID, the study was underpowered; *post hoc* power analysis indicates that a sample of the same size would only have a 55% chance of detecting an effect of this size. The comparison of INFACT to other CT programs was also limited by the lack of variation in the other programs. Many were coding-centric and did not include the kinesthetic and hands-on activities that were a core part of INFACT teaching and learning activities. Further testing is needed to confirm the reliability of the effect and how INFACT compares to other programs.

3.2 RQ2: Moderating effect of EF scores and INFACT on CT performance

To study the moderating effects of individual differences in EF and participation in INFACT on external CT assessments, we examined the relationship among IACT scores and ACE scores for students using INFACT compared to those using other CT activities. This analysis included only students who had a complete set of data for both the pre/post IACT assessments and the ACE EF tasks. Pre-assessment scores showed a significant predictive effect of ACE score on IACT performance, with students scoring lower on ACE tending to score lower on IACT as well. However, this effect disappeared at post-assessment for both INFACT and comparison students.

While we did not observe a statistically significant interaction between ACE score and experimental condition (INFACT vs. comparison) in our analysis of RQ2, there were interesting findings when we looked at students scoring in the lowest third on the ACE tests in our *post hoc* analysis. Upon closer inspection, there was indication that the intervention was quite effective for students with low ACE scores. In fact, the *post hoc* analysis indicates that the intervention may have a large impact on students who struggle most due to EF barriers. We observed significant increases in scores on the IACT post-assessment for students in the INFACT group (see Figure 11) with Model 3 indicating that the lowest third of ACE scorers exhibited statistically significant gains (see Table 4). Students in the highest and middle thirds on the EF scores did not show this improvement. This was true for the INFACT and the control groups. This may be caused by ceiling effects in the assessment instrument or by an unrelated impact that the pandemic or other extraneous factor had on high EF students during that time. Further research is needed to understand the differential effects of INFACT on low EF and high EF students.

TABLE 2 Linear mixed-effects model used to analyze performance of students in the lowest third of ACE scores.

Model	Equation
Model 3	$Y_i = \beta_0 + \mu_i + \beta_1(Condition) + \beta_2(Time) + \epsilon_i$

Y_i= Predicted IACT score for student i, β = Fixed component, $\propto$ = Student random component, ϵ = Residual Error.

TABLE 3 Fixed effects for research question 1 model.

	Estimate	Std. Error	df	*t* value	*p*
(Intercept)	0.29	0.15	33.10	1.95	0.06
IACT.pre	0.1	0.08	332.30	1.73	0.08
ACE	0.090	0.09	245.41	0.96	0.34
Grade4	0.13	0.12	281.23	1.11	0.27
Grade5	−0.27	0.12	315.12	−2.23	0.03
Treatment	0.41	0.16	10.11	2.65	0.02

TABLE 4 LMEM results for *post hoc* analysis model described in Table 2.

	Estimate	Std. Error	df	*t* value	*p*
(Intercept)	0.37	0.10	221.96	3.56	<0.001
Condition: Treatment	−0.27	0.15	221.96	−1.85	0.07
Time: Post	−0.09	0.13	118.00	−0.74	0.46
Condition: Treatment x Time: Post	0.73	0.18	118.00	4.07	<0.001

3.3 RQ3: teachers' perceptions of CT and EF

Interviews with teachers provided insight into the linkages they saw between CT and their neurodivergent learners as they used the INFACT materials. While teachers rarely used the term "executive function," these interviews illustrate the many ways that using CT as a general problem-solving strategy helped teachers support neurodivergent learners across disciplines (Barchas-Lichtenstein et al., 2023).

Teachers used offline activities in complement with online coding and games to reach learners in different ways and reinforce the foundational CT concepts through related tasks. For example, we consistently heard teachers say that their high-energy students benefited from embodied, movement-based activities that helped them focus, while both visual and movement tasks were a valuable way to help less proficient readers participate alongside their peers.

Activities where students worked in pairs or small groups, rather than individually, were also advantageous in neurodiverse classrooms because teachers could encourage students with complementary strengths to work together; for example, a student who excelled at systematic thinking but who did not read as well could work with a strong reader who was more scattershot in their approach to problems. However, partnered activities required additional scaffolding for some students with social difficulties. Teachers also asked for additional physical and auditory adaptations (e.g., speech to text) for some of their students.

More than one teacher told us that some of their high-achieving students had a harder time connecting with INFACT. Often these students could complete a task correctly but had a harder time explaining their process. The INFACT materials required more metacognition and explicit expression of their problem-solving practices, which seemed to be a struggle for some of these students.

4 Discussion

The findings in this study help show that as CT continues to evolve as an educational discipline, innovative strategies can be used to broaden its appeal and impact. In particular, this study examined how embedding differentiation strategies and EF supports in CT teaching and learning materials can support CT learning, particularly for neurodivergent learners. The INFACT teaching and learning materials were designed to scaffold EF while engaging learners (in grades 3–8) in differentiated CT activities. While inclusive teaching methods used during INFACT are documented in the study, further development and research is suggested to support teacher professional development in the types of innovative teaching strategies required for inclusive CT learning.

CT has interesting connections with identified cognitive strengths of many neurodivergent learners and may be a rich area to broaden participation and nurture much-needed talent in the STEM workforce and in our society (Austin and Pisano, 2017). Systematic thinking and pattern recognition have been observed as extraordinary talents of some neurodivergent learners (Jolliffe and Baron-Cohen, 1997; Baron-Cohen, 2008; Mottron et al., 2009; Fugard et al., 2011), as has divergent thinking and abstraction of ideas (Beaty et al., 2015). INFACT was designed specifically with the hypothesis that these problem-solving talents may be revealed and nurtured through CT education, providing an avenue for neurodivergent learners to excel.

Our study of students in grades 3–5 who used INFACT showed a significant improvement on CT measures as compared to students in similar classes that used other CT teaching and learning activities (RQ1). This finding, while potentially unstable because of the small number of classes in each condition, shows promise and suggests further investigating how supporting neurodiversity in CT may improve participation in STEM problem-solving for a broad range of learners.

To address RQ2, which examined the impact of INFACT on neurodivergent learners, we explored the relationship between students' performance on ACE tasks (used to measure EF) and their performance on IACT items (used to measure CT) in both the INFACT and the comparison classes. We found that the ACE scores had a high correlation to the pre-assessment IACT scores, with students scoring lower on ACE tending to score lower on IACT as well. This provides further evidence that CT and EF may be related. Interestingly, however, this effect disappeared in the post-assessment scores for both INFACT and comparison students. To examine why the effect disappeared, we conducted a post-hoc analysis of students with the lowest third of ACE scores. The analysis revealed that students scoring in the lowest ACE third on the pre-assessment exhibited a dramatic improvement in CT after implementation of INFACT. This effect was not observed in the comparison condition.

What is clear from the disaggregated EF data is that INFACT dramatically improved the CT scores of learners in the lowest third of EF, compared to other forms of CT instruction. This finding presents an interesting start towards the inclusion of neurodiversity in CT. Supporting EF and differentiating teaching and learning for students, in CT and in STEM problem-solving in general, is not only a strategy for better inclusive education, it also may be critical for our future STEM workforce. Many STEM companies and research labs are starting to recognize the talent of neurodiversity, and opportunities are becoming more widely available for neurodivergent STEM problem solvers to be recognized for the contributions and innovative perspectives they bring to our workforce and society (Austin and Pisano, 2017).

In the examination of RQ3, we found that teachers attributed INFACT's success with neurodivergent learners, in part, to its variety of modalities of activities (e.g., offline activities, puzzles, games, and robotics) to help learners build foundational conceptual understandings in CT and apply those practices to new contexts. Teachers reported this flexibility helped them reach a wide range of learners and tap into the individual strengths of their students. Differentiation strategies such as allowing multiple entry points into an activity, and offering many different modalities for the activity were also seen to be important factors in the success of INFACT students. Because one of the foci of CT in INFACT is Clear Commands, the curriculum allows natural openings to discuss communications differences in class, and having different forms of activities that could be done individually, in small groups, or as an entire class enabled differentiation for students with social communication differences. These differentiation strategies are aligned with UDL principles and build on the teaching recommendations for an asset-perspective to education, where activities are designed to reveal and nurture individual learners' strengths while supporting their challenges (Tomlinson and Strickland, 2005).

Teachers noted in particular that "get-up-and-go" offline activities were important to engage their high energy students and were harder to find in other CT programs. Teachers reported that many of their students benefited from that physical engagement. Teachers also noted that while INFACT was designed with UDL principles, further accommodations were needed to reach some of the students with physical and auditory challenges. INFACT was primarily designed for in-classroom use with a group, so the activities were studied in that venue. The activities were also designed, however, during COVID lockdowns, and many of the early users were trying the activities at home and with families. The embedded differentiation of the activities made this transition easy and effective. Finally, we saw that differentiation to include all learners includes not only scaffolding for EF, but also an emphasis on vocabulary development and offering multiple contexts and entry points. In particular, some teachers suggested we also provide more choice and complexity for students who want to dig deeper into CT. These are some of our next steps for future design and development of INFACT.

There were limitations to this research compounded by the fact that it was conducted during the 2021–2022 school year when schools were still heavily impacted by the COVID pandemic, including lasting impacts of previous closures and restrictions. It was extremely difficult to find teachers who were able to commit to the rigid timeframe of the study, and to do all that was required to collect a complete set of student data. Because of this, the study was underpowered, and the effects should continue to be verified with more teachers and learners in the coming years. The comparison between treatment and comparison conditions also was limited by the lack of a standard CT teaching and learning experience outside of INFACT. In addition, a lack of standard CT assessment, particularly for this age group and without extraneous barriers for neurodivergent learners, limits the interpretation of the results. Finally, because of our limited sample size, we were unable to disaggregate data further by race, gender, or other demographics that may impact students' engagement in CT (Ardito et al., 2020; Leonard et al., 2021), as well as the likelihood they identify or have been identified as a neurodivergent learner (Asbell-Clarke, 2023).

Even with the limitations, the findings suggest that CT teaching and learning materials that support differentiation and scaffold executive function are worth further study. CT is an area where many neurodivergent learners may discover their own talents and interests. Supporting working memory, attention, and metacognition with CT activities may help reveal those talents and support innovative problem solving among this often marginalized group.

Features of INFACT teaching and learning materials that may be most responsible for supporting young neurodivergent learners include offering multiple entry points and modalities for learning activities, supporting clear communication and vocabulary, and using "get up and go" activities to engage high energy learners. While CT may be a particularly beneficial area to support neurodivergent learners, these types of supports may work well in other disciplines as well and should be explored, particularly in other areas of STEM problem solving.

Because CT is, at its root, simply a form of STEM problem solving (Weintrop et al., 2016; Shute et al., 2017), the findings of this research on INFACT may illustrate how these supports can be expanded and integrated into other areas of STEM.

Data availability statement

The datasets presented in this article are not readily available because Data are restricted by confidentiality of minor students' data. Requests to access the datasets should be directed to jodi_asbell-clarke@terc.edu.

Ethics statement

The studies involving humans were approved by TERC Institutional Review Board, TERC. 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.

Author contributions

JA-C: Conceptualization, Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. ID-H: Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – review & editing. JV: Data curation, Formal analysis, Investigation, Methodology, Supervision, Validation, Writing – review & editing. BA: Data curation, Investigation, Methodology, Writing – review & editing. JB-L: Data curation, Investigation, Methodology, Supervision, Validation, Writing – review & editing. TE: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing. EB: Conceptualization, Resources, Visualization, Writing – review & editing. TR: Resources, Visualization, Writing – review & editing. KP: Project administration, Resources, Writing – review & editing. SG: Resources, Writing – review & editing. MI: Conceptualization, Resources, Writing – review & editing. FK: Writing – review & editing. DW: Resources, 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.

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Toward institutional transformation: warming the chilly climate for women in STEM through macrostructural change

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Introduction: Although the demand for graduates with Science, Technology, Engineering, and Mathematics (STEM) credentials continues to climb, women remain underrepresented as both students and faculty in STEM higher education. Compounding social forces can hinder organizational change for gender equity in STEM, constraining institutions and individuals within them. This study advances macrostructural theory to examine the impact of gender composition (including group size and heterogeneity) of women faculty on structural change, as measured by gender desegregation of STEM degree earners. We advance this theory by incorporating faculty *rank*, rather than treating group composition as a static category.

Method: This study draws on a federal repository of data to assess institutional change in the share of STEM women faculty in the U.S. We employ quasi-experimental methods to explore the following research questions: (1) does hiring more women onto an institution's faculty roster shrink the gender gap among STEM degree earners? and (2) does segregation of faculty by gender within institutions shape the gender gap among STEM degree earners?

Findings: While institutional efforts herald their efforts of hiring more women faculty, our findings indicate that gender desegregation of STEM degree earners partially depends on the promotion of women faculty to tenure.

Discussion: Implications for theory, policy, and practice are discussed, with a focus on institutional-level change.

KEYWORDS

gender equity, academic workforce, higher education, macrostructural theory, STEM higher education, augmented inverse probability weighted

Introduction

Although the demand for graduates with Science, Technology, Engineering, and Mathematics (STEM) credentials continues to climb, women remain underrepresented in STEM higher education and among the faculty of STEM departments. This persistent gender gap in STEM writ large may seem surprising, as women have surpassed men's overall higher education degree achievement (DiPrete and Buchmann, 2013) and some STEM fields have made progress toward gender equity, especially at the undergraduate level (Perez-Felkner, 2018; National Science Board, National Science Foundation, 2021). Further, the scientific labor market has fueled United States economic growth (Maton et al., 2016), heightening the demand for graduates with STEM qualifications (Fayer et al., 2017). The STEM sector's continued expansion and purported reliance on fair, objective criteria for employment should facilitate gender integration into its myriad prestigious career tracks (Xie et al., 2015; Padavic and Prokos, 2016).

Why then do women hold a minority share of jobs in most STEM sectors in the United States economy, including less than 25% in computing and engineering roles (Beede et al., 2011; Fry et al., 2019)? Perhaps women's marginalization in STEM is an expected reflection of hegemonic male dominance in the sciences (Carter et al., 2019; Pawley, 2019) and academia (Bird, 2010; Haas, 2016). Organizational change for gender equity in academic STEM professions must counter compounding social forces affecting institutions and the individuals within them (Britton, 2017; Jensen and Deemer, 2019; Nichols, 2019). This study draws on a national repository of institutional data to analyze the impact of faculty gender equity on that of undergraduate STEM degree recipients. We aim to identify the mechanisms which effectively increase women's share of STEM degrees conferred and faculty roles.

In this study, we advance theory on *gendered organizations* (Acker, 1990, 2006; Ridgeway, 1997; Ely and Meyerson, 2000) and *social contact theory* (Blau, 1977; Fitzpatrick and Hwang, 1992). We identify mechanisms that may undo gender segregation in STEM. Research on institutional transformation programs in higher education has illuminated that successful gender transformation in STEM requires systemic approaches that support women at all organizational levels, rather than simply removing women's barriers to entry (Bilimoria et al., 2008; Griffin, 2020). Indeed, institutions across the U.S. are changing demographically (Grawe, 2018), whether institutions have formally implemented gender transformation methods. Stakeholders must understand how changes in women's enrollment, hiring, and promotion impact STEM outcomes, intentionally or otherwise. Equipped with this knowledge, colleges and universities can adapt mechanisms to improve STEM gender equity that best fit their institutional context.

We ask: does simply hiring more women onto an institution's faculty roster–regardless of tenure status–contribute to closing the gender gap in STEM degree attainment? Or should institutions seeking to reduce gender segregation in STEM specifically increase women's representation among *tenured* faculty roles? We also examine whether the degree of faculty gender segregation impacts gender exposure among STEM degree earners. Using the most recent federal data available on women's STEM degree outcomes at U.S. institutions, we investigate how changes in (1) the proportion of women faculty at each rank and (2) the degree of gender segregation among faculty at each rank between two timepoints impact the degree of gender exposure among STEM undergraduates. While institutional efforts herald their efforts of hiring more women faculty, we find that women's postsecondary STEM outcomes partially depend on the promotion of women faculty to tenure and the reduction of faculty gender segregation.

Literature review

Institutional responses to gender disparities

In recent years, higher education institutions have moved to address gender inequalities in STEM education alongside other diversity and inclusion issues on campuses (Ahmed, 2012). Recognizing gender and racial-ethnic disparities in STEM postsecondary education, federal policymakers and programs have established calls for action, and institutions have followed suit (Rincón and George-Jackson, 2016). The goal in taking these actions, including hiring more women and minorities within STEM, is to increase the presence of gender- and/or race-matched mentors, and warm potentially chilly climates within these fields. Prior studies on changing STEM climates have primarily used qualitative data, centered in single institutional contexts and point-in-time analyses (e.g., Gasman et al., 2017). While site-specific evaluations of institutional diversity and inclusion efforts offer useful insights, these studies are unable to evaluate how institutions and diversity-related outcomes are changing across the entire higher education landscape. Moreover, challenges in accessing rich higher education STEM outcomes data have limited researchers' ability to assess change over time (see Perez-Felkner, 2018).

One common institutional response to promote gender equity is to recruit more women faculty. While institutions have increasingly deployed diversity and inclusion efforts that publicly prioritize *hiring* of women and minorities, the processes of faculty *promotion and retention* are murkier (Seebruck and Savage, 2020). Although women currently earn most doctoral degrees conferred annually, they hold fewer tenured faculty positions and earn lower salaries than male academic peers (Johnson, 2017). Unequal representation of women in faculty roles may dissuade undergraduate women from lab- and research-intensive majors, notably in STEM. A dearth of representative faculty limits the opportunity for interactions that challenge stereotypes about women in STEM, contributing to the reproduction of a chilly climate (Cheryan et al., 2013; Britton, 2017). It also limits opportunities for women to have gender-matched academic role models and mentors, who may increase women's attraction to and retention in STEM (Kricorian et al., 2020; Swafford and Anderson, 2020). In contrast, receiving STEM instruction from a woman tends to improve students' beliefs about women's ability in these fields (Sansone, 2018). Accordingly, exposure to women faculty is vital for attracting and retaining women in STEM.

Previous research suggests women's faculty rank influences women's STEM degree production, as women's disproportionate presence in lower-ranked and non-tenure-earning roles may reinforce gendered stereotypes for STEM-aspiring women (Griffith, 2010; Griffith, 2014; Šaras et al., 2018). However, prior research has not examined whether gender composition of faculty by rank influences the degree of gender segregation present in STEM majors. We address this gap using quasi-experimental methodology to assess the likelihood of interaction within major disciplines, across gender (*gender exposure*). We measure the extent to which faculty gender composition by rank impacts the degree of gender exposure within STEM majors, furthering our collective understanding of its influence on women's STEM degree production.

Theoretical framework: Blau's macrostructural theory

Undergraduate women are positioned as inferior in many academic STEM environments, underrepresented in the cited literature, patents, and awards. At the interpersonal level, earlier research suggests faculty demonstrate bias in favor of men STEM students (Moss-Racusin et al., 2012); men–especially White men–tend to gain advantages from the cultural framing of science as masculine (Miller and Roksa, 2019). Prior research has identified microaggressions and discrimination toward women in STEM (Lester et al., 2017; Ong et al., 2018; Johnson et al., 2019) as well as gendered communication challenges among some faculty, staff, and students (Vitores and Gil-Juárez, 2016).

Structurally, scholars have found that women's underrepresentation in STEM faculty roles reduces the availability of gender-matched role models and mentors for undergraduate women (Sonnert et al., 2007), which is in turn associated with less connection and sense of belonging (Gaston Gayles and Ampaw, 2014). The absence or seemingly token presence of women STEM faculty can reinforce negative gender stereotypes at the departmental and institutional levels (Stoeger et al., 2013; Williams et al., 2021).

These interpersonal and structural contextual factors contribute to a negative or "chilly climate" in STEM fields, where women are less likely to become socially integrated and retained (Hall and Sandler, 1984; Šaras et al., 2018; Lee and McCabe, 2021). The degree of gender segregation between STEM and non-STEM fields is a major contributor to the chilly climate in STEM and associated the loss or "leaks" of talented scientists (see, e.g., Hinton et al., 2020). There are often limited opportunities in STEM for women to form meaningful social associations with more senior scientists, which in many STEM fields continue to be mostly men (Hall and Sandler, 1984; Simon et al., 2017). Research has documented its link to negative outcomes for STEM-aspiring women (Allan and Madden, 2006). These outcomes include reduced self-selection of women into STEM majors, increased attrition of women STEM majors, and fewer women STEM graduates entering the labor market (Glass et al., 2013). Altogether, the proportional share of women undergraduates and faculty may be strong institutional indicators of how welcoming academic environments are for women in STEM.

Macrostructural theory demonstrates that intergroup relations are dependent on the makeup of the social structure (Blau, 1977). To mitigate the chilly climate for women in STEM, the social structure must afford opportunities for positive interactions between women and men in STEM among and between students and faculty. Social structures affect intergroup associations. This hypothesis has been confirmed in studies spanning different fields, including interracial contact (Fitzpatrick and Hwang, 1992; Chakravarti et al., 2014), and intergender work relations (Randel, 2002; Kath et al., 2009; Merluzzi, 2017). We further demonstrate the utility of this theory by examining factors which foster gender segregation and chilly climates for women in STEM education. We expand Blau's theory by incorporating hierarchical rank as a factor shaping intergroup relations in this context.

