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CASE STUDY

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The Cellular Construction Workshop: an integrated STEM teacher–student co-learning experience

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Abstract
This paper presents the design and rationale of a novel workshop model that integrates high school teacher professional learning with out-of-school STEM learning experiences for students from racially and ethnically minoritized backgrounds. Grounded in a conceptual framework that combines situated learning theory, research-based principles of effective professional development, and culturally inclusive and responsive pedagogy, the workshop engages teachers and students as co-learners in authentic, collaborative, integrated STEM activities. By situating professional learning within the same context as student learning, the workshop offers teachers an immersive, integrated STEM experience that can inform their instructional practices while simultaneously fostering STEM interest among underrepresented youth. The goals of this paper are to (1) describe this hybrid teacher professional learning and student out-of-school STEM learning workshop, (2) provide guidelines for professional learning developers and informal educators who are interested in creating integrated STEM learning experiences to support teachers and/or students, and (3) provide some evidence of the workshop's value for both teachers and students. Findings from post-workshop interviews with teachers suggest that they gained valuable knowledge and insights about how to incorporate integrated STEM activities into their own classrooms. For students, participating in the workshop led to an increased interest in STEM and provided insights and new perspectives on the realities and possibilities of working in a STEM field. Thus, these findings suggest that hybrid teacher professional learning and student out-of-school STEM learning experiences have the potential to strengthen teacher pedagogy and broaden participation in STEM among historically marginalized groups.

Keywords Integrated STEM education, Teacher professional development, Out-of-school STEM learning, Equity in STEM

1 Introduction

Integrated approaches to science, technology, engineering, and mathematics (STEM) education and the broadening of STEM participation have become twin focal points of recent educational reform. These dual priorities highlight the need to support both teachers and students: in-service teachers require training to implement integrated STEM curricula effectively, and students from underrepresented and racially minoritized groups need enhanced opportunities to engage in STEM learning. This paper describes a hybrid teacher professional learning and student out-of-school integrated STEM (iSTEM) learning experience, the Cellular Construction Workshop (CCW). The CCW provides a model for teachers of how to teach iSTEM content, while simultaneously providing participating students a vision for how they may apply their science knowledge and engineering design skills to solve pressing real-world problems.

In this paper, we outline the need for in-service teacher professional development in iSTEM education and the importance of out-of-school STEM experiences for ethnically diverse and racially minoritized youth, establishing a rationale for our hybrid teacher professional learning and student out-of-school STEM learning workshop, which was designed to address these converging challenges. The goals of this paper are to (1) describe this hybrid teacher professional learning and student out-of-school STEM learning workshop, (2) provide guidelines for professional learning developers and informal educators who are interested in creating iSTEM learning experiences to support teachers and/or students, and (3) provide some evidence of its value for both teachers and students.

1.1 Integrated STEM education and the need for teacher professional development

Integrated STEM education involves bridging traditionally siloed disciplines to engage students in interdisciplinary problem-solving with real-world relevance [1]. Implementations of iSTEM often emphasize projects or problems that draw on multiple STEM domains and are purposefully designed to have social and cultural significance for students [2]. Such approaches hold promise for improving student engagement and achievement in STEM. However, implementing iSTEM in secondary classrooms poses significant challenges for educators [3]. Schools still offer discipline-based science courses, making it challenging for teachers to break out of their disciplinary silos [4, 5]. Teaching science in an integrated and interdisciplinary manner within this existing structure is challenging and requires new pedagogical approaches that teachers may not be equipped to incorporate into their teaching [6, 7]. Given that most high school teacher training is discipline-specific, they may find it difficult to adopt integrated STEM teaching practices [7, 8]. Many teachers report lacking adequate content knowledge in all STEM areas and sufficient pedagogical strategies to design and deliver integrated lessons [2, 9]. For example, teachers often find it difficult to incorporate engineering and technology concepts into science or math classes due to limited exposure to these fields in their training [9].

Empirical studies of teacher perceptions confirm the prevalence of such barriers and underscore the need for systemic support. In a recent review, Margot and Kettler [3] found that while K-12 teachers generally value STEM integration, they face persistent obstacles, including misaligned curricula, inadequate planning time, assessment concerns, and a lack of administrative support. Critically, teachers identified the absence of ongoing support and professional development (PD) as a major hindrance to implementing integrated STEM initiatives [3]. They reported that additional supports, such as opportunities to collaborate with peers, access to quality integrated curricula, and effective in-service training, would improve their capacity to adopt STEM integration in practice [3]. These findings align with the broader consensus that teacher learning is key to enacting education reforms. Well-designed PD is therefore vital for translating STEM integration policies into classroom practice. In sum, high-quality in-service training programs are needed to develop teachers' interdisciplinary content knowledge, pedagogical skills, and confidence in iSTEM education. Such programs, especially when they leverage collaborative and situated learning approaches, can empower high school teachers to overcome implementation challenges and create meaningful STEM learning experiences for all students.