Structural conditions in institutions–including faculty gender composition and faculty gender segregation across departments–may impact chilly climates by constraining or creating opportunities for both mixed-gender and gender-matched social relationships. We hypothesize that the *group size* (share of women employed at each faculty rank) impacts the likelihood of intergroup exposure between women and men in undergraduate STEM education. Interactions with tenured faculty may be key in challenging negative stereotypes about women in STEM by exposing students to women in rigorous research-centered roles. For women STEM students, interactions with tenured women faculty promote a sense of belonging, providing vital access to gender-matched mentors in academia (Sonnert et al., 2007; Gaston Gayles and Ampaw, 2014). In this study, we quantify group size as the proportion of each institution's faculty roles, at each rank, that are held by women.

Faculty are unevenly distributed across academic degree programs by gender. We hypothesize that *heterogeneity*—another structural condition referring to the degree of gender integration among faculty at each rank—influences gender segregation in STEM majors. Increasing heterogeneity in the form of decreasing segregation between women and men faculty at each rank may promote opportunities for positive interactions between women and men in STEM. We examine this structural condition as the change in gender composition in higher educational institutions' faculty population, and the impact it may have on gender desegregation in STEM.

Gendered faculty hierarchies: the focus on women faculty

Much like the gendered undergraduate STEM student experience, faculty roles on academic campuses are shaped by interactions that lead to gendered disparities in work tasks, salary, prestige, and promotion (Kelly and McCann, 2019). This is especially true for women faculty who are also Black, Indigenous, and People of Color (Kelly and McCann, 2014; Haynes et al., 2020). Bias and exclusions emerge for women in STEM during the processes of hiring and employment as faculty members (Bird, 2010). Accordingly, women are more likely to opt out of academic careers than men prior to entry into a faculty position (Armstrong and Jovanovic, 2015). Some scholars contend that women's underrepresentation among permanent, full-time STEM faculty positions results from reduced competence or interest in STEM compared to male peers (Summers, 2005). However, these perspectives fail to account for the social forces that impact the hiring and promotion of women faculty.

Underrepresentation of women faculty: group size

At the institutional level, STEM women faculty face myriad barriers to employment and promotion in a tenure-earning role. This results in smaller group size for women, and a greater degree of segregation between women and men faculty throughout departments on campus. In the U.S., federal and state laws prohibit gender discrimination in hiring and employment in higher education, yet hiring inequalities persist in this context (Simon et al., 2017). While many institutions have procedures to veto selected candidates for faculty hire, decisions about hiring faculty are typically made by faculty committees at the departmental level using subjective criteria (White-Lewis, 2020), limiting the institution's procedural ability to fully control hiring selections and ensure equity.

Additionally, women faculty experience disproportionate institutional challenges in the promotion and tenure process as compared to their male peers. Most institutions assign limited value to service work contributions in the tenure process (Bird, 2010). Traditional metrics for measuring productivity, such as publication counts, do not account for the gendered allocation of service tasks and their detraction from research productivity (Xie and Shauman, 2003). Some institutions offer policies allowing pre-tenure women who have children to *pause the tenure clock*, which extends the tenure-track timeframe without impairing candidacy (Mason et al., 2013). Women who take advantage of such institutional policies risk bias during their tenure evaluation and may experience more stigma than their male counterparts who use such policies. Moreover, *pausing the tenure clock* can postpone potential salary increases, reduce cumulative lifetime earnings, and delay the attainment of job security when tenure is achieved (Misra et al., 2012; Williams et al., 2013).

Even when accounting for differences in institutional context and candidate productivity, women achieve tenure at significantly lower rates than men (Weisshaar, 2017). This trend disproportionately affects women of color who experience compounding challenges—a double bind—at the intersection of race and gender in academia as well as specifically in STEM (Ong et al., 2011; Griffin, 2020). However, research has not yet accounted for how women's lower rates of faculty promotion and hiring correspond with gender segregation of STEM undergraduates.

Gender segregation of faculty by program: heterogeneity

Faculty and their roles are distinguished by their rank–i.e., untenured but tenure-eligible assistant professors as compared to tenured faculty at the associate and full professor levels. While rank exists for faculty off the tenure-track as well, promotion among tenure-eligible faculty often results in the attainment of tenure, and the intended "permanent" job stability and prestige associated with it (e.g., Youn and Price, 2009). Among those women who receive tenure, women in STEM remain a minority. In 2018, women comprised fewer than 30% of tenured or tenure-track faculty rolls among U.S. higher education institutions (Roy, 2019). The scarcity of women faculty in STEM reduces the potential for meaningful interactions between women faculty and students. Research on the positive effects of diversity indicates that compositional diversity is insufficient: *interaction* among individuals from diverse backgrounds drives the benefits of diversity in postsecondary educational institutions (Gurin et al., 2002). We argue that positive interactions between students and women faculty are necessary to challenge stereotypes about women in STEM and to warm the chilly climate.

Women make up a lower proportion of tenured faculty than men, however they tend to be overrepresented in non-tenure-earning roles (Kezar and Sam, 2013). This two-fold segregation may reduce opportunities for meaningful interaction among faculty, and among faculty and students. Faculty on the tenure-track have multiple publishing and service duties in addition to teaching and mentoring. Contingent faculty–as compared to "permanent faculty" with an opportunity to attain tenure–may not have the same amount of time and resources to dedicate to mentor students and engage in professional development; moreover, they tend to earn less (Childress, 2019).

The share of contingent faculty has been growing in recent decades, in part but not exclusively for budgetary reasons (McNaughtan et al., 2017). Non-tenure earning faculty appointments present status challenges for faculty within these roles, especially those with already marginalized identities (O'Meara et al., 2018; Rideau, 2019). Limited exposure to tenured and tenure-earning faculty appears to have negative consequences for student retention as well (Jaeger and Eagan, 2011). When women comprise a small minority in a STEM department, and even fewer women hold permanent, tenured faculty roles, there are limited opportunities for meaningful gender-matched association among women faculty and women students in STEM, like mentorship and advising.

The effects of such segregation have been demonstrated across contexts. Broadly, segregation diminishes intergroup contact and contributes to the production of intergroup bias and conflict (Enos and Celaya, 2018). For example, residential segregation has been shown to negatively predict interracial friendship in schools (Mouw and Entwisle, 2006). Although explorations of segregation and heterogeneity have typically focused on residential segregation by race, the flexibility of Blau's (1977) macrostructural theory allows us to expand this exploration into the university system.

Current study

Below, we present the first analysis of macrostructural theory in higher education and focus on the decade following the launch of a federally funded initiative to incentivize and support institutional-level transformation for gender equity among STEM faculty (Bilimoria et al., 2008). We seek to answer the following primary research questions. First, does an increase of at least 5% in women's proportional representation at different faculty ranks over time correspond with *increased gender exposure*–in other words, *decreased gender segregation*–of degree earners in STEM? Second, does a decrease in faculty gender segregation by rank lead to a decrease in gender segregation of STEM degree earners?

Methodology

Data source and sample

The present study uses publicly available higher education data from the National Center for Education Statistics Integrated Postsecondary Data System (IPEDS) to construct a model of change in gender exposure among STEM degree earners as impacted by changes in women's faculty composition, changes in women's enrollment, and various student and institutional factors. The dataset primarily features data from the 2000–01 and 2008–09 IPEDS reporting cycles. In each of these cycles, the IPEDS survey schedule posed an identical battery of questions about STEM degree completion by gender group. We limited our sample to include all U.S. institutions with a tenure system that offered bachelor's degrees in both 2000–01 and 2008–09. Although more recent years of data have been collected, these collection waves do not include the special, non-recurring battery of STEM-related questions needed to analyze our research questions.

Using this reported institutional data on STEM degree production, enrollment, faculty, and financial aid status reported in the 2000–01 and 2008–09 IPEDS reporting cycles, we generated variables for the degree of exposure between women and men STEM bachelor's degree earners, the change in women faculty group size by rank, the change in faculty gender heterogeneity within institutions, and the change in percentage points of students receiving federal financial aid between these two time points.

Quasi-experimental design: augmented inverse probability weighting

We selected augmented inverse probability weighting (AIPW) to conduct a quasi- experimental analysis. AIPW methodology uses doubly robust weighting techniques to control for the non-random assignment of increases in women faculty and heterogeneity by rank and by institution. The AIPW estimator is appropriate for modeling these relationships because it only requires specification of a logistic regression model for the propensity score, and specification of the regression model for the outcome variable (Glynn and Quinn, 2010). AIPW assumes that the treatment is not randomly assigned, which is appropriate for the present analysis as gender segregation of faculty is not random.

The goal is to estimate the potential outcome (gender integration) that would be observed if students were assigned the segregation treatment, then to compare the mean outcome if all students in the population were assigned either segregation or integration treatment at each faculty rank.[1] Coefficients produced from AIPW are probabilities ranging between 0 and 1 and can be interpreted as such.

To ensure the model appropriateness, we explored the assumptions of AIPW modeling, including stable unit treatment value assumption (SUTVA), consistency, exchangeability, and positivity. The primary tenet of SUTVA is to ensure that the treatment assigned to one unit has no effect on the potential outcomes of others. In our university-level analysis, each university is a distinct unit, and the treatment is applied solely within the confines of each specific university, thus having no effect on the others. The consistency assumption is met, as we explore how potential changes in structural composition of the university impact the structure of interactions within it. Thus, if gender desegregation among faculty occurs, it is plausible that gender desegregation among students would also occur. We explored the likeness of treated universities and untreated universities to consider the exchangeability assumption of AIPW. To this end, we control for university Carnegie classification, and the level of STEM exposure that existed during Time 1 of the analysis. The positivity assumption is also met, in that there is greater than zero chance that any university increases its women-faculty population by at least 5%.

To construct our model, the following variables were used to match institutions for the quasi-experimental comparison: increases in women's bachelor's degree attainment generally, increases in general enrollment and women's enrollment over time, changes in the proportion of students receiving federal aid over time, whether the institution is an Historically Black College or University (HBCU), whether a university is a Land Grant institution, whether the institution is publicly controlled, the size of the institution, whether an institution is located in a city, and highest degree awarded by the university as indicated by its Carnegie Classification. Our use of AIPW modeling techniques allows us to infer quasi-causality, that an increase of at least 5% in women faculty by rank and in heterogeneity is not only correlated with but *impacts* the degree of gender segregation between women and men STEM degree earners.

Treatment variables

Changes in women faculty group size by rank were dichotomized to a 5% or more increase in the proportion of women faculty vs. a less than 5% increase or decrease in the proportion of women faculty. We chose the benchmark of 5% because this modest increase suggests an institutional commitment to increasing the number of women faculty, while being attainable during the study window across institution types studied. We also test alternative specifications in a sensitivity analysis described later in the manuscript. It is important to calculate these variables by faculty rank, as we have posited throughout this manuscript that simply increasing the presence of women faculty is unlikely to affect student outcomes. Rather, we posit that increasing the number of *tenured* women faculty is most likely to have an effect.

Table 1 reports on our treatment, dependent, and control variables. About half of universities increased the proportion of tenured women faculty by 5% or more, while approximately 46% increased the proportion of tenure-track women faculty by the same amount. About 47% increased the proportion of non-tenure-track women faculty by 5% or more.

To construct each variable representing changes in women faculty group size by rank at each included U.S. institution, we first calculated the difference in the proportion of women faculty at each rank, between two time points. These measures were recoded such that 1 represents an increase of at least 5% in the proportion of women faculty, and 0 indicates a less than 5% increase or a decrease in the proportion of women faculty. The final dichotomous variables created by this procedure include (1) change in group size of all women faculty, (2) change in group size of tenured women faculty, and (3) change in group size of untenured or non-tenure-track women faculty. In sensitivity analyses, we treated the increased proportion of tenured women faculty at a series of levels (from 1% through 10%) to assess multiple potential interventions and contextualize the quasi-experimental analysis we focus on here.

The gender-specific faculty rank question was not a required response during the 2001–02 and 2008–09 reporting cycles. Thus, we substituted faculty data collected during the 1999–00 and 2007–08 reporting cycles. This is appropriate because we would expect some degree of lag between the hiring or promoting of women faculty and observed impacts on degree completers. To mitigate potential bias from missingness in enrollment for our first time point, we substituted 2001–02 data for the 2000–01 data on women's enrollment.

Dependent variable: gender exposure among STEM degree earners

Our dependent variable in this study is the degree of exposure between women and men STEM degree earners, derived from Massey and Denton's (1988) measures of segregation. The exposure index measures a group's exposure to other groups in the form of a weighted average depicting the gender distribution across STEM majors. It measures how likely women and men are to interact with one another within STEM majors. The index ranges from 0 to 1, where 1 indicates 100% likelihood of exposure between groups. Exposure is calculated using this formula:

$$\sum_{i=1}^{n}\left[\left(\frac{x_i}{X}\right)\left(\frac{y_i}{t_i}\right)\right],$$

where x refers to the minority population, X refers to the sum of the total minority population, y refers to the majority population, and t

1 Dichotomizing these variables is necessary to create the treatment conditions for our quasi-experimental design.

TABLE 1 Descriptive statistics.

	Mean/ Proportion	SD	Min	Max
Dependent variable: bachelor's degree outcomes				
STEM Degree Exposure 2008–09	0.39	0.13	0	0.93
STEM Degree Exposure 2000–01	0.39	0.14	0	0.97
Treatment variables: faculty indicators				
Proportion of institutions that increased tenured women faculty presence by 5% or more	50.00%		0	1
Proportion of institutions that increased tenure-track women faculty presence by 5% or more	46.16%		0	1
Proportion of institutions that increased non- tenure-track women faculty presence by 5% or more	46.80%		0	1
Women's enrollment indicators				
Increase in 12-month unduplicated enrollment of women (2001–02 to 2008–09)	116.04	219.65	−482	2,706
Federal financial aid				
% Point increase in students receiving federal grants	5.79	10.67	−53	69
Carnegie classification				
Doctoral degree granting	20.56%			
Master's degree granting	40.40%			
Bachelor's degree granting	38.72%			
Associate's degree granting	0.32%			
Institutional features				
Public institution	57.84%		0	1
Historically black college or university	42.16%		0	1
Land grant institution	5.68%		0	1
Urbanicity				
City	45.92%			
Suburb	22.24%			
Town	23.28%			
Rural	8.56%			
N	1,250			

National Center for Education Statistics Integrated Postsecondary Data System (IPEDS).

refers to the total population. In other words, the exposure measures the degree to which STEM majors have been desegregated within institutions.

The average degree of exposure in 2008–09 within STEM is 0.39, meaning that on average there is a 39% chance that women and men in STEM had the opportunity to form meaningful social relationships in the 2008–09 academic year. Our model controls for degree exposure at our first study time point in 2000–01. The average degree exposure in 2000–01 was 0.39, meaning that on average there is a 39% chance that women and men in STEM had the opportunity to form meaningful social relationships in the 2000–01 academic year.

Covariate independent variables

Change in faculty gender heterogeneity by rank

We also examine the change in faculty gender heterogeneity–via decrease in homogeneity–among faculty at each rank from 1999–2000 to 2007–08, including tenured, tenure-track, and non-tenure-track faculty. We created an isolation index (Massey and Denton, 1988) to measure changes in homogeneity (the likelihood that faculty members at each rank would interact only with members of the same gender at each time point). A decrease in homogeneity corresponds to an increase in heterogeneity. The isolation index is calculated using this formula:

$$\sum_{i=1}^{n}\left[\left(\frac{x_i}{X}\right)\left(\frac{x_i}{t_i}\right)\right]$$

where x refers to the minority population, X refers to the total sum of the minority population, and t refers to the total population.

Controls

Control variables measuring institutional context include: changes in women's bachelor's degree attainment over time, changes in general enrollment and women's enrollment over time, changes in the proportion of students receiving federal aid over time, whether the institution is an Historically Black College or

University (HBCU), whether a university is a Land Grant institution, whether the institution is publicly controlled, the size of the institution, whether an institution is located in a city, and highest degree awarded by the university as indicated by its Carnegie Classification. We include these controls because they are the exhaustive list of potential descriptive variables in our IPEDS data and are likely to have a significant effect on STEM degree production.

Hypotheses

Group size

While institutions may champion efforts to hire more women, placing more women in teaching or specialized faculty roles that deemphasize research duties reinforces gendered stereotypes about women's research abilities. As such, we hypothesize that only increases in faculty group size at the tenured level will significantly increase gender exposure among STEM undergraduates. We hypothesize that increases in faculty group size at the non-tenure-track and tenure-track levels will not significantly impact gender exposure among STEM undergraduates. Although tenure-track women faculty serve as role models for STEM-aspiring women, their visibility, availability, and agency are limited by pressures of the tenure process and by the gendered burden of institutional service work. On the other hand, with the tenure process complete, tenured women research faculty are more secure in the stability of their role with the institution and have more time to engage in non-research tasks, such as mentorship and advising of undergraduate women.

> *H1*: Increasing the proportion of non-tenure-track women faculty will not significantly increase gender exposure among STEM undergraduates.
>
> *H2*: Increasing the proportion of tenure-track women faculty will not correspond with gender exposure among STEM undergraduates.
>
> *H3*: Increasing in the proportion of tenured women faculty will increase gender exposure among STEM degree earners.

Heterogeneity

Our second set of hypotheses addresses changes in heterogeneity by gender among faculty at each rank. We hypothesize that increasing gender heterogeneity among faculty–by decreasing gender homogeneity–will only significantly increase gender exposure among STEM undergraduates when the increase is among *tenured* faculty. Because women faculty comprise a small share of the faculty in certain disciplines, decreasing homogeneity may not equate to fully gender-integrated programs. Regardless of the degree of gender integration among faculty, those who are not on the tenure track do not have the same job security and academic freedom as their tenured and tenure-track peers. In turn, such faculty members may concentrate their efforts on the teaching and administrative responsibilities most central to their job description, with little time left for mentorship of STEM undergraduates. Conversely, prior research demonstrates that tenured faculty have greater time and resources available to provide meaningful mentorship to STEM undergraduates. Thus, an increase in heterogeneity (via a reduction in homogeneity) among tenured faculty may significantly change the culture of a program in ways that help "thaw" the chilly climate in STEM.

We measure the limited interactions between men and faculty using an isolation index (Massey and Denton, 1988) at each time point, which assesses the degree to which women and men engage in only same-gender interactions. The index ranges from 0 to 1 and is represented as a proportion. We measure the change in heterogeneity at each faculty rank from 1999 to 2007.

> *H4*: Reducing the homogeneity by gender of non-tenure-track faculty will not significantly increase gender exposure among STEM undergraduates.
>
> *H5*: Reducing the homogeneity of tenure-track faculty will not significantly increase gender exposure among STEM undergraduates.
>
> *H6*: Reducing the homogeneity of tenured faculty will significantly increase gender exposure among STEM degree earners.

Recall Table 1 shows measures for the dependent and independent variables at the two time points of this study. Table 2 shows the test results for Hypotheses 1–3, where Model 1 tests the relationship between a general increase in STEM women faculty group size and STEM degree earner gender segregation, Model 2 tests this relationship among non-tenure-track women faculty, Model 3 among tenure-track women faculty, and Model 4 among tenured women faculty. Table 3 shows test results for Hypotheses 5–8. Model 4 tests the relationship between a general increase in faculty heterogeneity and STEM degree earner gender segregation. Model 6 tests this relationship among non-tenure-track women faculty, Model 7 among tenure-track women faculty, and Model 8 among tenured women faculty.

Results

Results for all hypothesis tests are presented in Tables 2, 3. Blau's (1977) original macrostructural theory does not account for differing statuses within groups, hindering its utility. The present study advances this theory through application to a new context and offers a unique contribution through the addition of the nuance of faculty rank as a status that shapes intergroup relations. The dependent variable—degree of exposure—is a calculated probability that ranges from 0 to 1 and can be interpreted as a proportion.

Hypothesis testing: group size

H1: increasing the proportion of non-tenure-track women faculty

Table 2 Model 2 shows the results of our Hypothesis 1 test. Increasing an institution's proportion of non-tenure track women faculty by 5% or more does *not* increase gender exposure. In other words, a substantial increase in non-tenure-track faculty does not contribute to the gender desegregation of STEM degree earners. Hypothesis 1 is confirmed.

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TABLE 2 AIPW regression of STEM degree exposure by increase in women faculty by 5% or more.

	[1]	[2]		[3]		[4]		
	5% Increase all ranks	5% Increase non-tenure track		5% Increase tenure-track		5% Increase tenure only		
STEM degree gender exposure (Time 2)	−0.001 [0.005]	−0.003 [0.003]		0.001 [0.003]		0.007* [0.005]		
	Control	Exp: 5% increase	Control	Exp: 5% increase	Control	Exp: 5% increase	Control	Exp: 5% increase
Women's enrollment indicators								
Increase in bachelor's degrees earned by women	−0.000* [0.000]	−0.000** [0.000]	−0.000** [0.000]	−0.000** [0.000]	−0.000** [0.000]	−0.000** [0.000]	−0.000** [0.000]	−0.000** [0.000]
Carnegie classification								
MA degree granting	−0.022*** [0.009]	−0.050*** [0.011]	−0.018*** [0.005]	−0.024*** [0.007]	−0.019*** [0.005]	−0.018*** [0.006]	−0.022*** [0.005]	−0.018** [0.005]
BA degree granting	−0.020** [0.001]	−0.012 [0.014]	−0.018** [0.007]	−0.011 [0.008]	−0.020** [0.007]	−0.005 [0.008]	−0.021 [0.007]	−0.004 [0.008]
STEM degree exposure (Time 1)	0.808*** [0.029]	0.417*** [0.045]	0.839*** [0.030]	0.772*** [0.037]	0.822*** [0.031]	0.745*** [0.042]	0.850*** [0.024]	0.745*** [0.042]
Constant	0.091*** [0.013]	0.208*** [0.028]	0.080*** [0.013]	0.104*** [0.016]	0.084*** [0.013]	0.112*** [0.018]	0.077*** [0.011]	0.112*** [0.018]
N	1,250		1,250		1,250		1,250	

Source. National Center for Education Statistics Integrated Postsecondary Data System (IPEDS). The following variables were included in the model but not reported for space reasons: Increase in Women's Enrollment Percentage, Federal Financial Aid % Share, Public Institution, Historically Black College or University, Land Grant Institution, and Urbanicity. Robust standard errors are reported in brackets under the unstandardized slope coefficients. $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

H2: increasing the proportion of tenure-track women faculty

We assess our second hypothesis as shown in Table 2, Model 3. An increase of tenure-track women faculty is not associated with increased gender exposure among STEM degree earners. Thus, Hypothesis 2 is confirmed.

H3: increasing in the proportion of tenured women faculty

Our test for hypothesis 3 is shown in Table 2, Model 4. As expected, an increase of tenured women faculty by 5% or more contributes significantly to the gender desegregation of STEM degree earners, increasing STEM degree earner exposure by 0.7%. In other words, a 5% increase in tenured women faculty increases the likelihood that women and men STEM degree earners will interact by 0.7% ($b = 0.007$, $p < 0.05$). Thus, Hypothesis 3 is confirmed.

Summary: hypotheses 1–3

Results of our first three hypotheses are confirmed. Increasing the share of non-tenured and tenure-track (but not yet tenured) women faculty is not enough to undo gender segregation in STEM degrees (via significantly increasing gender exposure). A modest increase of 5% or more of the proportion of *tenured* women faculty (treatment: increasing tenured women faculty) significantly increases gender exposure in STEM. By contrast, the same size increase in the proportion of tenure-track or non- tenure-track women faculty has a null effect.

Hypothesis testing: heterogeneity

H4: increasing non-tenure-track faculty gender heterogeneity

Model 2 in Table 3 shows that increased gender heterogeneity among non-tenure-track faculty does not significantly contribute to gender exposure among STEM degree earners. Specifically, decreasing faculty gender segregation among non-tenure-track faculty within institutions has a null effect. Hypothesis 4 is supported.

H5: increasing tenure-track faculty gender heterogeneity

Results of this test are shown in Table 3, Model 3. Supporting Hypothesis 5, a 5% or more increase in faculty gender heterogeneity at the tenure-track level does not increase gender exposure among STEM degree earners nor contribute to the gender desegregation of STEM degree earners. Hypothesis 5 is supported.

H6: increased tenured faculty gender heterogeneity

We evaluate Hypothesis 6 in Table 3, Model 4. Confirming Hypothesis 6, we find that a 5% increase in tenured faculty gender heterogeneity significantly increases gender exposure among STEM degree earners, again by 0.8% ($b = 0.008$, $p < 0.05$). Faculty gender desegregation leads to STEM degree earner

TABLE 3 AIPW regression of STEM degree exposure by increase in faculty gender heterogeneity by 5% or more.

	[1]		[2]	[3]			[4]	
	5% Increase all ranks		5% Increase non-tenure track	5% Increase tenure-track			5% Increase tenure only	
STEM degree gender exposure (Time 2)	−0.001 [0.003]		0.005 [0.003]	0.002 [0.003]			0.008* [0.003]	
	Without 5% increase	With 5% increase	Without 5% increase	With 5% increase	Without 5% increase	With 5% increase	Without 5% increase	With 5% increase
Women's enrollment indicators								
Increase in Bachelor's Degrees earned by women	−0.000* [0.000]	−0.000*** [0.000]	−0.000** [0.000]	−0.000** [0.000]	−0.000** [0.000]	−0.000** [0.000]	−0.000** [0.000]	−0.000*** [0.000]
Carnegie classification								
MA degree granting	−0.016** [0.006]	−0.011* [0.005]	−0.017** [0.005]	−0.014* [0.007]	−0.015** [0.005]	−0.014* [0.006]	−0.019*** [0.006]	−0.015** [0.005]
BA degree granting	−0.017* [0.007]	−0.006 [0.014]	−0.020** [0.010]	−0.002 [0.017]	−0.017* [0.007]	−0.007 [0.008]	−0.021** [0.007]	−0.004 [0.007]
STEM degree exposure (Time 1)	0.853*** [0.029]	0.853*** [0.032]	0.856*** [0.027]	0.842*** [0.037]	0.865*** [0.028]	0.804*** [0.038]	0.878*** [0.023]	0.774*** [0.044]
Constant	0.073*** [0.019]	0.071*** [0.014]	0.075*** [0.012]	0.072*** [0.016]	0.067*** [0.013]	0.092*** [0.016]	0.065*** [0.011]	0.106*** [0.019]
N	1,079		1,079		1,079		1,079	

Source. National Center for Education Statistics Integrated Postsecondary Data System (IPEDS). The following variables were included in the model but not reported for space reasons: Increase in Women's Enrollment Percentage, Federal Financial Aid % Share, Public Institution, Historically Black College or University, Land Grant Institution, and Urbanicity. Robust standard errors are reported in brackets under the unstandardized slope coefficients. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

gender desegregation (via increased gender exposure), but only when faculty are tenured. Accordingly, Hypothesis 6 is supported.

Summary: hypotheses 4–6

We find support for Hypotheses 4–6, confirming that increasing heterogeneity is vital for increasing gender exposure among STEM degree earners, but only when gender heterogeneity increases among *tenured* faculty members. A rise in faculty gender heterogeneity at the non-tenure-track or tenure-track level does not significantly increase the probability for interaction among STEM degree earners, across gender. However, an increase in *tenured* faculty gender heterogeneity contributes to the gender desegregation of STEM degree earners.

Additional predictive factors

We report additional significant independent variables in Tables 2, 3, these factors tend not to not meaningfully vary between the experimental and control groups in their effect on the dependent variables, and are therefore not discussed alongside the hypotheses. Not surprisingly, past STEM degree exposure positively predicts later STEM degree exposure. Yet, it bears mention that increasing undergraduate women's degree success generally (not specific to STEM fields) negatively predicts women's STEM degree success, as does being a graduate degree-granting institution. Our discussion below considers implications of our findings for equity in postsecondary institutions, with particular attention to women STEM faculty.

Sensitivity analyses

We look more closely at the requirement of institutional change in reducing gender segregation of STEM students by exploring the impact of a 1% or greater increase and a 10% or greater increase in tenured women faculty presence in additional sensitivity analyses. The 5% threshold utilized in the primary analysis indicates a deep institutional commitment to change. An increase of tenured women faculty presence by at least 1% shows, at the very least, a modest institutional commitment to increasing the presence of tenured women faculty, whereas 10% may indicate a strong institutional commitment, or a confounding high turnover rate within an institution.

In Table 4 Model 1, we test whether an increase of tenured women faculty of 1% or more leads to a reduction in gender segregation among STEM undergraduates. As expected, even a small institutional commitment to increasing tenured women faculty presence is associated with greater exposure among STEM undergraduates. An increase in tenured women faculty presence by at least 1% is associated with a 1.4% increase in gender exposure among STEM students ($b = 0.014$, $p < 0.01$).

TABLE 4 AIPW regression of STEM degree exposure by increase in tenured women faculty by greater than 0 and 10% or more.

	[1]	[2]	[3]	[4]	[5]	[6]
	1% or more increase tenure only	6% or more increase tenure only	7% or more increase tenure only	8% or more increase tenure only	9% or more increase tenure only	10% or more increase tenure only
STEM degree gender exposure (Time 2)	0.014** [0.005]	0.007 [0.003]	0.007 [0.004]	0.005 [0.004]	0.004 [0.004]	0.004 [0.005]
N	1,250	1,250	1,250	1,250	1,250	1,250

Source. National Center for Education Statistics Integrated Postsecondary Data System (IPEDS). The following variables were included in the model but not reported for space reasons: Increase in Bachelor's Degrees Earned by Women, Carnegie Classification, STEM Degree Exposure (Time 1), Increase in Women's Enrollment Percentage, Federal Financial Aid % Share, Public Institution, Historically Black College or University, Land Grant Institution, and Urbanicity. Robust standard errors are reported in brackets under the unstandardized slope coefficients. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Because between a 1 and 5% increase in tenured women faculty presence is significant enough of a structural change to reduce segregation (as were increases we tested within these margins, i.e., 2, 3, 4%), we also wanted to explore whether there is an upper threshold. In other words, is there a percentage increase of tenured women faculty that indicates structural instability rather than institutional commitment to diversifying faculty? To this end, we also tested increases of 6, 7, 8, 9, and 10% (see Table 4, models 2–6) increases in tenured women faculty. At each of these upper levels, the relationship between structural change in tenured women faculty presence and STEM degree exposure among undergraduate students is not significant. It may be because too few institutions saw increases higher than 5%; recall in Table 1, only 38% saw increases of 5% or higher of tenured women faculty.

Discussion

Here, we discuss the key findings of our study. First, we address each research question and discuss whether the findings align with our hypotheses across faculty rank. Second, we review the implications of this study for macrostructural theory in STEM education. First, we turn to women faculty's group size, the first component of Blau's (1977) macrostructural theory. We posited that only changes in the group size of *tenured* women faculty would impact gender desegregation among STEM degree earners (H1-H3). Our findings suggest that the mere presence of women faculty within institutions is not enough to desegregate undergraduate STEM degree attainment. Women faculty in non-tenure-track positions have limited job security (Kezar and Sam, 2013; Ceci et al., 2014) and may be burdened with responsibilities that limit their availability to serve as mentors to women pursuing STEM bachelor's degrees (Lubienski et al., 2018). On average, institutions sampled did not increase the share of women faculty at *any* rank by at least 5 %, illustrating that increases in faculty group size are generally modest at any rank.

To foster gender desegregation in STEM, women's representation must be considered across faculty rank. Untenured women faculty may not have enough agency, time, or resources to warm the chilly climate in STEM as role models and mentors. To potentially mitigate the insufficient numbers of tenured women faculty mentors within STEM for diverse STEM undergraduate women students, supplemental mentoring might encompass intentional mentoring (Shuler et al., 2021) and/or shadow mentoring (Davis-Reyes et al., 2022) to enhance impacts, especially within the institution. Students and other early career women scientists might also develop a mentoring network within and outside of the institution to enhance their career advancement (Montgomery, 2017) and sense of belonging in their institution and field (Perez-Felkner, 2018; Ovink et al., 2024).

Macrostructural change at institutional levels

While mentors outside of the university system are often helpful in improving student persistence and attitudes within STEM (Shuler et al., 2021; Davis-Reyes et al., 2022), tenured women faculty within the institution may be better positioned to help students foster campus relationships, advocate for students, and understand students' struggles that are unique to the institution they attend (see Baez, 2000; Perez-Felkner et al., 2022; Garrett et al., 2023). Having few tenured women faculty may result in fewer role models and less potential for skills transfer and positive socialization within the field (Whittaker et al., 2015). Stratification by rank as well as faculty type (tenure-track/tenured vs. non-tenure-track) may reproduce women's subordinate position and shape the aspirations of women—and perhaps especially women of color–undergraduate students all the way up through postdoctoral fellows pursuing STEM careers (Bilimoria et al., 2008; Lambert et al., 2020).

Undergraduate women are exposed to and influenced by the gendered norms of their faculty. Pre-tenure women faculty on the tenure-track are burdened with immense pressure to "publish or perish," which detracts from their ability to serve as mentors within their departments (Estrada et al., 2018). These responsibilities may detract from women faculty members' ability to serve as leaders in their departments and institutions, as well as in their scholarly fields (O'Meara et al., 2020). Observing that on average, women faculty have lower prestige and job security than men faculty, undergraduate women may come to understand themselves as subordinate in STEM and choose different educational and career paths accordingly (Main et al., 2020).

By contrast, tenured women faculty in STEM are better positioned to challenge stereotypes about women in their STEM discipline, and are often asked to serve as leaders and advocates for women undergraduates in their departments, to help undergraduate women bring their identity into congruence with STEM career aspirations (National Research Council, 2010; Britton, 2017). The job security that comes with the tenure status may allow women faculty to take on a stronger leadership role within their departments and allow them to be more intentional about the service tasks they accept. Indeed, these leadership positions may be necessary to transform department and disciplinary status quo – and contribute to transformation at the institutional level–to structure encouragement and reward for mentoring and promoting the success of underrepresented and women students in STEM fields (Lewellen-Williams et al., 2006; Ruiz et al., 2022). Such transformative leadership may benefit from increased shares of mid-career and senior women faculty, whose influence may synergistically facilitate macrostructural change within and across institutions.

However, high turnover can negatively affect institutions and organizations (Al-Suraihi et al., 2021). Large changes in faculty composition in a short timespan may indicate structural instability or a negative working environment, which research shows is associated with faculty and faculty leader attrition generally (Jo, 2008; Taylor et al., 2017) and for women in STEM fields specifically (Xu, 2008). In increasing the presence of tenured women faculty, universities must also maintain organizational stability. The average faculty turnover rate for all ranks was 9.4% in 2021, according to the CUPA-HR 2022 Higher Education Employee Retention Survey (Bichsel et al., 2022). Thus, a 6–10% increase in tenured faculty alone could be an indicator of generally high turnover within an institution—and perhaps institutional instability. Still, steady increases in tenured women faculty presence at institutions positively influences gender exposure among STEM undergraduates. Institutional commitment to improving faculty diversity is vital to warming the chilly climate among women STEM undergraduates.

Increases in women faculty group size at the tenure level is not the only contributor to gender desegregation in STEM. Instead, our study shows that desegregating faculty by gender and rank within institutions is also *necessary* to warm the chilly climate in STEM. Although these data do not allow us to evaluate women faculty's share within each department, measuring within-institution faculty segregation enables analysis of the degree of interaction among faculty across campus. Our findings isolate the importance of increasing the likelihood of interaction among women and men tenured faculty–achieved by increasing women's share of tenured roles—as this was the factor found to contribute to the gender desegregation of STEM degree earners.

Impacts of women faculty on STEM women student outcomes

Dismantling gender segregation among postsecondary faculty matters for shrinking STEM gender disparities among students. Since contingent (non-tenure-track) and otherwise untenured faculty do not have the same job stability and level of commitment from the institution (see, e.g., Zambrana et al., 2015; Rideau, 2019), it is important to undo faculty gender segregation at the tenure rank, perhaps especially for women of color faculty and the students they disproportionately mentor. Notably, future extensions of this research with regards to its implications should attend further to institutional variation and perhaps especially how STEM higher education might learn from Minority Serving Institutions like Historically Black Colleges and Universities (included in our models), whose missions focused on inclusive environments might be more favorable for women STEM faculty (see Strayhorn et al., 2013; Shuler et al., 2022). Future research may be able to investigate further as well the intersections of gender and other marginalized identities, to assess the impact of greater representation among the faculty on STEM degree attainment for women, across backgrounds, identities, and specific STEM fields.

Implications for theory and policy

This study expands upon Blau's (1977) macrostructural theory. While Blau identified both group size and heterogeneity as critical for increasing positive interaction opportunities among subgroups, he failed to account for differences in status between group members. Following the lead of later works using this theory (e.g., Fitzpatrick and Hwang, 1992), we incorporate differing statuses in our analyses. In addition, we demonstrate the utility of macrostructural theory in examining the effectiveness of institutional changes at the university level.

While institutions make public claims that hiring more women and minority faculty is a priority, the efforts institutions make regarding equality in promotion and tenure are not sufficiently transparent (see Mack et al., 2010; Ahmed, 2012; Bennett et al., 2020). If institutions hire women faculty to fill demographic quotas but fail to reduce gendered inequalities in the promotion process, institutions may fall short of their commitments to permanent, transformational change for students and faculty. Tenured faculty have more influence and agency than their untenured peers. In contrast, untenured women faculty may not have the positional leverage or job security to advocate for women students and peers, nor influence how resources are allocated (O'Meara et al., 2018; Kelly and McCann, 2019).

Implications for postsecondary institutions and practice

What does this mean for institutions? We suspect that warming the chilly climate for both undergraduate women in STEM and women faculty requires macrostructural change, specifically in the form of hiring *and tenuring* more women faculty, thus increasing gender parity at the departmental and institutional levels. As more women faculty advance to higher ranks across departments, they will have more influence over the undergraduate learning environment and will have more agency to advocate for more balanced distribution of service labor across gender. Given the positive results found in our national study, institutions' investment in tenured and tenure-track women faculty appears to demonstrate long-term commitment to gender equity, helping to thaw the chilly climate for women in STEM. These findings have potential implications for other sex-segregated fields and labor sectors beyond STEM departments and higher education institutions.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: https://nces.ed.gov/ipeds.

Author contributions

KE: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. ES: Conceptualization, Data curation, Formal

analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. LP-F: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – original draft, 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.

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Facilitating collaboration between Japanese high schools and universities: a qualitative exploration of the role of education outreach coordinators

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Introduction: In recent years, universities have been expected to participate in Japanese high school education, especially in the "period for inquiry-based cross-disciplinary study." Despite various university faculties engaging in diverse educational practices, there is insufficient research on human resource development and the creation of mechanisms to ensure continuous development.

Methods: This study conducted semi-structured interviews from July to November 2023, with 15 educators from universities and high schools, among others, to explore the current state of educational collaborations between these institutions and identify potential solutions.

Results: A reflective thematic analysis of the interview identified two key themes: the significance of university involvement in high school education and conflict areas generated from this collaboration. The findings suggest that the success of these initiatives relies on the involvement of coordinators who possess a high level of expertise and competencies.

Discussion: These coordinators, who work in the "third space" in universities, are crucial for realizing the ideal outcomes of educational collaborations between universities and high schools in Japan's new educational environment.

KEYWORDS

qualitative research, STEAM education, school-university collaboration, coordinator, third space professionals, Japan

1 Introduction

In the Japanese education system, particularly at the high school level, there is an increasing expectation for more university involvement. This supposition arises from the national education guidelines, the Course of Study established by Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT). Despite this, university participation is voluntary, lacking uniform standards or mechanisms. Since April 2021, the author has led a cross-institutional project at a university research institute, focusing on creating educational opportunities to collaborate with high schools or local governments. In this capacity, the author serves as a coordinator.

This study explored the following two key research questions:

i. What are the significant outcomes and challenges associated with collaborative educational activities between universities and high schools?
ii. What approaches can be implemented to maximize the benefits and mitigate the challenges associated with educational collaboration between universities and high schools?

Then, this study provides an overview of Japan's high school education policy, reviews the relevant literature, and explains the practices the author implemented at the university and the author's role. The national school education curriculum guideline in Japan, the Course of Study, is revised approximately every 10 years by MEXT.

The "period for inquiry-based cross-disciplinary study" (*So-go-tekina-tankyu-no-jikan*) in high schools was introduced in 2021 in the Courses of Study. However, its origins can be traced back to the 1990s. During that time, Japan was grappling with the challenges brought about by globalization and advancements in technology. Japan simultaneously faced concerns over intense competition in entrance examinations and a decline in scientific and technological interest among younger generations (Ministry of Education, Culture, Sports, Science and Technology, 1995).

In response to these challenges, the report published in 1996 by the Central Council for Education proposed a departure from the traditional knowledge-driven approach to education that focused on fostering students' autonomy and creativity (Chukyoshin and Central Council for Education, 1996). The concept of the "zest for living," which was first used in this report (Matsuo, 2020), emerged as a significant phrase in Japan's educational reforms from the 1990s (Kitamura et al., 2019). The introduction of the "period for integrated studies" across elementary, junior high, and senior high schools was a prominent reform feature. Officially implemented in high schools with the Courses of Study in 1999, the objective was to cultivate problem-solving abilities, independent thinking, and self-directed learning through interdisciplinary studies and student-driven interests (MEXT, 1999).

In the 2009 Course of Study revision, there was an increased emphasis on promoting inquiry-based learning at the high school level. This included the expectation of the university's involvement in the "period for integrated studies," which was indicated in the "Explanation of the Course of Study" (Explanation), such as, "It is considered effective to promote high school–university cooperation, for example, by having high school students visit universities and conduct research under the guidance of university faculties, university students and postgraduate students" (MEXT, 2009).

The 2018 revision further emphasized the importance of inquiry-based activities, shifting from a "problem-solving" approach to a "problem-finding" approach that connects to students' own ways of being and living (MEXT, 2018b). As part of this emphasis, the "period for inquiry-based cross-disciplinary study" (*Tan-kyu*) was retained and continued to serve as a key component of Japan's educational framework (Chukyoshin, 2016). One of the standard activities in the *Tan-kyu* is the "Research Project." This activity centers on the inquiry process, which comprises "problem setting," "information collection," "organization and analysis," and "summary and expression" (MEXT, 2018b). The key components of *Tan-kyu*, which diverge from the conventional subject-based education and revolve around the student's agency, entail project-based learning akin to the research process in academia.