1.2 Out-of-school STEM learning for racially minoritized students

Parallel to teacher-focused reforms, there is an urgent need to engage ethnically diverse and racially minoritized students in STEM learning and address long-standing disparities in participation. Black, Latinx, Indigenous, and other minoritized youth remain significantly underrepresented in advanced STEM courses in high school and in the STEM workforce [10]. This underrepresentation stems from a complex interplay of sociocultural and structural barriers that often manifest in students' K-12 experiences. Underrepresented and minoritized students may encounter cultural barriers in formal educational settings that lead to decreases in motivation to persist in science [11]. Research indicates that many minoritized students face a lack of inclusivity and a sense of belonging in formal science classrooms, contributing to disengagement from STEM during the critical high school years [12]. Curricula and teaching methods in many schools do not adequately connect STEM content to these students' cultural knowledge, community contexts, or everyday lives [13]. As a result, minoritized learners may perceive STEM as irrelevant or "not for people like them," which can dampen their interest and self-confidence. Over time, such experiences may translate into fewer underrepresented students pursuing STEM electives, enrolling in honors/AP courses, or aspiring to STEM careers. Beyond being an issue of social justice, the loss of diverse talent in STEM has broader repercussions: the inability to attract and retain a diverse pool of STEM learners ultimately impairs creativity, innovation, and knowledge production in STEM fields [14]. Diverse perspectives enrich problem-solving and drive innovation, so broadening minority students' participation in STEM is both an equity imperative and a means to enhance STEM outcomes for society as a whole [14]. Despite the recognition and calls to increase diversity in STEM, significant disparities remain, particularly in more quantitative and computational fields [15].

One strategy to address these disparities is to provide enriching STEM learning experiences outside of the formal school setting. Out-of-school and informal STEM programs have gained recognition as powerful avenues for engaging underrepresented students who might be overlooked or alienated in the classroom [14]. Out-of-school informal learning settings can provide a space where URM students can: (a) engage in authentic integrated STEM activities, (b) connect with peers, and (c) interact with role models from minoritized backgrounds, which may provide inspiration to persist in STEM [16, 17]. Informal STEM learning can take place in a variety of settings including afterschool clubs, weekend or summer camps, science museums and centers, community-based organizations, mentorship programs, and more. These environments offer hands-on, interest-driven activities that youth can explore voluntarily, in contrast to the more rigid and assessment-driven context of school. Importantly, informal programs can be designed to be culturally responsive and welcoming, creating a “low-stakes” space where minoritized students feel safe to explore STEM ideas. Research suggests that participation in informal STEM learning positively influences students’ attitudes and aspirations. For example, longitudinal studies have found that youth who engage in STEM experiences outside of school (such as science clubs or competitions) show increased interest in STEM and are more likely to pursue STEM majors and careers [12]. Such programs can boost learners’ STEM self-efficacy by allowing them to succeed at challenging, real-world projects in a supportive atmosphere [12]. Other research has shown that high school students who attend culturally relevant STEM summer camps or internships develop stronger STEM identities and career aspirations. For instance, one study found that students who participated in summer programs emphasizing real-life, community-relevant STEM problems were far more likely to express interest in STEM careers than their peers who did not have such experiences [12]. These successes illustrate the potential of informal learning environments to serve as “on-ramps” to STEM for marginalized youth. At the same time, researchers have noted a need for a more nuanced understanding of why and how informal programs work. By studying the specific features of effective programs (e.g., mentorship structures, hands-on activities, links to students’ culture or community), we can better translate those elements into formal education settings [14].

2 Rationale for the Cellular Construction Workshop (CCW)

The foregoing discussion highlights two intertwined necessities for advancing equitable STEM education: supporting teachers in delivering integrated STEM instruction and supporting minoritized students through inclusive STEM learning opportunities beyond the school setting. Taken together, these perspectives suggest that improving STEM education outcomes requires a dual focus on empowering educators and enriching student experiences. By bringing together these two strands of STEM education research, we aim to build a robust rationale for holistic STEM education initiatives that simultaneously prepare teachers and inspire underrepresented students. This integrated focus is crucial for creating STEM learning environments that are both pedagogically innovative and socially inclusive, ultimately contributing to a more diverse and empowered STEM talent pipeline [18, 19].

2.1 Conceptual framework

The design of the CCW is grounded in three complementary frameworks—situated learning theory, principles of effective teacher professional development (PD), and culturally inclusive and responsive pedagogy. Together, these inform a workshop structure that engages teachers and students in authentic STEM learning experiences, follows best practices in professional learning, and prioritizes cultural relevance to ensure equity. This section explains each foundation and how its integration creates a meaningful and equitable STEM learning experience for all participants.

2.1.1 Situated learning theory in iSTEM contexts

We begin with the premise that authentic, integrated science-engineering experiences foster active engagement and a deep understanding of STEM and engineering design for both teacher and student participants. The theoretical perspective that underlies our approach is situated learning, which considers learning to be a process of enculturation into a community of practice resulting in the development of knowledge, skills, and identification with the community [20]. In this perspective, learning is most effective when it occurs in authentic contexts and through social participation. Students and teachers gain knowledge and understanding by engaging in real-world activities alongside others [21] and construct their interests and identities through meaningful engagement, experience, and practice [22].

Applying situated learning to the workshop design, teachers and students are immersed in authentic STEM activities (e.g., hands-on experiments; engineering design challenges) that reflect the kinds of problems and practices found in actual STEM careers or everyday life. This authenticity is not only motivational but also social: teachers and students in the workshop collaborate to solve problems, thereby forming a mini "community of practice." The workshop's emphasis on teachers and students engaging collaboratively in STEM activities echoes the apprenticeship model of situated learning, where teachers and students learn with and from others while working on meaningful STEM tasks.