In the context of university collaboration, the explanation emphasizes that to effectively engage in inquiry, it is "crucial to utilize a variety of educational resources" (MEXT, 2018a), including university researchers and postgraduate students. When the "period for integrated studies" was initiated in 1999, there was no reference to university involvement; however, in the 2008 Explanation for Integrated Studies, the word "university" was mentioned 12 times, and in the 2018 Explanation for *Tan-kyu*, the frequency of mentions rose to 33 times. This indicates an increasing significance of universities in high school education in educational policy.

A comparable phenomenon can be observed in STEAM education promotion in Japan; however, the present study specifically concentrates on *Tan-kyu*.

In recent years, collaboration between high schools and universities in *Tan-kyu* has received increasing attention in educational research. Harada (2021) emphasizes the pivotal role of universities in inquiry-based and problem-solving learning in modern Japan. Research in this field includes efforts to evaluate educational impacts (Shimizu and Arai, 2023) and explore support patterns in high school–university cooperation (Harada, 2021). Addressing challenges, Maeda (2023) discusses such issues as the prevalence of one-off initiatives. Osugi et al. (2021) examine the tendency for one-sided, university-to-high school support, while Sugioka (2022) proposes the use of coordinators to alleviate the excessive burden on high school teachers managing these collaborations.

The ongoing and direct engagement of universities in high school education, particularly for high school students, extends beyond the traditional scope of universities' education and research. However, there has been limited discussion thus far on how to address the expanded role expected of universities. Should universities undertake activities beyond their conventional roles, new frameworks, and mechanisms must be established to facilitate these efforts in a sustainable and progressive manner. This study aims to clarify this viewpoint.

In April 2021, the Advanced Education Outreach (AEO) lab was established at the Research Center for Advanced Science and Technology (RCAST) at the University of Tokyo. The AEO collaborates with researchers and students from various academic fields to conduct educational activities for junior and senior high school students. From 2021 to 2023, the AEO worked with 25 schools and educational organizations, including local governments. Some are ongoing interactions throughout the year, while others are collaborations for one-off projects once a year. These activities include: (1) providing guidance and advice during the "period for inquiry-based cross-disciplinary study" at schools; (2) supporting "high school researchers" who wish to advance their research initiated during this period; (3) conducting webinars to explain cutting-edge research in an easily understandable way; (4) organizing the RCAST Research Tour for school groups, which includes lectures, lab tours, and interactions with graduate students; and (5) hosting "after-school talk" events, at which female students can engage with diverse science role models. Every year, approximately 30 university faculty members and over 20 "student affiliates" (graduate and undergraduate students) from various disciplines collaborate in these initiatives (Mori and Student Affiliates, 2023). Student affiliates maintain a closer relationship with the high school students compared with the university faculty and undertake multifaceted roles. They act as mentors to the high school students, implement the educational program, and fulfill a range of additional responsibilities. As the producer and coordinator, the author is responsible for conceptualizing, planning, and managing these activities. Since the job itself and the job title of this activity have not been established in Japan, the author's role was dubbed "education outreach coordinator" (EOC) in this study as a provisional job title. A significant aspect of this approach is "educational co-creation," which prioritizes dialog with schoolteachers, university faculty, and high school students to tailor and enhance programs based on their needs and feedback (Mori and Student Affiliates, 2023).

Student participation in these initiatives has yielded remarkable outcomes, such as the development of a cross-curricular perspective that integrates arts and sciences (Mori and Shimizu, 2023), the discovery of relevance to their school studies (Mori, 2022), and increased interest in science according to surveys of participants. These achievements highlight the AEO's model response to the educational policy expectations outlined above.

In Japanese universities, the role of an EOC is not yet clearly established. However, the author is attempting to pioneer this role by establishing the duties of a coordinator through action research. This effort could facilitate organic collaboration between high schools and universities. The present study is grounded in this approach.

The rest of the paper is structured as follows. The next section details the research methodology. Section 3 presents the findings of the thematic analysis of the semi-structured interviews. The final section discusses the study's limitations and future research directions.

Although the AEO's educational practices encompass interactions with students from various countries, this paper specifically concentrates on issues pertinent to educational practices involving Japanese students and schools.

2 Methods

2.1 Research design

This study used a qualitative approach to investigate and identify issues and provide future directions in educational collaboration between high schools and universities in Japan. The aim was to identify current challenges and thereby clarify the roles and quality competencies of an EOC, which have not yet been visualized.

In this study, semi-structured interviews were conducted with interviewees from July to November 2023. All the interviewees were involved in the AEO programs, which are described in Section 1, or engaged in similar activities. The interviewees were selected using convenience sampling and snowball sampling. To exceed the minimum size required and reach certain saturation, 15 people were selected as interview participants for this study (Morse, 2000; Guest et al., 2006); the study aimed to have an equivalent number of university faculties and school teachers, with one neutral party. This is because the author considered it important to hear opinions from both universities and schools, among others, to obtain a balanced insight into issues in the field.

The participants were divided into three main categories: (a) university teachers responsible for providing lectures, laboratory visits, and guidance to high school students, (b) high school teachers or local government school board employees who requested university cooperation, and (c) independent education activists. The demographics of the participants are shown in Table 1.

The interviews were carried out with the participants' informed consent, following the provision of guidelines that detailed the interviews' objectives and structure, along with a written commitment concerning data collection, utilization, and storage.

The research plan received approval from the Expert Committee on Ethical Review of the University of Tokyo (review number 23–212).

2.2 Data collection

Data collection involved 15 participants from July to November 2023. The interviews involved one-on-one interactions, except in one instance wherein departmental colleagues (participants I and J) responded together. The interviews lasted approximately 1 h but ranged from 30 to 90 min. Participants were asked to provide detailed insights into their perceptions regarding university involvement in high school education, including examples of their personal practices, the challenges encountered, their views on the necessity for coordinators, the anticipated roles of these coordinators, and the competencies deemed important. It adhered to the principles of the Consolidated Standards on Reporting of Qualitative Research (COREQ) (Tong et al., 2007).

2.3 Data analysis

This study employs reflective thematic analysis (RTA), as defined by Braun and Clarke (2019, 2021a), for data analysis.

The analysis was conducted through the six phases of RTA. This study initially used an inductive approach with open coding to analyze the current condition. Adopting an experiential orientation, the study initially used an inductive coding approach with open coding for the segments addressing current challenges. Moreover, for the analysis concerning the skills and competencies of EOC, a deductive method was also applied. The coding process, along with the development of themes and sub-themes, was carried out independently by the EOC.

During the phase of theme and subtheme development, the author consulted with Associate Professor Shinichiro Kumagai, who provided valuable insights and advice. After this consultation, the analysis underwent further reviews to refine the findings.

The analysis drew upon the foundational works of Braun and Clarke (2019, 2021a,b), complemented by insights from Byrne (2022) and Oka et al. (2022).

3 Results

First, two main themes were generated: the significance of university involvement in high school education (referred to as the "ultimate goal") and the points of conflict that arise during collaboration between high school and university collaboration. These themes are further elaborated in Figure 1, with supporting participant quotes provided in Table 1 (participant codes are referenced here).

TABLE 1 Attributes of qualitative study participants.

Occupational categories		Participant	Interview date	Position
(a)	University faculty (excluding RCAST members)	A	24-Jul-2023	Associate Professor (Vice Chancellor)
		H	5-Sep-2023	Professor (Vice Chancellor)
		E	22-Aug-2023	Professor (overseas university, Japanese)
		I	19-Sep-2023	Professor
		J	19-Sep-2023	Project Assistant Professor
	University faculty (RCAST members)	L	1-Nov-2023	Associate Professor
		O	14-Nov-2023	Project Associate Professor
(b)	School teacher	B	31-Jul-2023	Public school in the metropolitan area
		C	9-Aug-2023	Public school outside the metropolitan area
		K	24-Oct-2023	Former principal of a public school in the metropolitan area
		M	7-Nov-2023	Public school in the metropolitan area
		N	14-Nov-2023	Principal of a public school in the metropolitan area
	Educational administrator (ex-school teacher)	D	9-Aug-2023	Office of the Board of Education in the metropolitan area
		F	29-Aug-2023	Office of the Board of Education outside the metropolitan area
(c)	Educator	G	30-Aug-2023	Founder of an educational association

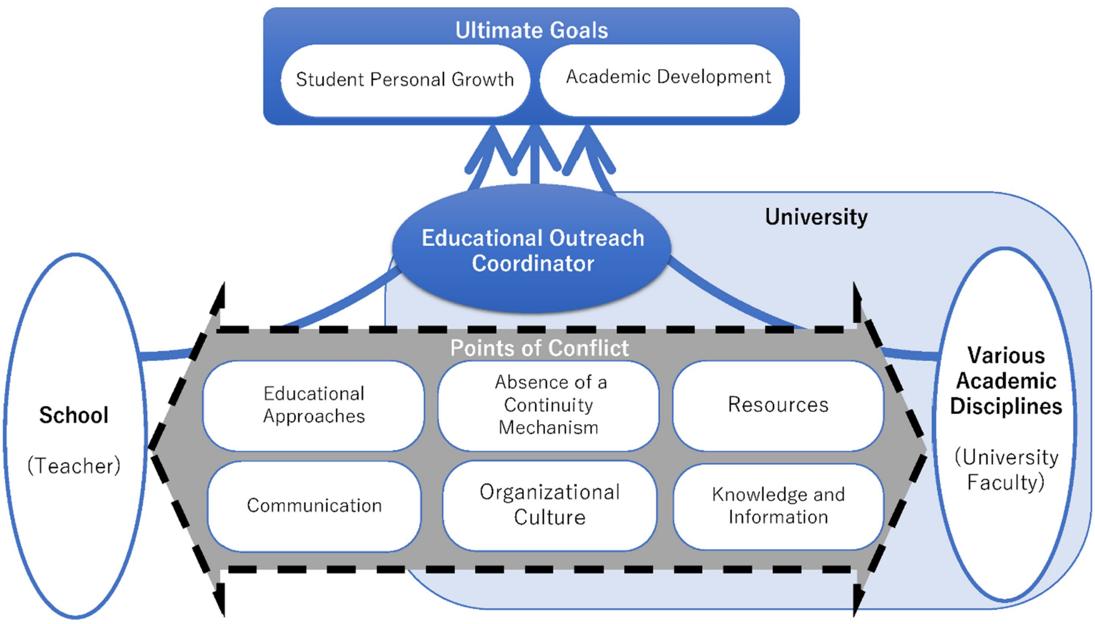

FIGURE 1
Common goals and points of conflict in school-university collaboration.

3.1 Ultimate goals

Both university and high school educators viewed the collaboration between universities and high schools positively. All 15 participants recognized the significance of such cooperative efforts in improving the educational experiences of high school students, with none expressing any negative views. The analysis revealed two primary perspectives, from which two sub-themes emerged: contributions to student personal growth and academic development.

High school educators highlighted an urgent requirement for collaboration with universities, notably to enrich *Tan-kyu*.

> *I feel that collaboration with universities, or having university staff visit or come to high schools, will become more active, and I think that this is what is required. In particular, there is a trend in high schools in which I am involved where there is an increasing emphasis on exploratory activities, so it is difficult to put such things into practice in the high schools alone. I feel that it is very important to*

> *have opportunities for students and teachers to learn from university professors and their knowledge. (F)*

Reflecting on their own childhood and various experiences, several university educators shared views grounded in a desire for social contribution. They expressed wishes for a system in their youth that would have connected them to universities and a keen interest in providing motivated students with the opportunity to engage with higher education. These sentiments stem from a commitment to offering a meaningful educational experience to each student.

Conversely, there were opinions that emerged from the anticipation of contributing to the advancement of academic fields.

> *For me, I feel there is a rising necessity and importance (of cooperating in education for high school students). First, I realize that there are not many people doing research, especially in our field. If there were more researchers, research could develop further, and we could provide useful technology to the world. In that sense, we would be very happy if we could get excellent students to take on our research. This is a request from a researcher, but from our point of view, we do feel the increasing necessity and importance of fostering the next generation. (O)*

School teachers have expressed a keen interest in providing students with exposure to researchers across diverse academic disciplines. This approach is a "contribution to the students," rooted in the aspiration to expand their opportunities and horizons, thereby fostering academic development.

3.2 Conflicts

Despite the consensus on the significance of collaboration between universities and high schools, as discussed in Subsection 3.1, the interviews revealed that university and high school teachers encounter distinct challenges and discrepancies.

3.2.1 Educational approaches

Inquiry-based learning in high school education does not always match university research, which assumes a vast array of knowledge skills. This can be perplexing to university teachers.

> *When high school students are asked to think based on a certain number of facts, rather than being taught various facts in depth at the high school stage, they may go in a variety of extremely liberal directions. University teachers feel a sense of crisis about this. In fact, we can see a glimpse of how it would be better to teach them solid facts. To put it more politely, if, in the end, students are allowed to think and discuss freely based on a certain number of facts at the high school level, and if they are allowed to think and discuss freely, which is a strange thing to say but if they are actively encouraged to do so, what is left out is actually the ability to connect various facts together and interpret them as history. In fact, what is left out is the interpretation of history by connecting various facts, and interpretation is also based on a great deal of accumulation so-called history of research, or academic theories. In a sense, they skip over the accumulation of academic theories and go in various directions. (A)*

High school teachers, meanwhile, may feel frustrated because they do not always get along with university teachers or because university teachers do not consider the realities of high school education.

> *The university content was communicated to the science and mathematics teachers. (Omitted) We also held online meetings. Even so, when we actually tried it, the results were not what we expected. We felt that we were in trouble. It's like it's too difficult, but the university content is also quite limited to those who are interested in the field, and it seems difficult for the students to keep up. (M)*

While it is crucial to present university research in an accessible manner to high school students, research remains highly specialized and distinct from the curriculum typically encountered in high school education. Depending on the discipline, crafting lectures that universally engage all students presents challenges, and researchers who irregularly interact with high school students may find it particularly challenging to gauge the appropriate level of complexity expected of them.

3.2.2 Absence of a continuity mechanism

In the interviews conducted, six out of the seven high school teachers mentioned their reliance on personal connections to facilitate collaborative activities with universities. In this context, the teachers conveyed a sense of reassurance in having direct communication with a known counterpart and expressed satisfaction in executing these activities through their own efforts and skills. However, several teachers also raised concerns about the sustainability of such educational initiatives. They noted that if either teacher were transferred or otherwise unavailable, it would undermine the continuation of these activities.

The participants expressed several concerns. For example, the reliance on personal relationships may bias the fields of study that high school students encounter. Staffing instability was also an issue raised by university teachers working on a voluntary basis. Participants mentioned that initiatives are not shared and information only reaches those who are interested and involved. Finally, organizational mechanisms are required to transform activities that depend on connections between individuals into permanent and universal initiatives.

3.2.3 Resources

Both teachers highlighted the constraints of time and human resources when planning and executing collaborative educational activities.

Some high schools have set up school departments, such as an "Inquiry Department" within the school, where the teacher assigned to the department is responsible for planning and coordination of *Tan-kyu*, but even in such schools, there are still challenges.

> *As teachers, they are required to do the same work as other teachers, so it is difficult for them to specialize in coordinator work in terms of time. So, of course, they have to do that, but they also have to work the same number of hours as other teachers, for example, four hours a day, and they also have to supervise club activities. (K)*

University faculty members understand the challenges they face.

> *It's the lack of people, isn't it? There is a huge shortage of people in relation to demand. This may be a problem for the universities. (J)*

3.2.4 Communication

High school teachers encounter difficulties in effectively communicating with university faculty, resulting in unmet educational objectives:

> *First, it would be easier for us if you showed us what you can do, as you tell us by e-mail. It's a bit awkward or scary for me to ask them if they can do something like this, maybe they are too busy. (C)*

As highlighted in Subsection 3.2.1, although the pedagogical approaches of high schools and universities differ, the challenges associated with integrating university-led activities into the high school curriculum cannot be easily dismissed. These activities, which may not pose issues when conducted outside the high school curriculum, become more conspicuous and potentially problematic when incorporated within it.

Furthermore, high school teachers and local government officials often find themselves in a position in which specifying the details of these activities and freely expressing their opinions to university faculty can be challenging. This situation may arise because university participation in high school education is voluntary and not mandated to align with high school curricular content. Consequently, making excessive demands is difficult, and there is a natural tendency to respect the expertise of university personnel.

3.2.5 Organizational culture

Even within the same country or region and across identical educational fields, notable disparities in approaches and values exist between high school and university educators. Engaging in interactions without acknowledging these distinctions can precipitate discomfort.

> *But the high school side is really lacking in manners (…) If the high school students want to do it themselves, that's fine, but in the case of the A's the other day, there were cases in which the high school was asking them to do it, and they wrote on a piece of paper saying something like "please do my request," attached it, and sent it widely to university teachers and business people, probably without any regard. I think it's a little bit that when high schools are doing it. (J)*
>
> *University researchers with a high degree of expertise have a good sense of commitment and pride in their own specialization. But the education field and the general public sometimes use language that is offensive and rude to researchers. I think it's necessary for both sides to work comfortably so that (coordinators) can come in between and make sure there is no rudeness on both sides. (G)*

At first glance, such issues might seem to be attributed solely to individual communication competencies. Upon deeper examination, however, it is posited that these discrepancies stem from divergences in organizational culture between high schools and universities. This phenomenon aligns with what Schein (1990) described as "basic underlying assumptions." Therefore, these opinions were classified under a distinct subtheme separate from Subsection 3.2.4.

3.2.6 Knowledge and information

School teachers lack sufficient knowledge about university disciplines and researchers, which hinders effective collaboration:

> *Right. There are still cases where we don't know [about academic fields or researchers]. If we are introduced to someone, or if we tell them that we want to do a project like this and they co-ordinate it with us, it can lead to people we didn't know at all getting involved in a good way, which is how we felt this time when we asked the AEO, and also when we asked the medical school. (F)*
>
> *First, I don't have any expertise on my side, so I talked to the contact professor at U of N, for example, about wanting to do this kind of course, and the other day, I talked with the committee members about wanting to do a project on engineering because engineering is not in our STEAM, but that concept of engineering is not in my side (…). When I have to tell them as a representative, if I don't know what they are talking about, I can't negotiate with them from the beginning. (M)*

Moreover, university teachers also deal with the situation in a hands-on way, as they have no means of knowing the actual situation in schools.

3.3 The need for a coordinator

The "final goal" and "points of conflict" are delineated in Subsections 3.1 and 3.2, respectively. Regarding the final goal, it is noteworthy that school personnel and university faculty members recognize the significance of university support for high school students and their involvement. This recognition holds promise for the development of more enriching educational opportunities.

However, the study identified a broad spectrum of conflicts, including differences in educational approaches, the absence of a structured ongoing relationship, resource limitations, communication hurdles, cultural disparities, and a deficiency in knowledge and information. These conflicts are not isolated; they are interconnected and can lead to complex challenges and unsatisfactory outcomes. Furthermore, these conflicts vary depending on the specific school, its faculty, the academic discipline, and the university faculty involved.

A potential source of these conflicts is the weak relationships between institutions. Upon deeper analysis, another contributing factor might be the fundamental differences in roles and responsibilities. High school teachers are tasked with the education of high school students—a responsibility not shared by university faculty, whose primary focus is on research and higher education. The extent to which university faculty engage with requests from schools is largely left to their discretion. Since the 2000s, the stagnation in the growth of academic publications in Japan, compared to other countries, is a concern to those working in science and technology policy. A reduction in research time is a key issue (Aoki and Kimura, 2016). Given the pressure to allocate more time to research, significantly increasing the time and effort devoted to educational activities outside their primary responsibilities may not be feasible for university faculty, despite potential willingness.

If the collaboration with universities is to extend beyond serving as a resource for high school education to being integrated within the high school curriculum itself, a clear need emerges for individuals who can bridge the gap between the two sectors. These individuals must understand the needs of both and foster improved educational opportunities. In this study, such individuals are designated as EOCs.

The findings from Subsection 3.2, detailing the various challenges faced by participants, also point to the necessity of a coordinator role. Additionally, there were indications of the need for coordinators to address issues not yet explicitly recognized as coordination challenges.

> *No, I mean [university education and high school education] are getting closer, but they are not completely close because there is still a gap. So, I think that when we were able to recognize that they were completely different, it was easier to co-ordinate. In a sense, the directions are the same, but they are not completely parallel, nor do they intersect, so it can be like a twisted position. So, I think that's why there is now a need for coordination to make connections. (A)*

The following remarks indicate confusion among university teachers regarding their relationship with high school students for whom they have no direct educational responsibility. They also refer to the importance of the role of the coordinator, either as a point of responsibility or from the perspective of ensuring transparency in their activities.

> *High school students are not in a position to receive higher education, so in that sense, it is fine for them to ask questions and seek advice when they are in high school, but it is not always possible for us to go into greater depth, for example. In those situations, for example, if there is a coordinator, I think it would be possible to ask them to control the situation. For example, if we go deeper and deeper, of course, we may have problems securing the time to do so, so I think that would also be a problem. And another thing is that I don't think we can publish articles or papers on our own with the high school students. In that sense, I think it is necessary to have some kind of follow-up in terms of control over that area. (O)*

Some of the challenges identified in the realm of collaboration between high schools and universities could be mitigated by creating opportunities for each party to learn about the other and by disseminating information. Nevertheless, as long as both parties continue to operate under the assumption that activities involving high school–university cooperation are not their primary responsibility or that they are burdened with numerous other tasks, it becomes crucial to involve individuals who specialize in this area of collaboration.

As delineated in Section 1, the author serves as an EOC within the AEO. This role primarily involves bridging the educational and collaborative divide between universities and secondary education institutions. The author has been instrumental in facilitating educational collaborations across a diverse spectrum of university faculties and academic disciplines with schools. For instance, in Fiscal Year (FY) 2022, the initiative led by the author successfully engaged 30 university faculty members from varied research domains—ranging from energy systems and nutriomics to mobility science, insect-controlled space design, art and design, rule-making strategies, and political science research—in the educational advancement of high school students. This initiative resulted in the enrollment of 1,300 students from 93 schools and organizations across Japan in these educational programs (Advanced Education Outreach Lab, 2023).

Furthermore, during FY2022, a total of 26 students, encompassing doctoral, master's, and undergraduate students from various research fields, registered as "student affiliates" at AEO to support secondary school students. These affiliates acted as tangible role models and mentors for high school students, guiding them through inquiry-based research projects and other educational activities (Advanced Education Outreach Lab, 2023).

In the capacity of an EOC, the author identified the characteristics of these student affiliates, strategically positioning them to leverage their strengths and foster the development of new skills. The contributions of these student affiliates were highly regarded, with three affiliates securing assistant professor positions at universities, where they continue to engage in outreach activities.

The initiatives of the EOC have been appreciated by educators at both the university and high school levels. For example, one university faculty member, directly involved in the initiatives spearheaded by the author as an EOC, remarked:

> *Prior to this initiative, I have rarely had junior high or high school students visit my laboratory. Unfortunately, there is currently a disconnect between elementary and secondary education and university education and research in Japan. Since FY2021, I have had the opportunity to actually meet middle and high school students through AEO, and (..) it is always a new learning experience for me as well. (MORI and Student Affiliate Team, 2022)*

School educators and local government officials have acknowledged the pivotal role of the EOC in bridging the gap to university research fields and researchers previously inaccessible to them. This sentiment is exemplified in the statement by Interviewee F, as cited in Subsection 3.2.6.

Thus, the EOC plays a crucial role in facilitating a multifaceted educational exchange between schools and universities, yielding outcomes that would be challenging to achieve through direct bilateral efforts between educators and university faculty alone.

The engagement of universities in providing educational opportunities to students below high school age, as well as the collaboration between universities and schools, can be observed merely beyond the objective of student recruitment by universities and is not an exclusively Japanese phenomenon. For example, such institutions as the University of Queensland in Australia and the University of Auckland in New Zealand have implemented school engagement activities aimed at high school students. Some of these initiatives are accessible on their official websites (University of Auckland, n.d., University of Queensland, n.d.). The demand for such coordinators is not confined to Japan but is also a significant aspect of the educational landscape internationally.

In these collaborative efforts, the role of coordinators should be pivotal. These individuals facilitate activities that surpass the conventional scope of individual researchers, encompassing university-wide initiatives or collaborations involving multiple researchers. This suggests the universal need for effective collaboration between universities and schools, highlighting the critical role coordinators play in this context.

3.4 Competencies (skills and competencies) required by EOCs

What competencies are essential for EOCs to address the conflicts identified in Subsection 3.2? This study considers that a distinct level of professional competence, diverging from the conventional roles of university faculty and staff, is required. This competence arguably belongs to a "third domain" of operation (Whitchurch, 2008, 2013), a realm already familiar in Japanese universities through the role of the university research administrator (URA). The skill standards for URAs, developed by the University of Tokyo under a project commissioned by the Ministry of Education, Culture, Sports, Science, and Technology (The University of Tokyo, 2014), outline "work performance indicators" across such categories as "business (mission understanding)," "knowledge," "practice," "language," and "interpersonal," each was further divided into sub-items. Analyzing the interview content with reference to these URA skill standards yielded five themes: "knowledge," "holistic perspective," "practical work," "interpersonal," and "education." Each theme represents both independent skills and competencies and is interrelated with the others.

3.4.1 Knowledge

"Knowledge" encompasses a broad spectrum, including specifics of school education and university research, diverse fields, and the organizational cultures of schools and universities. This addresses the conflicts between "differences in educational approaches" and "lack of knowledge and information" identified in Subsection 3.2. With this extensive "knowledge," EOCs are expected to facilitate the planning of more appropriate educational programs for high school students. These programs should consider university research and provide consultations to both school and university teachers.

University and high school teachers can consult with the EOC, who acts as an intermediary on matters difficult to address directly, enabling smoother cooperation.

3.4.2 Holistic perspective

The "holistic perspective" skill involves the ability to plan and envision both university research and high school education from a holistic perspective, identifying potential connections between academic disciplines and educational needs without bias.

The inherent value of an EOC lies in its ability to matchmake beyond specific academic fields or laboratories, facilitating activities that might otherwise be constrained by limited perspectives or resources.

3.4.3 Practical work

"Practical work" includes decision-making, management, financing, and analyzing results, beyond mere administrative tasks. This addresses the "resource constraints" conflict.

3.4.4 Interpersonal skills

"Interpersonal" skills primarily involve verbal and non-verbal communication, which is crucial for overcoming "cultural differences" and "communication barriers," and pivotal for resolving all identified conflicts.

3.4.5 Teaching and mentoring skills

"Teaching skills" entail the ability to engage high school students, facilitate discussions, and teach about university research in an accessible manner, addressing "differences in educational approaches" and alleviating "resource constraints."

The crux of the EOC's role extends beyond merely imparting expertise. Rather, its essential function lies in its capacity to forge close connections with high school students to unlock their potential and bolster their self-confidence. This approach might be particularly effective due to the EOCs' comprehensive overview of the university's diverse academic disciplines and their distinct position from that of high school teachers, who teach at school on a daily basis. The EOC staff fosters maximum psychological safety for the students, embracing and welcoming them with open arms, akin to a familial setting. This environment necessitates proficient mentoring and coaching skills. The primary mentor for the high school student is often an undergraduate or graduate student who assumes this pivotal role. Concurrently, the EOC also undertakes a mentoring responsibility, acting either as a mentor to the mentor or in the interests of inclusivity. This arrangement mirrors the "closed triad" model discussed by Montgomery and Page (2018).

The ability of the EOC to unlock students' latent talents, incite intellectual curiosity beyond what is catered for in the school curriculum, and forge avenues for high school students to manifest their competencies further affirm the significant inherent value of the EOC's activities.

EOCs must integrate extensive "knowledge" with a "holistic perspective," "practical skills" for implementation, and "interpersonal" skills for effective communication, potentially taking on educational roles to ease the burden on university faculty and foster broader cooperation.

4 Discussion

This study provides a comprehensive analysis of the perceived objectives and conflicts inherent in educational collaborations between universities and high schools in Japan, emphasizing the crucial role of EOCs in mitigating these challenges and outlining the requisite skills and competencies for such roles. This study explores areas that have received scant attention in existing literature, thereby making significant contributions to understanding these collaborations.

As Section 1 indicates, the importance of universities in facilitating inquiry-based and problem-solving learning is well documented in recent Japanese educational discourse (MEXT, 2018b; Harada, 2021). These educational practices are implemented through diverse methodologies, often characterized by experimentation and iterative refinement. To transcend the limitations of *ad-hoc* and generational initiatives by pioneering entities and to foster a sustainable and evolutionary approach to educational collaboration, it is imperative to establish a framework that seamlessly integrates the distinct roles and values of schools and universities. This study delves into the intricacies of such integration, highlighting the discrepancies between educational institutions, as detailed in Subsection 3.2.

The need for coordinators as a linchpin between schools and universities forms a central thesis of this study. While previous research (Sugioka, 2022) has touched on the potential utility of coordinators, there remains a lack of detailed discourse on the specific responsibilities these roles entail, the skills and competencies required, and the nature of expertise coordinators should possess.

In discussions about the collaboration between high schools and local communities, MEXT also emphasizes the importance of coordinators (MEXT, 2020). This indicates that the Japanese educational policy recognizes the need for intermediaries when schools collaborate with external organizations or individuals. However, the discussions at MEXT primarily focus on coordinators placed in high schools, and do not address the unique and essential challenges of collaboration with universities, nor the need for universities to adapt to new roles as discussed in this study. This study advocates for the necessity of coordinators in universities, as incubators for creating new educational opportunities through collaboration with schools.

In the context of Japanese society, the term "coordinator" typically denotes roles focused on logistical support, such as matching people and scheduling. This study, however, posits that coordinators in educational collaborations should transcend logistical functions to act as vital agents of change, fostering optimal educational opportunities through advanced professional skills. This necessitates a re-evaluation of the conventional understanding of coordinators, as highlighted by feedback from interviewees questioning the appropriateness of the term and suggesting a more supervisory capacity.

Effective collaboration between schools and universities requires coordinators who not only possess specialized skills but also embody a broad spectrum of competencies, as outlined in Subsection 3.4. Given the practical challenges of employing numerous specialists within a single organization, department, or team, the study advocates for individuals who can amalgamate various qualities and competencies, thereby ensuring the cohesive coordination of educational efforts.

Prospective coordinators are envisaged to have a foundational level of expertise, further enhanced by targeted training programs and practical experience. Potential candidates for this role include educators and educational administrators with a deep understanding of school education, as well as PhD holders with insights into university education and research, the latter being particularly well-suited given the ongoing discourse on career development for PhD holders in Japan (MEXT, 2023).

The Sixth Science and Technology Basic Plan (Cabinet Office, 2021) underscores the need for diversified career paths for doctoral graduates, a sentiment echoed by MEXT's initiatives to promote doctoral students' engagement across various societal sectors, including such roles as research administrators in universities. This study's proposal for coordinators as advanced professionals not only aims to enhance secondary education but also addresses broader societal challenges related to doctoral career development.

The research of this study offers valuable insights into the dynamics of collaboration between college and high school faculty. However, it is important to note that these findings are derived from a relatively small participant pool and predominantly reflect the perspectives of individuals already engaged in such collaborations. This limitation suggests that the conclusions drawn might not comprehensively represent the broader spectrum of faculty members across educational institutions.

Moreover, the scarcity of examples of university coordinators in Japan underscores the need to extend the scope of investigation to international precedents. A thorough examination is needed of the practices employed by universities and schools abroad in fostering cooperation, including the roles of professionals who facilitate these partnerships and the strategies implemented to secure personnel and operational funding. Such an analysis would significantly contribute to a more nuanced understanding of the coordinator profession and its critical functions within the educational sector.

Another limitation of this study and the presumed practices in AEO education is the absence of participants who were students with special needs, alongside the lack of teachers from schools specifically attending to such students. Although the interviewees from university faculties included a participant with special needs, the interview did not specifically focus on such students. Consequently, the findings of this study do not reflect experiences with inclusive responses. Conversely, the RCAST, where the AEO is situated, is a research institution renowned for its expertise in inclusive design and barrier-free access. It is pivotal to explore how the EOC can facilitate inclusive responses moving forward.

Additionally, this study highlights the need to devise specific strategies for cultivating the qualities and capabilities of coordinators. Developing these competencies is pivotal for enhancing the effectiveness of educational collaborations and ensuring their success.

Another key aspect of this research is the organizational placement of coordinators. Unlike positions tied to specific laboratories or departments, the coordinators discussed herein are envisaged to be employed by the educational institution at large. This broader organizational role necessitates a detailed exploration of whether the demand for coordinators, as evidenced by this study, justifies the encouragement of institutional hiring practices. It is imperative to determine the extent of this need, identify desired outcomes, and advocate for the establishment of roles that align with organizational objectives.

Furthermore, the study underscores the critical issue of funding for personnel costs. A comprehensive examination of potential mechanisms for financing these expenses is crucial for the sustainable implementation of coordinator roles. Addressing this challenge requires innovative approaches and careful consideration of various funding models.

In conclusion, the findings of this study serve as a preliminary step toward the development of improved educational practices and the creation of new models for collaboration between educational institutions. Continued practice and research are essential for refining these approaches and achieving meaningful advancements in the field of education.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

The studies involving humans were approved by the University of Tokyo's Ethics Review Committee. The studies were conducted in accordance with the local legislation and institutional requirements.

The participants provided their written informed consent to participate in this study.

Author contributions

AM: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

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

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The role of holistic mentoring ecosystems in mitigating COVID-19 pandemic impacts on the persistence of low-income STEM students

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Holistic mentoring ecosystems are a comprehensive approach to addressing the diverse needs of students through interconnected support networks. While mentoring has been well-documented in existing literature, more research is needed to determine the effectiveness of mentoring ecosystems in mitigating the impact of critical junctures for vulnerable, high-attrition student populations. Guided by Tinto's model of retention, this qualitative case study investigated the role of holistic mentoring ecosystems in mitigating the impacts of the two combined critical junctures—the COVID-19 pandemic and the first year of college—on low-income STEM undergraduates. Our findings suggest that holistic mentoring ecosystems were essential in helping students adjust to the academic environment and fostering a sense of belonging in the STEM community amid the severe limitations imposed by the pandemic. This study adds to the growing body of literature investigating the approaches and strategies effective in supporting vulnerable student populations through critical junctures in their educational journey.

KEYWORDS

low-income college students, COVID-19 pandemic, higher education, holistic mentoring ecosystem, first-year academic experience, STEM disciplines

1 Introduction

The completion rates of college education for students pursuing science, technology, engineering, and mathematics undergraduate academic programs are impacted by various factors and contexts. Finding solutions to remedy these factors has greatly interested scholars and educational leaders. Many factors can impact college completion (Bastedo and Jaquette, 2011; Berg, 2016; Carnevale and Smith, 2018; Taylor and Turk, 2019), including socioeconomic status, which is a primary indicator of an individual's probability of completing their studies (Reber and Smith, 2023). Low-income students who pursue higher education face challenges similar to those of their counterparts. However, their socioeconomic status exacerbates these challenges, making it less likely for them to complete their studies successfully compared to their more affluent peers. Statistics reveal that graduates from high-poverty high schools only have a 21 percent chance of attaining a college degree within 6 years of high school (Reber and Smith, 2023). In contrast, those who graduated from low-poverty schools have a 53 percent chance of achieving a college degree within the same time frame (Reber and Smith, 2023).

Existing studies have documented that students from low-income backgrounds often face inequities such as financial constraints, insufficient academic preparation, a lack of access to high-quality educational resources, and limited exposure to the STEM fields (Agrawal et al., 2016; Robinson and Meadows, 2020; Hansen et al., 2023; Madsen et al., 2023). They also need help with high education costs, such as the high cost of tuition, textbooks, and other related expenses for housing, subsistence, and living expenses. These challenges can be further compounded at critical junctures on their collegiate journey and can often hinder their academic success and may discourage them from pursuing higher education altogether.

Berg (2016) argued that providing low-income students with financial support alone is not enough. Low-income students also need academic support, opportunities to establish social connections and access to resources to help them develop essential life skills to support their success, particularly at critical junctures in their academic pursuits (Bastedo and Jaquette, 2011; Carnevale and Smith, 2018; Madsen et al., 2023). For instance, critical junctures such as the first year in college, transitions to new schools, changes in educational programs can be adversely impact students from a low-income background if not connected to the necessary supports to mitigate the impact (Muraskin, 1998; Michalowski, 2010). Recognizing the critical nature of the first year, institutions have implemented various initiatives and touchpoints to monitor first-year students using proactive methods.

1.1 COVID-19 critical juncture

Freshman year is known as a critical juncture for all students. In particular, studies have well documented that the transition from high school to college exposes students to a host of challenges that can impact their persistence from first year to second year of college (Muraskin, 1998; Michalowski, 2010). Interestingly, the high school class entering college in 2020 were met with an unprecedented critical juncture—COVID-19 pandemic. The COVID-19 pandemic presented a significant challenge for college freshmen in 2020, one of the most critical junctures of the last century. The pandemic coupled with known challenges of the first year in college made the college experience for freshmen in 2020 an incredibly tough and unique situation. Students had to navigate not only the typical challenges of adjusting to college life but were also forced to adapt to new technology and online learning platforms, lack in-person social interactions, and navigate the loss of loved ones. The sudden change in routine and learning environment left many overwhelmed and struggling to keep up with their academics.

Institutions across the world scrambled to rapidly mediate the impacts of the pandemic. Namely, the institutions shifted adopt virtual formats for academic instruction and social engagement (Mondisa et al., 2021; Alqashouti et al., 2023). This move toward virtual engagement allowed institutions to provide academic instruction and social engagement while adhering to social distancing restrictions. However, it also presented widespread challenges for students, threatening their academic success and overall well-being. For instance, students who relied on in-person interactions to establish connections and build networks with their faculty and peers found it challenging to form meaningful relationships without social opportunities and experienced isolation (Madrigal and Blevins, 2022).

Particularly for STEM majors, the pandemic significantly impacted their ability to acquire fundamental technical skills and research knowledge, mainly because of the absence of in-person lab courses and undergraduate research opportunities. This disruption is of significant concern because existing literature has emphasized the significance of engaging the STEM-related activities is imperative for fostering sense of belonging and connection to the STEM community. Namely, access to mentors and role models, engaging in peer interactions, and honing one's skills are essential in cultivating one's actualization as a science person (Dortch and Patel, 2017; Tellhed et al., 2017; Chen et al., 2021; Hansen et al., 2023). These opportunities are even more critical for low-income students who face a higher risk of leaving their studies.

Moreover, research on the impact of the COVID-19 pandemic on different communities has shown that marginalized or low-income individuals have been disproportionately affected by the crisis (Lederer et al., 2021; Kiebler and Stewart, 2022; Molock and Parchem, 2022). These communities have faced numerous challenges during the pandemic, such as limited access to proper healthcare, fewer job opportunities, and inadequate social support systems. For example, some students may not have access to the technology or equipment required for online learning, which has become the norm during the pandemic. Also, they may be struggling with mental health issues caused by the stress, uncertainty and increased financial pressures due to the pandemic's impact on their families (Gopalan et al., 2022; Kim et al., 2022). Therefore, the data suggests that targeted interventions and support are necessary for these communities during this critical juncture.

1.2 Holistic mentoring ecosystems

Mentoring in the STEM context has traditionally explored the impact of formalized programs focused on topical areas such as student academic success and early career STEM faculty development (Packard, 2015; Haeger and Fresquez, 2016; Mullen and Klimaitis, 2021). More recently, research in postsecondary STEM education has shifted to explore the ways in which comprehensive and inclusive approaches can be implemented to the growing needs of diverse groups of students. One such approach is holistic mentoring ecosystems. Holistic mentoring ecosystems are a comprehensive approach to addressing the diverse needs of students through interconnected support networks (Mondisa et al., 2021). This approach is particularly beneficial for at-risk students who may require additional support to overcome challenges and achieve success in their academic and personal lives (Patton and Harper, 2003; Crisp and Cruz, 2009; Luedke et al., 2019).

Research has consistently shown that mentoring in STEM fields is essential for fostering a sense of belonging, expanding social networks, and developing a science identity, among other long-term benefits (Wilson et al., 2012; Packard, 2015; Haeger and Fresquez, 2016; Dennehy and Dasgupta, 2017; Atkins et al., 2020). This is particularly important for students from marginalized backgrounds, who tend to leave STEM disciplines at higher rates than their peers (Kricorian et al., 2023). Often, their decision to depart from their discipline is not due to a lack of ability but rather environmental factors and the need for a greater connection to the scientific community (Hill et al., 2010; Harris, 2019; Corneille et al., 2020).

Our study focuses on a holistic mentoring ecosystem structure that aligns with the definition proposed by Mondisa et al. (2021). The ecosystem comprises interconnected support networks, including a scholarship mentoring program, science living-learning communities, student support services, and STEM student organizations. Central to the holistic mentoring ecosystem is a multi-year scholarship mentoring program that began in 2020. The overarching goal of the mentoring program is to foster an inclusive and supportive environment that equips low-income students with the necessary resources to ensure their academic and professional success. The program is based on an appreciative advising approach and offers various forms of support, including financial assistance, personalized development planning, 1-on-1 coaching, and monthly group sessions. The one-on-one bi-semesterly coaching sessions are guided by the personal development plans tailored to each students. The monthly groups meetings occur throughout the academic year and are focused on topics related to STEM success. We posit that the culmination of these activities facilitates the growth and achievement of students as navigate their collegiate careers.

1.3 Purpose and research question

As we shift to a post-pandemic environment, we sought to explore the ways in which students from low-income backgrounds in STEM disciplines persisted through the combined critical junctures of freshman year and the COVID-19 pandemic. In particular, the study seeks to explore the specific ways in which a holistic mentoring ecosystem provided critical support to these students, such as academic and emotional support, social connections, access to resources, and financial aid.

The purpose of this present study investigates the role of holistic mentoring ecosystems in mitigating the impact of critical junctures for low-income student populations. Specifically, the study explores how such involvement supported the matriculation of low-income STEM students during the COVID-19 pandemic. The central research question guiding this study is: *In what ways did participation in a scholarship mentoring program aid in mitigating the impacts of the COVID-19 pandemic on the persistence of low-income STEM students?*

2 Theory

Undergraduate student retention has been investigated as early as the 1930s. Scholars and practitioners alike have long sought to understand the factors and contexts that impact a student's ability and likelihood to be retained through to college completion. Most of the earlier student retention models and theories mainly focused on the student's attributes, knowledge, motivation and skills as the determinant for retention (Gekoski and Schwartz, 1961; Panos and Astin, 1968; Newcomb, 1994). However, a reoccurring critique of these works is the lack of focus on the impact of an individual's environment on their retention.