2.1.2 Tenets of effective professional learning for teachers

The CCW's design is consistent with the tenets of effective professional development: it is content focused, incorporates active learning, integrates structures for teacher collaboration, provides ongoing support, and models effective practice [23, 24] Professional development (PD) that zeroes in on STEM content (e.g., integration of biology concepts and engineering practices) and pedagogy has the greatest impact on teachers' instructional effectiveness and student achievement [25]. In the workshop, sessions are tailored to address the Science and Engineering Practices from the Next Generation Science Standards (NGSS), helping teachers deepen their content knowledge and explore pedagogical strategies for teaching an iSTEM unit. Teachers also learn best when professional development is designed to engage them actively (e.g., completing sample activities, analyzing student work or data, or receiving feedback on their practice) [26]. We integrate active learning by having teachers partake in the same activities that they might later implement with students. This hands-on approach allows teachers to experience learning from a student's perspective and reflect on instructional strategies, rather than just hearing about them. High-quality PD provides opportunities for teachers to collaborate, building networks and communities of practice with peers [23, 25]. When teachers from the same school, grade level, or subject area learn together, they can share experiences, brainstorm solutions to everyday challenges, and support each other's growth [25]. Accordingly, our workshop is highly collaborative, providing opportunities for teachers to engage in group discussions and co-reflect on their experiences. This collective participation not only mirrors the social nature of situated learning but also promotes a professional learning community that can persist beyond the workshop. Finally, one-day or short-term professional development sessions are often less effective than those that occur over an extended period [23]. Research suggests that PD spanning multiple sessions or an extended period is necessary for teachers to internalize and apply new strategies [23]. In line with this, our workshop is not a single event but rather occurs over several weeks, providing ongoing support and access to materials and resources.

These features of effective PD are interrelated and mutually reinforcing, rather than isolated elements. The workshop's design holistically combines them, for example, teachers actively learning content in a collaborative setting over a series of sessions, to maximize the impact on teacher growth. By adhering to research-based PD principles, the workshop ensures that teacher participants are not only engaged during the training but also well-supported to transfer their learning into improved STEM instruction for students.

2.1.3 Culturally inclusive and responsive learning environments

Finally, we aim to foster a culturally inclusive and responsive learning environment that supports all participants, ensuring relevance and inclusion for diverse learners. A key strength of informal STEM learning for underrepresented students is its alignment with sociocultural and culturally relevant pedagogy principles. Freed from strict curricular requirements, informal educators can incorporate students' cultural backgrounds, interests, and community issues into STEM activities. This culturally relevant approach can help students see STEM as connected to their own lives and values. When programs intentionally validate participants' cultural identities and provide content that resonates with their experiences, students are more likely to develop a sense of belonging in STEM [19]. Fostering this sense of belonging is crucial, as feeling included in STEM learning communities correlates with greater persistence [27, 28] Culturally relevant pedagogy offers a framework for designing such inclusive experiences: it calls for facilitating academic success while affirming students' cultural competence and cultivating their critical consciousness about societal issues [19] In practice, an informal STEM program might achieve these aims by, for example, involving students in solving problems relevant to their neighborhoods, highlighting diverse scientists and engineers as role models, or encouraging students to tackle STEM problems that address the needs of their communities [29]. These strategies enable minoritized youth to engage with STEM on their own terms, as active contributors rather than outsiders. In effect, informal programs can function as "situated" learning contexts where students participate in STEM practices in authentic ways, apprenticing alongside mentors and peers in a community of practice. Such experiences not only build STEM skills and interests but may also empower students with a sense of identity as STEM learners. By complementing formal instruction with culturally responsive, community-grounded STEM experiences, out-of-school programs can help bridge opportunity gaps and drive more equitable participation in STEM.

We draw upon Kolonich, Richmond and Krajcik's [30] framework to create an inclusive, integrated STEM learning space, especially for students from underrepresented backgrounds, by: (a) positioning students as knowledge generators, (b) leveraging students' funds of knowledge, (c) encouraging the use and sharing of student language, and (d) valuing students' lived experiences as evidence. In addition, the CCW incorporates features identified by the National Academies [31] as being effective for encouraging underrepresented students to aspire to STEM majors: (a) providing an introduction to scientific research, (b) exposing them to STEM role models, and (c) providing information about paths to college and STEM careers.

3 The workshop

3.1 Integrated STEM curriculum

The workshop focuses on the interdisciplinary domain of Cellular Engineering, a discipline that leverages a growing understanding of how to control cellular structure and function to solve environmental, medical, and industrial problems. Cellular engineers "reprogram" cells to alter single-cell or multicellular structures, thereby allowing the cells, or cellular assemblies, to take on new functions. This work takes place at the interface of biology, physics, chemistry, engineering, and computer science, providing a robust example of "New Biology," an interdisciplinary, convergent research approach that can improve human lives [32].

The workshop centers on an analogy of "cells-as-robots," and this concept is interwoven throughout all lessons. Participants' time is roughly equally divided between biological investigations and modeling in robots, with the former framing and inspiring the latter. This progression, from wet lab to programming and robotics, framed through the cells-as-robots analogy, adds dimension to the workshop's biology content in unique ways. First, the analogy of a cell as a robot offers insight into unseen cellular processes. Participants use computational thinking to "unpack" the steps involved in transmitting an environmental input (stimulus) to an output (e.g., behavior) and connect the role that code (either genetic or computer) plays in directing the response. Second, modeling cellular behavior with a LEGO EV3 robot extends wet lab investigations into interactive engineering activities that teach the design-build-test cycle. These added dimensions enable the comparison of how cells and robots sense and respond to their environments, helping participants understand that cells are dynamic and readily adapt to alter their function and behavior.

For example, the workshop reframes a typical high school genetic transformation lab experiment with the cell-to-robot analogy to demonstrate how cellular engineers can reprogram a cell's sense-and-response programming. By introducing a plasmid (a small circle of DNA), participants alter the behavior of the bacteria, thereby creating simple biosensors that can "sense" a chemical in the environment and "respond" by changing color. Participants then discuss what the cellular "program" might look like if it were written in computer code, thus deepening their understanding of the role of DNA and the mechanisms of genetic transformation and cellular reprogramming. Participants also explore chemotaxis using the slime mold *Physarum* (an inexpensive, classroom-friendly, single-celled organism). Chemotaxis is a cellular behavior in which cells sense a chemical gradient in their environment and respond by moving toward food or away from a toxin. Participants set up an experiment that reduces chemotaxis to a binary choice (i.e., food vs. toxin). Codifying chemotaxis in this way is the first step toward their next activity, modeling chemotaxis in a robot by programming it to move up a color gradient. In combination, these experiences elucidate the simple solutions nature devises for seemingly complex behavioral outputs. As cellular engineers have found, the act of creation through modeling leads to the rapid identification of simpler solutions than those surmised through observation alone [33].

In addition to deepening participants' biological knowledge, collaboratively developing robot models allows them to build their understanding of the design-build-test engineering design cycle, and develop computational thinking skills, as outlined by Wing [34] and the National Research Council [35] This process requires participants to: decompose and reformulate the problem; identify approximate solutions; engage in algorithmic thinking; test, debug, and refine their model; and identify assumptions and compromises made in developing their model. As teams work on design challenges, there are periodic "Lab Meetings," where all workshop participants come together as a whole group. Designed to emphasize the collaborative nature of science, this time provides a scaffolded opportunity for teams to identify and reflect on successes and challenges, get feedback from other teams about their approach, troubleshoot collectively, and share knowledge about programming strategies. This structure also helps participants realize that, in engineering, there are multiple possible solutions to a problem and the best solution often comes from incorporating many people's ideas (NGSS ETS-1.C [29, 36]). Lab meetings also allow teachers to see how students can benefit from this type of reflection period with others, an activity often overlooked in classrooms.

The workshop culminates in teacher-student teams tackling a complex, biologically relevant challenge, which serves as a performance assessment. These projects require teams to investigate the biology underlying the challenge and explain its biological significance to other participants. In addition, participants discuss the strengths and limitations of their model, as well as the design decisions and iterations that occurred during development. Challenges are designed to reflect current medical and environmental problems, connecting the science content to students' lives and highlighting the breadth of applications for cellular engineering techniques. The process also serves as an authentic assessment of the programming skills the participants have learned. Examples of challenges include developing robot models of: (a) a biosensor that signals when levels of an environmental contaminant reach dangerous levels; (b) an immune cell that targets and removes cancerous cells without interfering with healthy cells; and (c) bioremediation, where a bacterium is engineered to break down toxic chemicals like petroleum.

3.1.1 Connection to NGSS

The workshop provides teachers with a road map to integrate Science & Engineering Practices from the NGSS into their teaching. Figure 1 presents a detailed map of the alignment of workshop activities to the NGSS DCIs. Many of the lessons focus on life science specific DCIs (e.g., HS LS1 A & C in the *Physarum* example), but because the biology is presented through the cell-as-robot analogy, computational thinking and programming are interwoven throughout. When students model these phenomena with a robot and optimize their model via the design-build-test cycle, these lessons build natural bridges from life science to engineering DCIs (e.g., HS ETS-1.A-C). By combining observations of phenomena with robot modeling, participants also deeply engage with several Crosscutting Concepts (e.g., "Patterns," "Systems and Systems Models," "Structure and Function," "Stability and Change," and "Cause and Effect") and all of the Science & Engineering Practices at some point in the workshop.

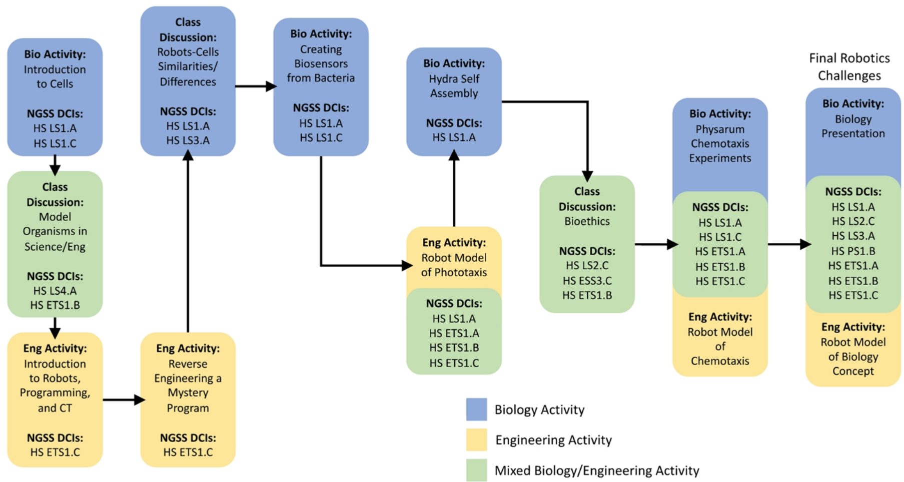

Fig. 1 Workshop activities aligned to the NGSS DCIs. Arrows indicate curriculum progression

3.1.2 Programming support and tools

The workshop programming lessons are paced with the novice programmer in mind, with lessons and activities ordered to ease new learners into programming habits of mind. Differentiation is built into the workshop programming activities, with each having multiple possible solutions and extensions, making them adaptable in terms of difficulty. For example, if a team or participant completes a project early, they can be challenged to find another solution under stricter constraints (improved accuracy, increased speed, fewer sensors, etc.). Additionally, regularly built-in class polls and individual written check-ins help identify points of clarification.