Factoring in this critique from previous literature, Tinto developed a model of retention that accounted for the individual and their environment and the ways in which these entities interplay to impact retention. The model of retention posits that students who are academically and socially integrated into a campus community are more likely to be retained (Tinto, 1987, 2006). His work suggests that strategic practices that help students navigate critical junctures in their acclimation to college and their majors have a higher likelihood of supporting their success. In many ways, the work of supporting students' integration into the campus community supports students' sense of belonging and identity development as a member of the community (Tinto, 2017; Strayhorn, 2020).

Our study is based on Tinto's retention model, a widely used framework for identifying factors contributing to a student's success in college. However, it's important to note that this model has limitations. One significant limitation is the initial design of this model was based on the experiences of traditional students with access to resources and networks that support academic navigation (Berger and Malaney, 2003; Kuh et al., 2006; Palmer et al., 2011; Louten, 2022). This means that the model may not fully capture the experiences of students from marginalized groups, such as low-income students. With this limitation acknowledged, we center our work on the fundamental tenets of the retention model, emphasizing the importance of a student's integration and acclimation to the college community, which can bolster their persistence and retention.

Tinto's retention model has been utilized extensively in education exploring contexts and factors of retention across a multitude of institutional contexts and demographic populations (Tinto, 1975; Terenzini et al., 1996; Hurtado and Carter, 1997; Robbins et al., 2004; Nandy et al., 2021). Particularly in STEM fields, scholars have grounded their work in the retention model is explore factors influencing retention and persistence in STEM pathways for historically underrepresented groups, women and first generation college students (Lo et al., 2020; Brewer et al., 2021; Premraj et al., 2021; Louten, 2022). There are still opportunities to research additional populations, especially low-income students, as this population remains under-researched. Therefore, this paper focuses on the retention of low-income STEM students during their first year in college amidst the COVID-19 pandemic. By examining academic and social integration, we aim to identify effective strategies that could help overcome the unique challenges faced by low-income STEM students who are at risk of dropping out during their first year of college.

3 Methods

This study utilized a qualitative case study approach to gain insights into the experiences of low-income STEM students who participated in campus mentoring programs during the COVID-19 pandemic. The goal of case studies is to "describe a phenomenon in its real-world context" (Yin, 2014). The target population of this study was undergraduate students participating in the scholarship mentoring program for STEM majors. Also, the participants in this study were classified as low-income and academically talented diverse groups. We define diverse groups in this study as participants with differences in race, ethnicity, socioeconomic, religious beliefs, sexual orientations, academic pursuits, and life experiences, among other identifying demographics. We determined the low-income status of the students through financial need analysis for college attendance.

Of the 10 students in the sample, nine were enrolled in college between Fall 2020 and Fall 2021. The remaining one senior entered college in the Fall of 2019. Half of the students were out-of-state students. By classification, there were four sophomores, four juniors, and two seniors. By field of study, eight students were pursuing science fields, one was pursuing engineering, and one was pursuing mathematics. The gender and race/ethnicity makeup of the group is illustrated in Figure 1.

3.1 Data collection and analysis

Aligned with case study methods, we utilized multiple forms of data, including interviews, student metrics, and self-reporting surveys (Yin, 2017). The primary data source collected in this study were one-on-one, semi-structured interviews lasting approximately 45 min and conducted via the Zoom platform. The Institutional Review Board approved this study at a research university in the Deep South region of the U.S. Participants were assigned pseudonyms to ensure anonymity.

Interviews were conducted in October 2022. At the time of the interviews, four students were in the scholarship program for 2 years, and six students for 1 year. Our focus for this paper is on the experiences of students who began their college journey during the COVID-19 pandemic. The interview protocol was intended to gather participants' perspectives about various aspects of college life, such as transitioning to college, the impact of COVID-19, academic perceptions, and curricular engagement. Guided by Tinto's model, we investigate points of academic and social integration to identify effective strategies that could help overcome the unique challenges faced by low-income STEM students.

Additionally, we evaluated student metrics on each participant's academic performance, including data on their grade point average and progress reports on their individual development plans. This information was gathered to gain a better understanding of the factors that contribute to student success. In addition, we carefully reviewed the annual end-of-year evaluation of the mentoring program to assess its effectiveness in supporting student growth and development.

Prior to engaging in the analysis process, all interviews were transcribed verbatim and read through to gain an overall understanding of each participant (Creswell and Poth, 2016; Yin, 2017). Our first analysis stage was open-coding each transcript using Dedoose qualitative analysis software. Utilizing an inductive coding approach, we identified preliminary patterns and labeled codes based on concepts of interest in the interview data. Using the initial codebook, we reviewed all the transcripts through subsequent rounds of axial coding to continue refining the codebook. This codebook refining process involved consolidating, merging, and renaming codes to achieve the finalized codebook. The final codebook comprised 76 codes. Once the final codebook was completed, we then organized our codebook to determine which codes answered the research questions. Through an iterative debrief process, we utilized the codes by research questions to discover this study's emerging ideas and themes based on the identified patterns or trends between the participants' experiences. Specific to this paper, we explored the codes and emerging ideas connected to their experiences navigating the COVID-19 pandemic, college transition and supports during this transition.

4 Findings

This study centered on how holistic mentoring ecosystems mitigated the impact of the combined critical junctures of freshman year and the COVID-19 pandemic on students from low-income backgrounds in STEM. The two main themes emerging from the analysis of the students' experiences were acclimation to the academic environment and fostering connection to the STEM community. The presentation of these themes is based on the interview protocol, which concentrated on the impact of the critical junctures in the participants' academic and social contexts.

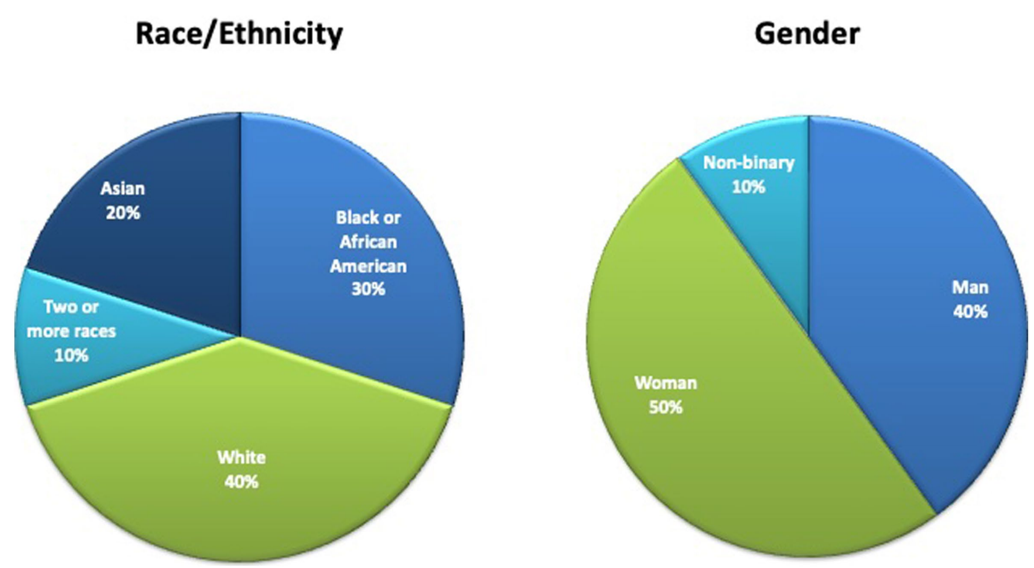

FIGURE 1
Makeup of participant sample by race/ethnicity and gender.

4.1 Theme 1: acclimation to the academic environment

Entering college amidst the pandemic proved to be a daunting challenge for many of our students. They encountered various anticipated and unforeseen hurdles while acquainting themselves with the college environment. As our students reflected on their first semester in college amid the pandemic, there was a shared sentiment of uncertainty navigating their environment under these circumstances. Participant 9 entered college after taking a gap year. He explained, "I was coming off of a year of no school and then to go into online school [due to the pandemic]. That was a large learning curve… I had been out of a classroom and my classes in high school were not online." He further expressed, "You're in a new environment. There's a pandemic and you are on your own… These are fairly hard classes, especially for someone in college for the first time." Similarly, Participant 6 recounted having to use "ingenuity" going into her first year because "it pretty much was like we did not really have teachers." Much like their peers, Participant 2 discussed how entering college amid a pandemic impacted his acclimation to the campus and where to find resources. "As a freshman in the pandemic, and then going in the sophomore year of being expected to know where these offices are, where these buildings are, how to get around campus… I had never even been in the library. I did not even know we had a library."

In addition to making sense of their non-traditional collegiate experience, students recounted academic setbacks due to an inability to engage in through traditional means. Participant 2 shared regarding establishing connections with faculty, "It was a lot harder to meet most of my freshman professors… It was also the faculty not getting to know me personally freshman year, because it's first impressions or coming into college… where it counts the most." Several students shared instances where their confusion could have been mitigated by in-person connection to faculty or support staff at the start of their first-year. Participant 1 recounted her experience with course selection her first semester, "It was confusing…there was some questionnaire where I picked trigonometry but somehow, I ended up taking calculus… There was a lot of confusion, and not really understanding what to do, and not really being able to talk to my professors because they were swamped with emails." Another significant hurdle was an inability to engage in educational experiences, such as shadowing and undergraduate research, that is known to be critical experiences for their career trajectories in STEM. Participant 8 entered college in Fall 2021, she was still met with similar restrictions that were implemented during the onset of the pandemic when trying to find external educational opportunities. "A lot of opportunities, even still, were unavailable. There was one shadowing program I wanted to do with a certain doctor, but I could not do that because of Covid, and it was too restricted."

Several of the students attributed their involvement in a small, cohort style campus mentoring program assisted in their navigation of their academic challenges amid the pandemic. Participant 8 and Participant 2 shared similar sentiments about access to essential information and resources needed to navigate college. Participant 2 explained, "The meetings we had every month are extremely helpful… the information we talk about in these meetings are things I did not know existed, and every time I think I know everything about campus I learned something new in the next meeting." He further shared about the benefit of the one-on-one advising amid the pandemic. "One on ones are extremely helpful because I'm able to communicate what's going on in my life, so I know somebody is aware… I know I have somebody to ask questions to, or things come up." Similarly Participant 4 stated, "I think it's that stability and mentorship… If I really have a problem… I have someone from the program to reach out to… that's been really helpful." Even after the initial impact of the pandemic began to subside, students expressed the importance of participating in specialized programs to mitigate the lasting effects of the pandemic. Participant 9 eloquently explained, "I have a pretty good idea of what I want to do. But I am strong enough to admit that I do not have all the resources and knowledge that I need to get to places."

4.2 Theme 2: fostering connection to the STEM community

Despite best efforts to interact socially through alternative means, the participants collectively described the feelings of isolation and difficulty in making social connections with peers. Participant 4 expressed, "…with the pandemic it was definitely hard to adjust to like not really getting that college experience like not having a welcome week, not really getting to make a lot of friends." Participant 5 shared how severely limited his social engagement was due to fear about being exposed to COVID. When asked how the pandemic impacted his social connected, he shared, "Socially probably quite a bit because I was a bit anxious about COVID…I was a bit paranoid at first. I made sure I had my health at the forefront, so that lessened than my chances of good social interactions and hurt my chances of getting out there."

Even for participants with more access to opportunities for social engagement, they still encountered isolation and minimal social engagement. For instance, Participant 9 discussed his experience living in the science learning community with more opportunities for social engagement. However, he recounts the feelings of isolation even though he was in in-person classes.

> It would feel so weird living in the Science residential college… seeing people and not talking to them…both of my Calculus classes were in person because they were taught in the basement [of the residence hall] … I think everyone was just afraid to be near someone else. We'd walk out of class, and then we'd walk up [to the building lobby] together in silence and then go back to our rooms.

On the other hand, Participant 2 discussed how the opportunities for social connections within the science living learning community made it possible to withstand the feelings of isolation. He shared, "… in the science learning community… they were still doing events. They took precautions to make sure everything was safe and I really appreciated the effort to get people outside because everything I went to otherwise were Zoom calls." These accounts of the academic and social experiences from the same living-learning community highlights that even with more opportunities for engagement, it is still essential to have an organized effort from faculty and staff to foster community development.

Two of the participants, participant 3 and 6 both agreed that their education would have been severely impacted without the invaluable support they received from the mentoring program. They both acknowledged that the program's guidance, support, and resources were crucial to their persistence. They expressed that, without this program, they would have either transferred from their institution or discontinued their education altogether. Participant 3 shared their initial concerns about making social connections and explained that their involvement in a cohort-style campus mentoring program provided them with the community they needed to stay enrolled at their current institution.

> How am I going to find people? It's COVID time and they aren't doing in-person events so I don't really know how to go about meeting people… having that community built in [through the mentoring program] when I came to college… it was really helpful getting you through that first semester… Because if I didn't have anyone around me, I probably would have transferred back to Arizona.

All of our research participants agreed that being a part of a holistic mentoring ecosystem gave them opportunities to engage socially with a community of peers, which satisfied their need for social connection during a time when many students had limited opportunities for social connection. Participant 5 expressed that the program provided him with a consistent connection point with his peers despite the fear of catching COVID. "I'm happy I had the mentoring program because… you are attending meetings, and I do not have a choice. It balanced things out. I did not feel so alone." In the same way, Participant 4 highlighted the uncertainty she had as a freshman. "It was the combination of sort of not knowing where to go… not knowing what resources are available… not knowing what your community could be like… what and who you could depend on in college." She elaborated on how the mentoring program helped alleviate those concerns. "I really like the aspect of the program… to guide me through certain parts of the College of Science."

5 Discussion and conclusion

Extensive research has been conducted on mentoring practices in STEM undergraduate programs. Yet, the current global context, marked by impactful events like the COVID-19 pandemic, has paved the way for new avenues of exploration regarding the potential of mentoring to ease the burden of traumatic experiences on college students' perseverance. As such, our study seeks to investigate the role of a comprehensive mentoring ecosystem in supporting low-income and diverse students pursuing STEM fields at critical junctures. Through the accounts and reflections of our 10 participants, we explore the central research question on how the participation in a holistic mentoring ecosystem mitigated the impacts of the COVID-19 pandemic on their persistence in their first year of college.

Our research examined the academic and social engagement of undergraduate students during their freshmen year of college amid the COVID-19 pandemic. Specifically, we investigated how students dealt with limited educational opportunities and connections with faculty. Our findings show that students who participated in a structured mentoring program during the pandemic attributed it to helping them navigate the academic environment. Specifically, our students expressed how the monthly meetings and one-on-one check ins through the mentoring program provided guidance, information about resources and motivation, which helped them feel more integrated into the educational community and enabled them to thrive despite pandemic-related obstacles. This finding builds on existing literature and deepens our understanding of the impact of mentoring at critical junctures.

In addition to supporting academic engagement, our findings show that involvement in a holistic mentoring ecosystem provided students with multiple points of social connections. In particular, engagement in a holistic mentoring ecosystem facilitated and bolstered students' social connections by creating a supportive environment that encouraged students to interact with their peers, mentors, and other individuals within the mentoring ecosystem. For instance, several of our participants lived in a science living-learning community, which gave them access to smaller, cohort-style group settings for classes and social programs. This allowed students to cultivate meaningful relationships and foster a sense of belonging, which is crucial for their overall well-being. Aligned with Tinto's retention model, we too found that acclimation and connection to the college community was vital to students persisting through their first year of college despite challenges.

Echoing Berg (2016) sentiments regarding low-income students' needs in college, we, too, assert that simply providing financial assistance is not enough. Low-income students need academic guidance, mentoring, and support that fosters community. The need is even more significant in pivotal moments, such as critical junctures during their college career. It is only through a combination of financial assistance, academic counseling, and supplementary resources that we can ensure the success of low-income students.

While this study centers around the difficulties encountered by first-year college students amidst the pandemic, this work possesses the potential for broad applicability in other scenarios. Critical junctures are not limited to the first year of college. As such, this study emphasizes the significance of holistic mentoring ecosystems in supporting students and navigating a diversity of critical junctures in the academic training of students in STEM disciplines. Moreover, the study contributes to the current body of literature on mentoring, particularly holistic mentoring ecosystems in supporting low-income student populations.

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 LSU Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

RD: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. ZW-K: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing.

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Scientific creativity in secondary students and its relationship with STEM-related attitudes, engagement and work intentions

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The role of creativity in education is pivotal, since it is regarded as an essential skill enabling students to cope with future challenges, not only at their professional, but also at their daily life. Consequently, the assessment and improvement of creativity skills among secondary school students has been tackled both at international (OECD reports and the recent inclusion of creativity in the 2022 PISA tests) and national spheres (such as the LOMLOE law at Spain, in which this study is framed). In this context, this longitudinal quasi-experimental study explores the scientific creativity performance of Spanish secondary students (N=780) and its relationship with their attitudes and engagement towards science, and work intentions in STEM-related careers. Results show a noteworthy deficiency in scientific creativity, in terms of problem-finding abilities, alongside with moderately accurate and positive perceptions about how science works and its individual and collective implications. In addition, limited engagement in science-related activities and a low rate of expectations in pursuing STEM-related careers have also been detected. Gender differences were found in scientific creativity, as well as perceptions and career expectations related to science. No differences were found in the scientific creativity across the levels of compulsory secondary school, but an improvement in perceptions about science was observed as the students progressed in the educational system. Nevertheless, a decrease in the rate of engagement and willingness to embracing a STEM-related pathway has also been detected in higher levels. Positive correlations between engagement and career expectations related to science were also found. The importance of nurturing scientific creativity is discussed in terms of enriching learning experiences and the design of interventions and specific policies. Finally, the impact of implementing creativity-focused educational strategies is highlighted in order to promote interest in pursuing STEM careers beyond the obligatory boundaries of education.

KEYWORDS

scientific creativity, attitudes, engagement, STEM, secondary education

1 Introduction

One of the main issues dealing with students' engagement with STEM (science, technology, engineering and mathematics) subjects is the deeply rooted perception that those are complex and detached from reality. This is directly related to a lack of concentration and perseverance, which contributes to expand the barrier for diving into a STEM-related academic journey

(Tinto, 2010). This challenge hinders the scientific literacy, specifically at secondary school levels. In this context, conventional teaching methods that emphasize memorization, often divorced from real-life contexts, persist despite their drawbacks (Allchin, 2014). This approach fails to engage students with scientific concepts, leaving them uninterested and struggling with comprehension. Bridging these concepts to everyday life is crucial; dismissing this approach solidifies disinterest in STEM subjects, and particularly in science (Chambers et al., 2019).

According to the recently published results of the Program for International Student Assessment (PISA), there is a notorious general decrease of the performance at science, mathematics and reading, since the implementation of the program (OECD, 2023). Considering the case of Spanish data, mean performance in all three subjects was significantly lower in 2022, when compared to 2012 and 2015 editions. Indeed, the number of 15-year-old students scoring below the basic level of performance (Level 2) increased in all three subjects (over the 2012–2022 period). However, over 79% of Spanish students achieve, at least, this level. Consequently, those students are supposed to be able to recognize the correct explanation for familiar scientific phenomena and can use such knowledge to identify, in simple cases, whether a conclusion is valid based on the data provided. Nevertheless, they were not able to creatively and autonomously apply their knowledge of and about science to a wide variety of situations, including unfamiliar ones (OECD, 2023). Hence, students are not thought to be equipped with the necessary creativity skills and competencies to cope with the current society paradigm, in which uncertainty and change are the main characters. Within this landscape, there is predominant research focused on evaluating student learning outcomes and performance in light of the widely recognized 21st-century skills (Xia et al., 2022). Among these essential competencies, creativity stands out as a subject of considerable interest across diverse disciplines, since it embodies a pivotal human capacity, encompassing intra and inter-psychological processes that profoundly influence individuals personally and collectively (Beghetto, 2016; Sawyer, 2021). Moreover, creativity has been strongly related with problem-solving abilities, divergent thinking, metacognition processes and remote-associations construction (Jia et al., 2019), which are essential in STEM-related endeavors.

In this context, the present study contributes to the understanding of scientific creativity among Spanish secondary school students, shedding light on their performance and its interrelation with attitudes towards science and STEM career aspirations. By using a longitudinal quasi-experimental methodology, potential variations across different educational levels and gender differences are explored. Moreover, the integration of scientific creativity assessment with the assessment of students' STEM attitudes and career intentions offers a novel perspective and a holistic understanding of the challenges and opportunities faced by students in pursuing STEM-related pathways.

Firstly, literature review and theoretical framework sections outline the research background, exploring the nature of creativity with emphasis on scientific creativity, as well as the diversity of assessment methodologies, and their implications for educational practices. Afterwards, the methodology section describes the longitudinal quasi-experimental design employed in this study, detailing the participant characteristics, data collection procedures, and analytical techniques. Results are then presented, highlighting key findings regarding scientific creativity of students, their perceptions about science, and their STEM career aspirations. Finally, discussion and conclusion sections synthesize these findings, emphasizing the importance of nurturing scientific creativity through targeted educational interventions and policies.