The workshop uses the open-source platform Open Roberta Lab [37]. Open Roberta: (1) is cloud-based, and therefore accessible on any internet-connected device; (2) is free to use, thus reducing cost for teachers to implement in their classroom; (3) offers an in-platform simulation environment, further reducing cost as robot modeling can be done without purchase of Lego Mindstorms; (4) is multilingual, a feature that allows English-learner students to program in their native language and share their programs with their English-speaking peers through a simple language toggle; and (5) uses a visual programming language, making it easy to learn and accessible to novice programmers.

3.2 Key features of the CCW

3.2.1 Co-learning model

A distinctly unique feature of the CCW is that it relies on a co-learning model, wherein high school science teachers and high school students collaborate and learn together. In a co-learning model, both teachers and students are engaged as active learners, blurring the traditional lines in their relationships. This co-learning model draws upon work done by Kermish-Allen and colleagues [38–40] in which they describe a concept termed non-hierarchical learning, wherein teachers and students are engaged in "…collaborative learning experiences in which adults are no longer perceived as the sole owners of knowledge. Instead, youth and adults are both generators of knowledge as well as active learners." [38]. In line with Kermish-Allen and Kastelein [40], in the CCW, we view the relationship between the teachers and students in the workshop as non-hierarchical. That is, students and teachers are co-learners, actively participating in creating meaning together during the iSTEM activities throughout the workshop. The co-learning model supports the notion that both teacher and student participants bring different expertise to the table, and each has something to learn from and teach the other [39, 40].

Co-learning creates opportunities for several potential benefits for both teachers and students. In the CCW, participating teachers bring high levels of content expertise; however, few have had recent laboratory experiences connected to cutting-edge research. They are often novices when it comes to programming, and the majority have limited engineering experience. In the CCW, teachers experience research-based pedagogy in biology, programming, and engineering as learners while also observing students' thinking, their struggles, and how students learn in real-time. From this experience, teachers may gain deeper insights into the challenges students face while learning, which may positively impact their teaching practices back in their own classrooms.

In addition, co-learning can provide teachers with the opportunity to observe new pedagogies in action, thereby helping them gain the confidence to implement these new approaches in their own classrooms. While the NGSS articulates a vision of science teaching that includes the Engineering DCIs and Practices, little guidance is given to teachers on how to integrate these into their science courses [41, 42]. For many teachers, this would require a re-conceptualization of their role in the classroom, and such a co-learning experience can help teachers feel comfortable and confident in integrating new pedagogies and curricula into their practice.

Co-learning offers several potential benefits for participating students as well. Students in the CCW have the opportunity to work closely with teachers (in a non-hierarchical relationship), both generating knowledge alongside the teachers and sometimes providing knowledge to the teachers. This may help students build confidence in their abilities to participate in STEM activities competently and as knowledge generators, not just consumers. Being recognized by other participants (both teachers and students) as being competent and knowledgeable in STEM can help strengthen students' STEM identities and interests. Co-learning also allows students to interact with teachers in a new way, which may alter or shift their perceptions of teachers, fostering stronger bonds and connections with teachers and other adults in the future.

3.2.2 Teacher breakout sessions

During the workshop, in addition to experiencing the cellular engineering content as learners, participating teachers have dedicated time to focus on translating the workshop lessons to their classrooms. When teachers are given an opportunity to learn with and from one another, teacher learning is enhanced [43–45]. During the teacher breakout sessions, teachers are given the opportunity to discuss ideas, ask questions of one another and the workshop facilitators, and discuss the types of support they need to implement the curriculum in their schools.

3.2.3 Scientist guest speakers and science lab tours

Throughout the workshop, scientists, ranging from Master's level students to full-time faculty, participate as guest speakers, instructors, and teaching assistants. The scientists who are invited as guest speakers are from backgrounds similar to those of our student participants. Additionally, our teacher and student participants are given the opportunity to tour several science labs and learn about the research being conducted by the scientists. The scientists share their path to science, how they collaborate with other scientists and engineers, and how their work addresses solutions to benefit the world. Addressing these topics is important for helping female, first-generation, and students from backgrounds underrepresented in the sciences understand how a career in STEM can be compatible with their goals to work in collaborative environments on projects that benefit others [46, 47]. Additionally, exposing students to STEM role models and providing information about pathways to college and STEM careers can encourage underrepresented students to aspire to STEM majors [31].

4 Implementation

The CCW is a 10-day (60-hour) summer workshop held on the campus of a local university, typically in mid-to-late June over two weeks. As noted previously, teacher and student participants work in collaborative teams throughout the workshop. Facilitators assign teams, consisting of one teacher and three students per group, and seat them at designated team tables (Tables 1 through 5).

Team membership is intentionally varied across activities to ensure that teachers and students have opportunities to collaborate with different individuals. For the robot programming activities, teams remain stable during the first week to support continuity and team building. In the second week, for the final robot programming challenge, facilitators reorganize the groups based on observations of participants' strengths, after which the new teacher–student teams are named and remain fixed. For the biology-related activities, however, teams are reshuffled throughout the workshop to encourage broader interaction among participants.

To illustrate the program's structure, Table 1 presents a sample daily schedule, providing readers with a sense of the workshop experience.

Iterations of this workshop have been implemented for several years, supporting 36 teachers and 110 students. These successful field trials with teachers and students demonstrate the effectiveness of this workshop in supporting teachers in implementing iSTEM instruction and fostering the interest of minoritized students in STEM by providing inclusive out-of-school STEM learning opportunities. We now turn to data collected from the two most recent implementations of the workshop (2023 & 2024) to highlight the impact the workshop had on both student and teacher participants.

4.1 Methods

This qualitative case study draws on semi-structured interviews conducted with both teacher and student participants at the end of the workshop. The data that we share are drawn from a larger study that documents and explores the influence of the CCW experience on teachers' and students' co-learning experience [48]. The data for this paper include findings that focus specifically on (1) teachers' reflections and insights about iSTEM and the influence of the CCW on their future teaching practice, and (2) students' reflections about the influence of their experience in the CCW on their interest in STEM and future career aspirations.

4.1.1 Teacher participants

Teacher participants were recruited from local public schools and needed to be currently teaching a STEM subject. Teachers received a small stipend (USD 1350/teacher)

Table 1 Sample schedule (Day 4) in the CCW

Time	Focus: biology or robot modeling	Activity	Activity description
9:00 am–9:15 am	N/A	Icebreaker/ Warm Up Activity	Community-building activity to get participants engaged and ready to participate
9:15 am–10:15 am	Robot Modeling	Chemotaxis Programming *(continued from Day 2)*	This is a programming lesson that models cell movement up a chemical gradient. Groups are given a program called Chemosense that helps them calibrate the color sensor to the chemotaxis mat. At the end of this activity, groups are asked to present their completed chemotaxis program.
10:15 am–10:30 am	Break		
10:30 am–2:00 pm	Biology	Bacterial Transformation (with pGLO)	This activity explores genetic engineering as a tool for constructing new cellular organisms while framing it as a biosensor activity. The students first observe biosensor reporting using a premade biosensor, then perform a transformation to create their own biosensor.
12:00 pm–2:45 pm	Lunch		
12:45 pm–1:00 pm	N/A	Icebreaker/ Warm Up Activity	Community-building activity to get participants engaged and ready to participate
1:00 pm–1:30 pm	Bioethics	Ethics Discussion	This activity introduces students to the concepts of ethics and bioethics. Bioethics concerns some of the more difficult dilemmas and decisions facing scientists as science advances, particularly in the field of Cellular Engineering, which strives, in part, to make new forms of life capable of solving problems for humankind. Students are given a framework to analyze and discuss bioethical questions that may arise from Cellular Engineering research.
1:30 pm–2:00 pm	Biology	Observe Physarum (Final Conclusions)	Check Physarum growth from experiments started on Day 3. Groups note the Physarum growth path in their science notebooks or on the Physarum worksheet. Participants are encouraged to explore the Physarum growth under the dissecting scopes.
2:15 pm–3:00 pm	Biology	Lab Tour	Throughout the workshop, participants are given the opportunity to tour several science labs and learn about the research that the scientists are doing. The scientists share their path to science, how they collaborate with other scientists and engineers, and how their work addresses solutions to benefit the world.

for completing the workshop; however, there was no additional compensation for agreeing to participate in the research study. There were eight teachers (five from 2023 and three from 2024) who participated in the workshop, and all agreed to participate in the larger study. Seven of the eight teachers self-identified as being part of an underrepresented ethnic, racial, and/or gender minority group in STEM (Gender: 63% women, 37% men; Race/Ethnicity: 50% Asian, 13% Hispanic or Latine, 13% Black or African American, 13% South Asian, 13% White). Teachers came with a range of teaching experience, having taught anywhere from 1 year to 10.5 years ($M = 6.4$ years, $SD = 3.9$). Most teachers taught at least one type of biology class per year (Biology or AP Biology), except for two teachers who primarily taught chemistry or physics. See Table 2 for their demographic profiles.

Table 2 Participating teacher demographics

Name (Pseudonym)	Gender	Age range	Race/ ethnicity	Years teaching	School type	Subject(s) taught
Alex	Man	31–35	Asian	4	Public	Chemistry
Christine	Woman	30 or under	White/ Caucasian	2	Public	Biology/ AP Biology
Francine	Woman	31–35	Asian	5	Public	Biology and Chemistry
Janet	Woman	36–45	Black or African American	10	Public – Title 1	AP Biology, Biotechnology, and Health
Kevin	Man	36–45	Asian	10	Public	Biology, Chemistry, AP Biology, Physiology
Michael	Man	31–35	Asian	2	Public	Physics
Shannon	Woman	36–45	Hispanic or Latine	10.5	Public – Title 1	Biology
Uma	Woman	46–55	South Asian	9	Public - Title 1	Biology