1.1 Literature review

Despite the existence of a vast number of creativity definitions at the literature, those commonly embody two pivotal traits: novelty and utility (Stein, 1953). Novelty is associated to uniqueness or originality, while utility is referred to meaningfulness or appropriateness (Runco and Jaeger, 2012). Moreover, it is widely accepted that the nature of creativity is multi-componential (Barbot et al., 2019). Hence, diverse theoretical and empirical frameworks, stemming from various psychological perspectives, delve into this phenomenon. Additionally, understanding the mechanisms underlying creative performance is critical. Models such as the "Four P model" (Rhodes, 1961) or the more recent "Four C model" (Kaufman and Beghetto, 2009) help to delineate different levels of creative expression. Those frameworks capture various manifestations of creativity during the learning process, emphasizing the intertwined nature of creativity and learning (Lemmetty and Collin, 2021). Particularly, by providing access to diverse perspectives, knowledge and experiences, STEM education plays a crucial role in developing creativity in conjunction with other essential skills, such as communication, teamwork, and adaptability (Harris and De Bruin, 2018), which in turn broad personal, professional, and collective objectives (Vincent-Lancrin et al., 2019).

The relationship between creativity and education is often addressed by assessing the influence of personality traits, cognitive factors, or educational programs on creative processes. These studies often rely on diverse instruments and settings to assess creativity (Hernández-Torrano and Ibrayeva, 2020; Sahin et al., 2023). The assessment methodologies primarily include three major approaches: evaluating creativity through accomplishment, profiling individual characteristics related to creative potential, and evaluating creativity potential via predefined tasks (Thornhill-Miller et al., 2023). Techniques employed in these approaches range from expert evaluations to self-report questionnaires, divergent thinking tasks, such as the Torrance Tests of Creative Thinking (TTCT) (Torrance, 1972), to personality tests (Costa and McCrae, 1992), among others. Several reviews have been published aiming to provide a comprehensive overview of creativity assessment approaches (Acar and Runco, 2019; Cotter and Silvia, 2019; Karwowski et al., 2019; Snyder et al., 2019). Furthermore, emphasis on accuracy, homogenization, and transparency in reporting creativity results is regarded as critical for advancing on creativity research, despite its complex and multidimensional nature (Barbot and Said-Metwaly, 2021).

Indeed, the existence of creativity domains has been extensively discussed since the early stages of this research field (Guilford, 1950). Nevertheless, in recent years a consensus has grown acknowledging the multi-componential nature of creativity, compiling both domain-specific and general features and also including social and cultural interconnections (Baer, 2012; Glaveanu et al., 2020). From a theoretical point of view, the well-known Amusement Park Theory (APT) (Kaufman and Glaveanu, 2019) states that there are four hierarchical stages that allow creative processes to occur. These include from initial requirements that must be present, such as a supportive environment or a basic level of intelligence and interest; knowledge at general thematic areas, such as science or arts; to specific domains and microdomains, which correspond to concrete sub-themes and tasks (Baer and Kaufman, 2005).

In this regard, there are numerous studies in the literature focused on specific areas of creativity (Said-Metwaly et al., 2017), such as scientific creativity (Hu et al., 2010; Chen et al., 2016; De Vries and Lubart, 2019), linguistic creativity (Bowdle and Gentner, 2005; Bergs, 2019), and other knowledge areas like music, art or mathematics (Erbas and Bas, 2015; Mansour et al., 2018; Kladder and Lee, 2019; Leikin and Sriraman, 2022). Therefore, even though divergent thinking tests, are still the most commonly used (Kapoor et al., 2021), researchers are recently more prone to adopt a more comprehensive approach by evaluating multiple areas of creativity. This implies not only evaluating isolated creativity domains, but considering the relationships between them and exploring how they influence each other (Long et al., 2022), as well as taking into account further key aspects that forge one's individual creativity profile (Glaveanu et al., 2020), such as life satisfaction, engagement, positive emotions and academic preferences and performance (Conner and Silvia, 2015; Caballero-García and Sanchez Ruiz, 2021; Bekker et al., 2023). In this context, the impact of teaching strategies that allow students to express their creativity have been proved to be remarkably relevant, not only at learning outcomes, but also at their attitudes towards science (Aguilera and Perales-Palacios, 2020; Bi et al., 2020). Regarding STEM-related subjects, some studies proved that project-based STEM learning enhances the creativity of students (Hanif et al., 2019; Salmi et al., 2021), while other studies point out to the influence of creativity in STEM-related career choices (Conradty and Bogner, 2019; Higde and Aktamis, 2022).

1.2 Theoretical framework

As mentioned above, despite not having a standard definition of creativity, its multi-dimensional character is well-acknowledged among researchers of the field, and it is considered to include specific-domains, general-domains and further aspects related to personal, social and cultural traits (Baer, 2012; Glaveanu et al., 2020). Among all the possible dimensions, relatively limited attention has been paid to scientific creativity in comparison to artistic or linguistic domains of creativity (Raj and Saxena, 2016; Hernández-Torrano and Ibrayeva, 2020), for example. Nevertheless, scientific creativity differs from other dimensions, since specific knowledge and skills are needed to perform creatively in any given scientific creativity endeavor, such as experimental practices or problem finding and solving. Consequently, general/specific knowledge and skills, as well as divergent and convergent thinking, are considered to play a key role when approaching science education creatively (Zulkarnaen et al., 2018; Yildiz and Yildiz, 2021). In this regard, scientific creativity may be conceptualized as an interplay of knowledge, skills and divergent/convergent thinking, which provides a creative pathway to science (Klahr, 2000; Heller, 2007; Mukhopadhyay and Sen, 2013). Particularly, Hu and Adey (2002) develop the three-dimensional Scientific Structure Creativity Model (SSCM) in order to conceptualize scientific creativity, within the context of science education. This model consists of three scientific dimensions: process (scientific thinking and imagination); product (scientific knowledge, phenomenon, technical artifacts and problems) and personality (fluency, flexibility and originality). Although this approach is highly in line with the perspective of Guilford (1950) and Torrance (1972), it also includes scientific creative endeavors such as generating and corroborating hypothesis as well as problem finding and solving (Aschauer et al., 2022).

In addition, the students' ability to think creatively and to produce creative outcomes at STEM subjects is thought to be analogous to professional scientists' endeavors, regardless the evident differences between formal scientific work and scientific education (Kind and Kind, 2007). Those are the reasons why nurturing and cultivating scientific creativity of students is essential, not only to enhance their academic performance, but also to increase their self-efficacy/self-concept and in turn encouraging them to pursue a science-related academic journey (Lent et al., 1986; Taskinen et al., 2013; Tytler, 2014; Xu, 2023).

In this context, prior to developing interventions and curricular programs addressed to promote creativity in the scientific dimension it is essential to explore the scientific creativity of secondary students, their potential and limitations (Alves-Oliveira et al., 2022; Hu et al., 2023). Several instruments have been used for measuring scientific creativity (Hu and Adey, 2002; Hu et al., 2010; Ayas and Sak, 2014) based on different creativity aspects, such as curricular science knowledge and skills related to experimenting and managing data from observation, generation of scientific products and analysis of scientific processes, or formulation of questions of scientific nature. They converge in the idea that scientific discovery stems on different aspects of the scientific method, such as searching for possible hypothesis, performing experiments, etc. (Aschauer et al., 2022). These instruments have been used not only to assess secondary school students' creativity (Hu et al., 2010; Pont-Niclòs et al., 2023), but also to get insight into the impact of teaching experiences in STEM subjects at creativity performance (Jia et al., 2017; Demirhan and Sahin, 2019).

Considering the imminent publication of the 2022 PISA creativity results and the still recent law modification within the Spanish educational system, which praises creativity as a key transdisciplinary pillar of students' formation (LOMLOE, 2020), it is imperative to reckon on studies assessing the scientific creativity of secondary school adolescents. This will serve to gain a better understanding of the prospects and chances in the design of specific interventions and programs, targeting the development of scientific creativity and the encouragement of students to pursue a science-related pathway. Thus, the main aim of this study is to assess the scientific creativity of Spanish compulsory secondary school students, and its relationship with their attitudes towards science, in terms of perceptions, engagement and career expectations. Particularly, the research questions that nurture this investigation are the following:

- What is the performance in scientific creativity of Spanish secondary school students?
- Which is the predominant nature of their perceptions, engagement and career expectations with regard to science?
- Are there any differences depending on the student's level or gender?

- Is there any correlation between scientific creativity and attitudes towards STEM subjects (particularly Sciences) in Spanish secondary school students?

To answer these questions, this study encompasses a quasi-experimental research evaluating students' scientific creativity, perceptions about science, engagement in science-related activities, and STEM career expectations, exploring potential variations across different educational levels and gender differences via statistical analysis, as described in the following section.

2 Materials and methods

2.1 Participants

A total of 780 Spanish students pertaining to four different high schools from the eastern region of Spain participated in the study. The sample was selected through non-probabilistic and convenience sampling, which is one of the most common sampling protocols used when the aim of the research is to obtain insights about a particular aspect within a group of individuals. Hence, the selection of the sample maximizes the understanding of the underlying studied phenomena (Onwuegbuzie and Collins, 2007).

The levels of the secondary school involved in this research correspond to the compulsory stage of the secondary education in Spain. Of the total sample, 210 participants were studying the first level of that stage (52.4% male, and 47.6% female); 207 students correspond to the second level (53.6% male and 46.4% female); 169 of them were studying the third level (49.7% male and 50.3% female), while 194 participants were adscripted to the last level of compulsory secondary education (51.0% male and 49% female). Regarding the ages of students of each level, those were between the typical ranges within the educational system in Spain, being 12 for the first ($M = 12.3$; SD = 0.6); 13 for the second ($M = 13.4$; SD = 0.5); 14 for the third ($M = 14.3$; SD = 0.5); and 15 for the fourth level ($M = 15.3$; SD = 0.6).

2.2 Design and procedures

This study corresponds to an exploratory and semi-empirical research (Cohen et al., 2002), carried out during the 2021–2022 academic year. Specifically, previously reported, and validated instruments were used to perform a quantitative analysis. The procedure began by explaining our research project to the headmasters of a selection of high schools situated in the Valencian Community. Those willing to participate received more detailed information about the research, protocols and data processing. That information was appropriately distributed to parents and legal tutors of students, which signed an informed agreement form to collaborate in the study. After that, one class session (c.a. 50 min) was used for students to complete paper-based questionnaires. During the session both the teacher in charge of the students' group and a researcher were present. The combination of informed consent with the anonymity and confidentiality of responses ensures the ethical principles and requirements established by the Ethics Committee of the University of Valencia. Hence, ethical approval was not required for the study involving human samples in accordance with the local legislation and institutional requirements.

2.3 Instruments and data collection

Both daily (DSCI) and specific (SSCI) scientific creativity were assessed by means of the questionnaire developed by Hu et al. (2010), which is based on problem-finding abilities and combines two types of instruction: opened and closed (see Supplementary Table S1). This set-up is addressed to evaluate all potential creativity outcomes related to scientific problem-finding, whether those stem on every-day observations or specific knowledge about science-related matters. Hence, the questionnaire includes two subsequential items, one corresponding to the opened and other to the closed instruction. Directions were shown as slides during the session and the researcher was available for participants to ask any further inquiry. Students had a total of 16 min (8 min for each item) to complete the questionnaire. Firstly, students were asked to generate science-related questions, based on their life/daily experiences and their own curiosity, from as many perspectives as they could, and as unique as possible (opened instruction). Secondly, participants were asked to generate as many scientific questions as possible related to an image of an astronaut at the moon (closed instruction). The scoring process is based on the TTCT conceptualization of creativity (Torrance, 1972). Consequently, the questions generated by students were assessed by means of a three-folded framework consisting on fluidity, flexibility and originality: fluidity corresponds to the number of questions generated by each student; flexibility is scored as the number of knowledge areas used in order to generate those questions, with 12 categories included for DSCI and 7 categories for SSCI (Pont-Niclòs et al., 2023; see Supplementary Tables S2, S3); and originality emerges from a statistical treatment of the data, since it is related to the frequency percentage of a particular generated question within the whole sample (2 originality points if the frequency percentage is lower than 2%, 1 point if the frequency is between 5 and 10%, and 0 points if above 10%). The total score for each scientific dimension is calculated as the sum of the fluidity, flexibility and originality scores.

The perceptions and engagement of students regarding science were assessed with a questionnaire adapted from a validated scientific literacy survey (Huang, 2012; Wu et al., 2019). On one hand, items corresponding to the "perceptions" dimension were based on epistemological and ontological concepts in conjunction with assumptions about the influence of both science and technology on society (Osborne et al., 2003). On the other hand, the "engagement" dimension was rooted on the conceptualization of enjoyment and intrinsic motivation on leisurely science learning (Ryan and Deci, 2009) and involvement on scientific activities as a source of pleasant life experiences (Nugent et al., 2015). Finally, the expectation to pursuing a science-related career was evaluated via items at the section ST113 (students' attitudes towards science and expectations of science-related careers) from the PISA 2015 tests (OECD, 2016). Those items are based on the instrumental motivation to learn science, in terms of usefulness for students to pursuing their future studies or careers (Wigfield and Eccles, 2000). Items 1 to 6 correspond to the "perceptions" dimension, whereas items 7 to 12 correspond to the "engagement" dimension, and items 13 to 16 assess the willingness to develop a scientific career (see Supplementary Table S4).

A four-point Likert scale was used to score each of the items. The final score for each of the above-mentioned dimensions was calculated as the mean/median value of the items included in that dimension.

2.4 Data analysis

The statistical analysis of the data was carried out with the software IBM SPSS Statistics (version 28). Firstly, descriptive analysis of the sociodemographic and assessed variables was performed (frequencies, percentages, mean, standard deviation, median and IQR) to elucidate the general characteristics of the sample. Secondly, Kolmogorov–Smirnov test was applied to get insight into the normality of the sample distributions. Since the normality assumption was not corroborated for any of the studied variables ($p < 0.001$ for all variables), non-parametric tests were used. Particularly, Kruskal-Wallis test was applied to investigate differences among levels of compulsory secondary education, whereas Mann–Whitney U test was used to explore gender differences. The effect size was calculated using the formula described by Field (2018) for non-parametric samples. The magnitude of the effect size was evaluated according to Cohen's (1988) classification for behavioral sciences, being small (up to 0.2), medium (from 0.2 to 0.5) and large (higher than 0.5). Finally, the correlation among variables was estimated by means of Spearman correlation coefficient. In all cases, the level of statistical significance was 0.05.

3 Results

3.1 Assessment of daily (DSCI) and specific (SSCI) scientific creativity

Scores corresponding to daily and specific dimensions of scientific creativity of Spanish secondary school students are shown at Table 1. Regarding fluidity (number of questions generated by student), the mean value is lower for the DSCI ($M = 6.8$, SD = 3.9, Me = 7.0) than for SSCI ($M = 8.1$, SD = 4.0, Me = 9.0), although the former corresponds to an opened instruction and the latter to a closed one. Considering the flexibility parameter (the quantity of knowledge areas included by each student in their questions), the value for daily ($M = 3.8$, SD = 1.7, Me = 4.0) and specific dimensions ($M = 4.1$, SD = 1.4, Me = 5.0) are analogous. Nevertheless, it is essential to note that the areas defined for each dimension differ from each other (see Supplementary Tables S2, S3), since the spotlight of DSCI and SSCI encompasses distinct scopes of science.

Particularly, Figures 1, 2 show the knowledge areas mostly used by students, for DSCI and SSCI, respectively. As it can be observed, with the open instruction of DSCI test, students resort to the fields of astronomy or human body/health in order to formulate their scientific inquiries, while the areas related to the Moon's composition and meteorology, spatial technology/communications and physics (gravity, space motion) are mainly used in order to create questions related to the image of the astronaut at the moon (SSCI test). Concerning the originality scores, the scarcity of unusual or unique questions generated by students, for both DSCI ($M = 2.5$, SD = 1.5, Me = 2.0) and SSCI (M = 1.7, SD = 1.0, Me = 1.0) must be highlighted. Some examples of original questions produced by students at the DSCI dimensions are "why is the snow white if water is transparent?" or "why are we addicted to sugar?," while some examples of original SSCI questions are as follows: "is it possible to set a fire at the moon?" or "which sort of fuel did they use?"

Finally, the total value for creativity at each of the assessed dimensions, calculated as the addition of the three parameters mentioned above, is remarkably lower than those reported by Hu et al. (2010) for the equivalent grades assessed in this study.

3.2 Assessment of the perceptions, engagement and career expectations related to science

Table 2 shows the results of the descriptive analysis corresponding to each of the items used to assess perceptions, engagement and career expectations related to science of Spanish secondary students. Regarding perceptions, students display moderate awareness of the influence of science, individually and collectively, as well as sufficient knowledge about the epistemological and ontological principles of science ($M = 3.0$, SD = 0.4, Me = 3.0). It must be highlighted that from all items included in that category, the one corresponding to the versatility and dynamism of scientific knowledge (item 4) have the lower score ($M = 2.5$, SD = 0.9, Me = 3.0). With respect to the engagement category, values are slightly lower than the ones for perceptions ($M = 2.3$, SD = 0.6, Me = 2.2). This fact may indicate that students rarely enjoy or are prone to engage in science-related learning, activities, or events. Particularly, item 12 shows a notably low score ($M = 1.5$, SD = 0.8, Me = 1.0), indicating that students scarcely participate on divulgation events. The scores of item 11 ($M = 1.9$, SD = 0.9, Me = 2.0), which is associated with non-formal and autonomous processes of learning, are also low. Finally, the expectations to pursuing a science-related career are also low to moderate ($M = 2.7$, SD = 0.8, Me = 2.7), which may be correlated to the instrumental motivation of students. Therefore, values for all three

TABLE 1 Descriptive statistics for the studied dimensions of scientific creativity.

	Daily scientific creativity (DSCI)						Specific scientific creativity (DSCI)					
Parameter	Min	Max	M	SD	Me	IQR	Min	Max	M	SD	Me	IQR
Fluidity	0	27	6.8	3.9	7.0	5.0	0	28	8.1	4.0	9.0	5.0
Flexibility	0	9	3.8	1.7	4.0	2.0	0	7	4.1	1.4	5.0	1.0
Originality	0	8	2.5	1.5	2.0	3.0	0	6	1.7	1.0	1.0	1.0
Total	0	39	12.5	6.5	14.0	7.0	0	39	13.0	5.5	15.0	7.0

M, mean; SD, standard deviation; Me, median; IQR, interquartile range.

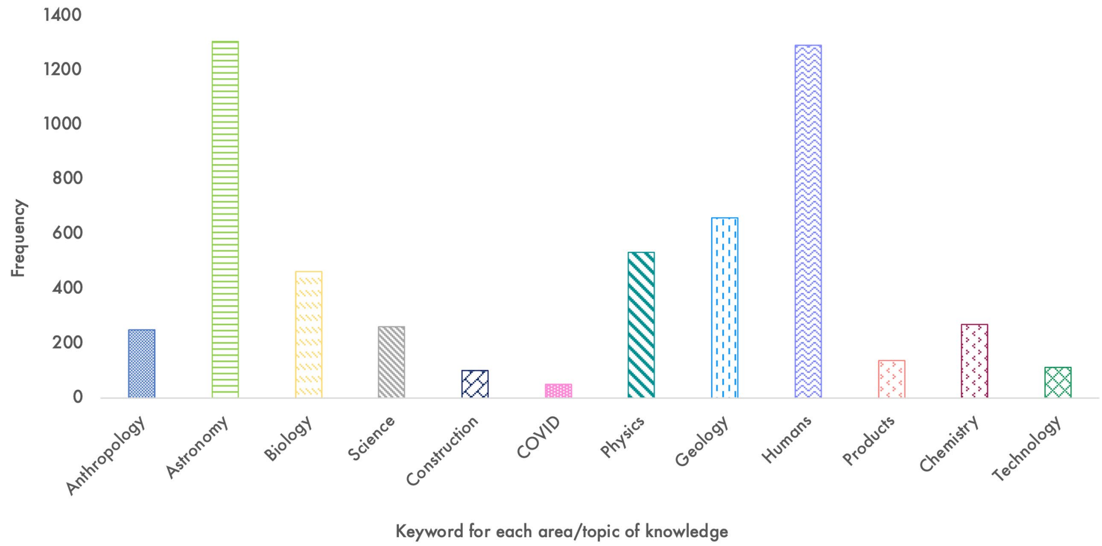

FIGURE 1
Number of questions formulated by students depending on the area of knowledge for DSCI. Keywords for each area/topic of knowledge are described at Supplementary Table S2.