4.1.2 Student participants

Student participants were recruited from local public schools, needed to be 10th or 11th graders, identify as individuals from backgrounds historically marginalized in the sciences, and ideally had taken at least one biology course. Student participants received a small stipend for completing the workshop (USD 1000/student); however, there was no additional compensation for agreeing to participate in the research study. In total, there were 28 student participants (15 in 2023, and 13 in 2024), of which 72% were 10th graders and 28% were 11th graders. This paper focuses on data from the 18 (eight in 2023; 10 in 2024) student participants who completed the post-workshop interviews. All 18 students self-identified as being part of an underrepresented ethnic, racial, sexual, and/or gender minority group in STEM (Gender: 50% woman, 44% man, 6% non-binary; Race/Ethnicity: 44% Asian, 33% Hispanic or Latine, 11% Black or African American, 6% Nepali, 6% Asian & Native Hawaiian/Pacific Islander). Languages spoken at home include Spanish, English, Cantonese, Mandarin, Vietnamese, Tagalog, Amharic, and Nepali. To gauge students' interest in STEM, a pre-workshop survey included two items rated on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree): *Topics in STEM excite my curiosity*, and *I am interested in learning more about STEM*. Responses indicated that students entered the workshop with high levels of interest in STEM, with mean ratings of 4.4 ($SD = 0.6$) for curiosity and 4.4 ($SD = 0.6$) for interest. See Table 3 for their demographic profiles.

4.1.3 Data collection and analysis

Teacher and student participants were emailed following the workshop to request their participation in a 30–45-minute interview via Zoom. Teacher interviews covered a range of topics, including: (a) their overall experience in the workshop, (b) their experiences working with the students and other teachers; (c) the cohesion and dynamics within their small groups; and (d) themselves, their school, and their approach to teaching. Student interviews were designed to probe about the following topics: (a) their overall experience in the workshop, (b) their experiences working with the teachers and other students; (c) the cohesion and dynamics within their small groups; and (d) their interest in STEM and their future career aspirations.

Interviews were transcribed and then imported into *ATLAS.ti* for analysis. For this paper, we focused our data analysis on four questions from the teacher interviews (*"How,*

Table 3 Participating student demographics

Name (pseudonym)	Gender	Race/ethnicity	Grade	Languages spoken	Curiosity (C) and Interest (I) in STEM *(Ratings on Likert scale)
Anna	Woman	Asian	10	Cantonese; English; Mandarin	C = 4 I = 4
Andy	Man	Hispanic or Latine	11	English; Spanish	C = 5 I = 5
Anthony	Man	Asian	10	Cantonese and English	C = 4 I = 4
Charlotte	Woman	Asian	10	Cantonese	C = 4 I = 4
Ella	Woman	Hispanic or Latine	10	English; Spanish	C = 4 I = 4
Emilia	Woman	Hispanic or Latine	10	Spanish and some English	C = 5 I = 5
Emma	Woman	Asian	10	English; Vietnamese	C = 5 I = 5
Henry	Man	Asian	11	Cantonese and English	C = 4 I = 5
Ian	Man	Asian	10	Cantonese	C = 4 I = 4
Isaiah	Man	Hispanic or Latine	10	English; Spanish	C = 3 I = 3
Jake	Man	Asian, Native Hawaiian/Pacific Islander	11	Tagalog and English	C = 4 I = 4
Lily	Woman	Asian	10	Cantonese; English; Farsi; German; Italian; Mandarin	C = 5 I = 5
Maria	Woman	Hispanic or Latine	10	Spanish	C = 5 I = 5
Nafisa	Non-Binary	Black or African American	10	English and Amharic	C = 5 I = 5
Nora	Woman	Hispanic or Latine	11	English; Italian; Spanish	C = 4 I = 4
Raj	Man	Nepali	10	Nepali and English	C = 5 I = 5
Savannah	Woman	Black or African American	11	English	C = 5 I = 5
Vinh	Man	Asian	10	Vietnamese	C = 4 I = 5

*Likert scale: 1 = strongly disagree and 5 = strongly agree

if at all, has this workshop influenced how you think about teaching the NGSS Science and Engineering Practices?"; "How do you envision taking what you have learned during the CCW, back into your classroom?"; "What insights, if any, did you gain about teaching and learning through working on teams with students?"; and "In what ways do you think this experience learning with students, will influence how you approach teaching in your own classroom?"). For the student interviews, we focused our data analysis on two questions (*"Now that you've completed the workshop, in what ways has your level of interest or excitement for science, engineering, or computer science changed?"*; and *"When you think about your future, do you want to pursue a career in science, engineering, or computer science? Did your participation in the workshop influence your thinking about this at all?").*

We used an inductive thematic analysis approach to code the interview transcripts. Inductive analysis allowed us to derive our themes from the data rather than using a priori codes based on theoretical ideas [49]. We relied on Braun and Clarke's [49] six-step approach to thematic analysis to guide our process. We began by familiarizing ourselves with the data, doing multiple readings of the interview transcripts, and developing an initial set of codes, focusing specifically on (1) teachers' perspectives of iSTEM and their future teaching practices, (2) students' interest in STEM. Codes were then collated into potential themes (categories) and reviewed against the coded extracts to determine if they fit. Through this iterative process, themes were refined, defined, and named, and illustrative excerpts were selected.

To ensure the trustworthiness of the analysis, the first author conducted all coding and theme development, maintaining analytic memos to document decisions and reflect on potential biases. Codes were generated inductively and refined through multiple rounds of review to ensure they reflected the breadth of participant perspectives rather than preconceived expectations. To guard against selective interpretation, the first author engaged in constant comparison across transcripts and examined disconfirming evidence. Categories and themes were developed by grouping related codes and testing them against the complete data set for coherence and distinctiveness. For transparency, Table 4 provides a sample coding chart that traces how interview excerpts were linked to codes, categories (sub-themes), and a final theme.