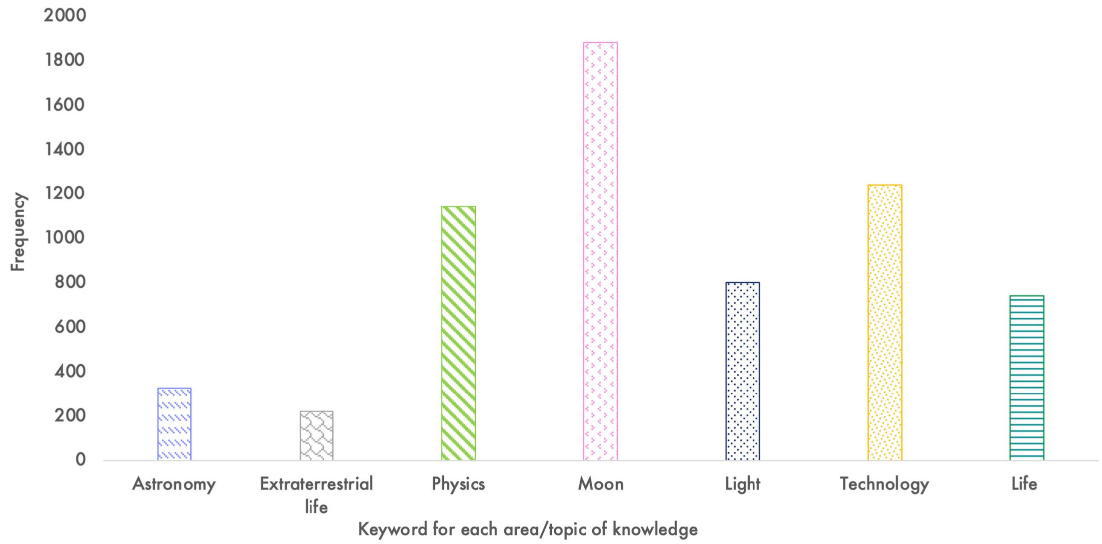

FIGURE 2
Number of questions formulated by students depending on the area of knowledge for SSCI. Keywords for each area/topic of knowledge are described at Supplementary Table S3.

considered categories are analogous, meaning that students are equally likely to understand the principles of science knowledge and perceive it as enjoyable as useful, when they expect to work in science-related occupations.

3.3 Differences according to gender

Aiming to get insight into the role of gender on the scientific creativity performance and the perceptions, engagement and career expectations related to science, inferential analysis was carried out. Since none of the studied variables displayed a normal distribution, non-parametric Mann–Whitney U test was applied (Table 3). As it can be observed, statistically significant differences have been found for performance on both dimensions of scientific creativity. Further analysis of the data reveals that girls outperform boys at DSCI (males: $M = 11.7$, $SD = 6.4$, $Me = 11.0$; females: $M = 13.4$, $SD = 6.4$, $Me = 13.5$) and SSCI (males: $M = 12.0$, $SD = 5.6$, $Me = 12.0$; females: $M = 14.0$, $SD = 5.2$, $Me = 14.0$). Regarding the attitudes towards science, there are statistically significant differences across genders for perceptions and career expectations, while there are not statistically significant differences on engagement. Specifically, girls have more positive and accurate

TABLE 2 Descriptive statistics for the perceptions, engagement and career expectations.

Attitudes towards science	Item	Min	Max	M	SD	Me	IQR
Perceptions	1	1	4	3.2	0.7	3.0	1.0
	2	1	4	2.8	0.9	3.0	1.0
	3	1	4	3.5	0.7	4.0	1.0
	4	1	4	2.5	0.9	3.0	1.0
	5	1	4	3.2	0.7	3.0	1.0
	6	1	4	3.0	0.8	3.0	2.0
	Total	-	-	3.0	0.4	3.0	0.5
Engagement	7	1	4	2.4	0.9	2.0	1.0
	8	1	4	3.2	0.9	3.0	1.0
	9	1	4	2.3	1.0	2.0	1.0
	10	1	4	2.2	0.9	2.0	1.0
	11	1	4	1.9	0.9	2.0	1.0
	12	1	4	1.5	0.8	1.0	1.0
	Total	-	-	2.3	0.6	2.2	0.8
Career expectations	13	1	4	2.8	1.0	3.0	2.0
	14	1	4	2.6	1.0	3.0	1.0
	15	1	4	2.8	0.9	3.0	1.0
	16	1	4	2.6	1.0	3.0	1.0
	Total	-	-	2.7	0.8	2.7	1.0

M, mean; SD, standard deviation; Me, median; IQR, interquartile range.

TABLE 3 Descriptive statistics for the studied variables according to gender ($N_{male} = 404$; $N_{female} = 376$) and results of the Mann–Whitney U test.

	Gender	Mean	SD	Median	IQR	z	*p*	g
DSCI	M	11.7	6.4	11.0	7.0	4.0	<0.001***	0.1
	F	13.4	6.4	13.5	9.0			
SSCI	M	12.0	5.6	12.0	7.0	5.5	<0.001***	0.2
	F	14.0	5.2	14.0	6.3			
Perceptions	M	2.9	0.5	3.0	0.7	4.75	<0.001***	0.2
	F	3.1	0.4	3.2	0.6			
Engagement	M	2.2	0.6	2.3	0.8	0.83	0.4	–
	F	2.3	0.6	2.2	0.8			
Career expectations	M	2.5	0.8	2.7	1.0	3.8	<0.001-	0.1
	F	2.8	0.8	3.0	1.2			

M, male; F, female; SD, standard deviation; IQR, interquartile range.
***There are statistically significant differences at the 0.001 level.

perceptions of science (males: $M = 2.9$, $SD = 0.5$, $Me = 3.0$; females: $M = 3.1$, $SD = 0.4$, $Me = 3.2$) and unexpectedly they are also more prone to pursing a science-related career (males: $M = 2.5$, $SD = 0.8$, Me = 2,7; females: $M = 2.8$, $SD = 0.8$, $Me = 3.0$). However, it must be taken into account that the size effect for all those differences is small ($g \approx 0.2$).

3.4 Differences according to level

Tables 4, 5 show the statistical descriptives for the scientific creativity performance and the perceptions, engagement and career expectations related to science of Spanish compulsory secondary school students. As it can be observed at Table 4, the values for both scientific creativity dimensions (DSCI and SSCI) are remarkably similar across levels.

However, some differences are apparent between students at the first level of Spanish compulsory secondary school and those at the upper levels, for the perceptions, engagement and career expectations variables (Table 5). Further analysis highlights an increase of the positive and accurate perception of science from the first level ($M = 2.9$, $SD = 0.5$, $Me = 2.9$) up to the fourth level ($M = 3.2$, $SD = 0.4$, $Me = 3.2$) and at the same time a decrease in the engagement category

TABLE 4 Descriptive statistics for the studied dimensions of scientific creativity according to level ($N_1 = 210$; $N_2 = 207$; $N_3 = 169$; $N_4 = 194$) and results of the Kruskal-Wallis test.

	Level	Mean	SD	Median	IQR	z	*p*
DSCI	1	11.5	6.5	12.0	9.8	6.3	0.097
	2	13.1	6.6	12.0	7.0		
	3	12.4	5.6	12.0	7.0		
	4	13.2	6.9	13.0	8.0		
SSCI	1	12.8	5.4	13.0	7.0	1.2	0.75
	2	13.4	5.8	13.0	7.0		
	3	13.3	4.8	14.0	6.0		
	4	12.7	5.8	13.0	7.0		

SD, standard deviation; IQR, interquartile range.
Ages corresponding to each level: first (M = 12.3; SD = 0.6); second (M = 13.4; SD = 0.5); third (M = 14.3; SD = 0.5); and fourth level (M = 15.3; SD = 0.6).

TABLE 5 Descriptive statistics for the studied variables related to science attitudes according to level ($N_1 = 210$; $N_2 = 207$; $N_3 = 169$; $N_4 = 194$) and results of the Kruskal-Wallis test.

	Level	Mean	SD	Median	IQR	z	*p*
Perceptions	1	2.9	0.5	2.9	0.7	32.5	<0.001***
	2	3.0	0.4	3.0	0.7		
	3	3.1	0.4	3.2	0.5		
	4	3.2	0.4	3.2	0.7		
Engagement	1	2.4	0.6	2.3	0.7	9.4	0.024*
	2	2.3	0.6	2.3	0.7		
	3	2.2	0.6	2.2	0.8		
	4	2.2	0.6	2.1	1.0		
Career expectations	1	2.9	0.7	3.0	1.0	12.4	0.006**
	2	2.8	0.8	2.8	1.0		
	3	2.6	0.8	2.5	1.0		
	4	2.5	0.9	2.7	1.0		

SD, standard deviation; IQR, interquartile range.
*There are statistically significant differences at the 0.05 level.
**There are statistically significant differences at the 0.01 level.
***There are statistically significant differences at the 0.001 level.

(1st level: $M = 2.4$, SD = 0.6, Me = 2.3; 4th level: $M = 2.2$, SD = 0.6, Me = 2.1) and the career expectations related to science positions (1st level: $M = 2.9$, SD = 0.7, Me = 3.0; 4th level: $M = 2.5$, SD = 0.9, Me = 2.7), from the first to the fourth level. Hence, the results of the non-parametric Kruskal-Wallis test revealed statistically significant differences among levels for the three categories (perceptions: $p < 0.001$; engagement: $p < 0.05$; career expectations: $p < 0.01$). To gain better understanding of those differences, a *post hoc* analysis (Bonferroni test) was performed. As expected by the inspection of the mean/median values, differences are mainly between the first level of compulsory secondary school and the higher levels. Specifically, for the perceptions category, there are differences between the first level and either the second ($p = 0.02$; $g = 0.2$), the third ($p < 0.001$; $g = 0.4$) and the fourth ($p < 0.001$; $g = 0.7$) level. In the case of the engagement category there are differences between the first level and either the third ($p = 0.02$; $g = 0.3$) and the fourth level ($p = 0.005$; $g = 0.3$). Finally, for the career expectations dimension, there are differences between the first level and either the third ($p = 0.03$; g = 0.4) and the fourth level ($p < 0.001$; $g = 0.5$).

3.5 Correlation between scientific creativity and perceptions, engagement and career expectations of secondary school students related to science

Lastly, to explore the potential correlation between the studied dimensions of scientific creativity (DSCI and SSCI) and the variables related to the students' attitudes towards science (perception, engagement and career expectation), Spearman's correlation coefficients (r_s) were calculated (Table 6). As it can be observed, there are strong positive correlations between both dimensions of scientific creativity ($r_s = 0.52$, $p < 0.001$), meaning that a student with high performance in the DSCI task, also display an analogous ability at the SSCI task. Conversely, DSCI and SSCI have no significant correlation with neither the engagement nor the career expectations categories, although there is a positive correlation between the perception one with DSCI ($r_s = 0.12$, $p < 0.001$) and SSCI ($r_s = 0.12$, $p < 0.001$). Finally, there are strong correlations among the three categories exploring the attitudes towards science of students ($p < 0.001$ in all cases).

TABLE 6 Spearman's correlation coefficients between the studied variables.

	DSCI	SSCI	Perceptions	Engagement	Career expectations
DSCI	–	0.52***	0.12***	0.05	0.06
SSCI	0.52***	–	0.12**	0.04	0.08*
Perceptions	0.12***	0.12**	–	0.33***	0.34***
Engagement	0.05	0.04	0.33***	–	0.5***
Career expectations	0.06	0.08*	0.34***	0.5***	–

*There are statistically significant differences at the 0.05 level.
**There are statistically significant differences at the 0.01 level.
***There are statistically significant differences at the 0.001 level.

Nevertheless, from those the highest value of the Spearman's coefficient corresponds to the duet engagement-career expectations variables ($r_s = 0.5$, $p < 0.001$).

4 Discussion

This study explores the scientific creativity of Spanish compulsory secondary school students. Particularly, two dimensions have been assessed: one related to every-day experiences (DSCI) and one to specific knowledge (SSCI). In addition, attitudes towards science have also been evaluated, aiming to shed light into any possible correlation between scientific creativity and perceptions, engagement and career expectations related to science of those students.

Found data have pointed out the low performance of students in scientific creativity (both DSCI and SSCI), particularly at the originality category. These results are in line with previously reported studies (Hu et al., 2010; Huang and Wang, 2019; Pont-Niclòs et al., 2023). Nevertheless, it must be considered that the assessment process has been mainly based on problem-finding abilities, and scientific creativity include several microdomains related to general/specific scientific knowledge and skills, as well as general/specific creativity competencies (Hu and Adey, 2002; Hadzigeorgiou et al., 2012; Barbot et al., 2016). Hence, scientific creativity may be assessed not only in function of problem-finding abilities, but also as performance on generating and testing hypotheses or problem-solving (Sternberg et al., 2020). Considering all the above stated, scientific creativity performance depends on multitude of factors related not only to the subjects' cognitive (De Vries and Lubart, 2019; Zhu et al., 2019) or metacognitive abilities (Jia et al., 2019), but also their science formation, personal experiences, interests and motivation (Collins and Amabile, 1999; Yang et al., 2016).

In this context, it is crucial to explore the potential influence of attitudes towards science on scientific creativity performance, as these attitudes may correlate with how people approach and engage with creativity and learning tasks (Conradty et al., 2020; Hernández-Torrano and Ibrayeva, 2020). However, it is important to recognize that this relationship may be influenced by other factors such as interest and effort, and causality has yet to be established. The assessment conducted at this study, regarding perceptions, engagement and career expectations, has revealed students' moderate willingness and interest in science-related matters. Specifically, their conceptualization and thinking about the scope of science have been found to be relatively accurate and positive, which may be related to the teaching style that they have been confronted (Lumpe et al., 2000; Southerland et al., 2001; Bereczki and Kárpáti, 2021). Despite that, the obtained data have indicated a low rate of students that genuinely enjoy science, especially when referred to voluntarily participate at divulgation or non-formal learning activities (Christidou et al., 2022). Those factors, alongside with the learning processes that they have experienced at the science classroom (Hampden-Thompson and Bennett, 2013; Steidtmann et al., 2023), are directly related to the interest and motivation of students in pursuing a science-related professional pathway (Drymiotou et al., 2021). That may be the reason why the rate of students that are prone to follow a science-related professional life has been found to be relatively moderate as well (Jack and Lin, 2018).

Without underestimating the fact that these results may be influenced by sociodemographic factors, gender and level differences have been also assessed in this study. Specifically, gender differences have been found at both dimensions of scientific creativity (DSCI and SSCI), which is in consonance with similar studies (Hu et al., 2010; Pont-Niclòs et al., 2023). These results sum up to the evidence of the role of gender in creative performance, even though the nature of that role is not fully understood, since it depends on additional personal and sociocultural factors (Nakano et al., 2021). Regarding attitudes towards science, no gender differences have been detected at the engagement category, although girls have slightly more accurate and positive perceptions about science, and they are barely more prone to pursuing science-related careers. Nevertheless, it must be taken into account that effect sizes are small, and scores hardly exceed 2 points (in a 4-point Likert scale), meaning that girls' expectations to embrace a science professional pathway are still moderate. These results are heavily influenced by what students perceived as a science-related career (medical doctor, software engineer, artist, architect or journalist) and the worthiness of school science at the daily and professional spheres. Consequently, data may highlight the narrow view of students about the usefulness of procedural or epistemic scientific knowledge at the real/professional world (OECD, 2016). In addition, it has to be considered that female traditionally have been associated to caring and non-time-consuming careers, while males are more prone to outcome-oriented occupations (Kang et al., 2019). Regarding students' level differences, researchers suggest that creativity can be, and must be, nurtured by appropriated training within the classroom to prepare students to cope with future demands of society (Beghetto, 2019; Alves-Oliveira et al., 2022). In this regard, statistically significant differences were expected among the levels of secondary school education. Unfortunately, no differences between levels have been identified on any of the dimensions of scientific creativity. That continuity in the creative performance throughout compulsory secondary education underpins the need to promote specific actions that carry policies and international efforts effectively into classroom routines, which translates to the intentional curriculum design and the formation of pre-service and in-service teachers in creativity conceptualization and development (Bereczki and Karpati, 2018; Echegoyen-Sanz and Martín-Ezpeleta, 2021; Echegoyen-Sanz et al., 2024). In addition, engagement and willingness to pursuing a science-related pathway of students show a decrease from the first level of compulsory secondary school to the higher level. This fact may be related to the disparity in approaching science learning from the beginner levels, generally stem on curiosity and experimenting; to the advanced levels, typically more theoretical and disconnected from daily experiences (Yang et al., 2016), as also happens for other STEM-related subjects.

The interplay of scientific creativity and attitudes towards science has also crucial implications for any effort to promote creativity, scientific learning, and aspirations to continue studying sciences beyond the limits of compulsory secondary education (Conradty et al., 2020). In this paper, the correlation between scientific creativity and an accurate and appreciative perception of science has been found to be slightly positive. However, scientific creativity performance was not correlated to engagement or career expectations of a science-based professional position. These findings may be related to the fact that scientific creativity requires of specific knowledge about the nature of science, its processes, and influences on society (Ozdemir and Dikici, 2017; Huang and Wang, 2019), although it may not be related to a particular scientific professional orientation, but the learning experiences that students have been confronted to (Chi and Wang, 2023). However, the three dimensions analyzed with respect to the attitudes towards science (perceptions, engagement and career expectations) show positive correlations, being the one between engagement and career expectations the strongest, indicating that an individual's choice of a future occupation is hugely influenced by personal preferences, interests and motivations, in spite that the whole decision process include intricated further factors (Taskinen et al., 2013; OECD, 2016; Vinni-Laakso et al., 2022).

5 Conclusion

This study explores the scientific creativity of Spanish secondary school students and its correlation with perceptions, engagement, and career expectations related to science. Findings shed light on several significant aspects dealing with scientific creativity performance and attitudes towards science. Firstly, the assessment of scientific creativity, encompassing both daily and specific dimensions, revealed a considerable shortfall among students (Hu et al., 2010; Pont-Niclòs et al., 2023). While the study primarily focused on problem-finding abilities, the multi-faceted nature of scientific creativity is emphasized, suggesting that a more comprehensive evaluation including various creativity competencies could offer a deeper understanding (Kaufman, 2012; Barbot et al., 2016; Elisondo, 2021). Secondly, students exhibited moderately positive and accurate perceptions about science, yet demonstrated limited interest and engagement in science-related activities outside, and even within, the classroom. Moreover, their willingness to pursue science-related careers remained relatively low, suggesting a need for more effective strategies to incite interest and motivation in science learning, as well as in other STEM subjects, beyond compulsory stages of education (Conradty et al., 2020). These may be addressed by contextualizing contents by incorporating real-world applications of science in daily life and professional scenarios, since perceiving the usefulness of science has been demonstrated to positively influence students' attitudes towards STEM-related topics (Wijaya et al., 2022). Regarding gender differences, those were appreciable in scientific creativity, aligning with some prior research (Nakano et al., 2021), while differences across levels of secondary education were not apparent. These findings highlight the necessity for targeted interventions that integrate policies promoting creativity and science education into classroom practices, ensuring continuity and enhancement throughout secondary education (Yang et al., 2016; Cotter et al., 2022; OECD, 2023). In addition, the correlation between scientific creativity and attitudes towards science pointed out a strong relationship between engagement and career expectations in science-related fields (Ainley and Ainley, 2011), suggesting that fostering scientific creativity and enhancing the learning experiences, while learning specific scientific knowledge, may result in higher enrolment rates in science-related matters (Struyf et al., 2019; Drymiotou et al., 2021).

Despite its insights, this study has limitations that must be taken into account. The assessment was primarily focused on problem-finding abilities, overlooking other dimensions of scientific creativity. Additionally, the cross-sectional design limits the depth of understanding longitudinal effects between creativity and attitudes towards science. Moreover, the study sample was confined to a specific geographical area, which might restrict the generalizability of the findings. Further research may broaden the scope of this study, such as expanding the sample to other Spanish regions or including additional assessment tools addressed to evaluate diverse general and specific creativity domains, in conjunction with other tests dealing with self-perceptions in creativity endeavors or life satisfaction (Caballero-García and Sanchez-Ruiz, 2021; Ivcevic, 2022). This multi-approach may help to construct a more accurate and complete creativity profile of students, as a starting point to design effective teaching approaches, especially at STEM subjects (Tran et al., 2021).

It seems clear that integrating creativity into teaching methodologies could revitalize the engagement and interest in scientific matters, offering students a more solid connection between conceptual learning and real-world applications. Moreover, this may reinforce the attitudes towards facing STEM subjects, which in turn benefits students' satisfaction willingness to embrace a STEM-related education (Zhao et al., 2022). For instance, teachers may provide examples of creative behaviors that students would be able to emulate (Jonas and Chambers, 2017). In addition, the use of Artificial Intelligence offers a novel framework to nurture creativity among students by its proper usage (Miao and Holmes, 2023). Indeed, fostering creativity equips students with essential skills, such as problem-finding/solving, divergent thinking, and metacognition, which are essential for coping with future challenges, particularly in STEM-related fields where adaptability and innovation are imperative (Perignat and Katz-Buonincontro, 2019).

In conclusion, providing engaging and holistic learning experiences could not only nurture scientific creativity, but also enrich the interest and motivation in pursuing science-related careers. Effective integration of creativity-focused educational strategies is needed for the training of a generation ready to embrace future challenges at a rapidly evolving world. However, further studies are needed to get more integrative insights, thereby bridging the gap between creativity, science education and career aspirations. This is a global and historical problem, but the present and future of STEM careers have creativity, a key competence of the 21st century, as their best ally.

Data availability statement

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

Ethics statement

Ethical approval was not required for the study involving human samples in accordance with the local legislation and institutional requirements because of the nature of the research and the anonymization procedure followed. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

IP-N: Conceptualization, Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. AM-E: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – review & editing. YE-S: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, 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.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1382541/full#supplementary-material

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