4.2 Results

4.2.1 Impact on teachers

While teachers expressed a wide range of insights during their post-workshop interviews, we focus here on two of the most prominent themes that highlight how the workshop shaped teachers' thinking about iSTEM and their future teaching practices. These themes center on (1) the value teachers found in gaining new perspectives on iSTEM and the NGSS science and engineering practices, and (2) the insights they developed by experiencing the curriculum as learners and as co-learners alongside students.

Theme 1: The workshop provided teachers with new insights on the value of iSTEM and ways to address the NGSS science and engineering practices

Across subject areas and years of experience, teachers described the workshop as providing practical ways to connect disciplinary content with NGSS science and engineering practices. Several noted that this gave them concrete strategies for thinking about their own instruction in more integrated ways.

Michael, an early-career physics teacher, emphasized how the workshop helped him see new opportunities for bridging disciplinary boundaries. He felt that the activities illuminated concrete ways in which physics concepts could connect to biology, and he left the workshop eager to consider how such integrated lessons might be incorporated into his own curriculum.

> *I guess it's just, there's different ways that you can teach these standards, and how you can definitely cross the different subjects. I'm a physics teacher, but I feel like all this biology that I've been learning has a lot of cool applications and cool lessons in them that can really bridge the gap between biology and physics. Yes, that's just like, I can combine more of the standards together. - Michael.*

Table 4 Sample coding chart illustrating development of themes

Interview excerpt	Initial code	Refined code	Sub-theme(s)	Final theme
And I think one of the best things is being able to work with students in a workshop like this…you actually get to see what this looks like in practice…The model…having the school teachers and the students put together, it has a ton of upside. – Kevin	Insights about students	Seeing curriculum tested with real learners	Seeing curriculum work in practice with learners	Experiencing the curriculum as a learner and working with the students as co-learners provided valuable insights
I think I gained a lot of like, personal like, oh, my gosh, what it's like to be in the students' positions again! I think that was the biggest takeaway for me… - Alex	Insights about students	Remembering what it feels like to be a learner	Experiencing the learner perspective	
…It reminded me a lot of group work that when I was a student and I actually don't like group work. I prefer independent work. A lot of my students that I teach now really prefer to work independently…but some students really thrive on it and need it. So just reminding myself…to make sure I include both options for students. – Shannon	Insights about students	Not all students thrive in group work	Experiencing the learner perspective	
I think it's made me reflect a lot more about the digesting time, and just the time as a student was really shown to me in the program because I was a student…it's just…a very good reminder…about how I need to take things slow and also be patient. – Alex	Insights about students	Reminder to adjust pacing for learners	Experiencing the learner perspective	
…Students might have different perspectives of the same… problem…I was quite surprised several times at their knowledge, at their logical thinking, at the way how they think differently. So…I had to tone down myself…just to see and just to be awestruck at how they can solve the problems differently. – Uma	Insights about students	Students bring novel problem-solving approaches	See learners' thinking up close	
…Be learning in groups with high school students to kind of get a sense of their thinking at a much more in-depth level than I get when I visit groups, walking around my classroom. – Shannon	Insights about students	Closer view of student thinking	See learners' thinking up close	
Yeah, I learned- I learned a lot about their skillsets and, like, how they communicate, what works well for them. Are they more of a visual learner? Do they need to, like, see it or hear it or, like-like, actually do the code and, like, visualize it on their own screen…- Christine	Insights about students	Awareness of diverse learning preferences	See learners' thinking up close	

While Michael's takeaway focused on making cross-disciplinary links more explicit, Janet, a mid-career biology teacher, described a related but distinct benefit: the potential to diversify her curriculum by blending different kinds of activities, such as robotics and cellular engineering, rather than focusing narrowly on a single topic.

> *...Seeing how you can relate different topics in science to each other, or not just focusing on one little thing, basically adding more diversity to the planning. Being able to do a little bit of robotics and a little bit of cellular engineering. It's nice blending the two. - Janet.*

For other teachers, the value lay less in conceptual integration and more in gaining concrete instructional resources. Shannon, also a mid-career biology teacher, noted that the workshop provided her with a ready-made activity she could bring directly into her classroom—something she found particularly helpful given her limited engineering background and the challenges she faced in creating such materials on her own.

> *For me, as a biology teacher, trying to implement the new NGSS science and engineering practices. I struggle with that one. I'm like, "Okay, I can try to create my own thing, but I don't really know." And I don't have much engineering background, so*

for me, that is a gift. I have a cool activity that kids will be into, totally opens their experience up to computer programming and engineering in terms of modifying the robots that I wouldn't have otherwise. So that was, for me, the biggest exciting take-away from [the] workshop. - Shannon.

Still others focused on the ways they might adapt workshop activities to fit within their existing curriculum. Christine, a first-year biology teacher, envisioned modifying the robotics activity so that it could serve as a metaphor for cellular communication in her AP Biology class, giving students a more interactive way to represent complex processes.

I definitely wanna use the robots for an AP Bio project. I have them talk about cellular communication, and they did a presentation last year with like a poster, and I'm like, "Okay, maybe if they did the robots as a metaphor of cellular communication." So they could do, one group can do direct signaling, one could do endocrine signaling, autocrine, one could do G couple signaling, like that sort of stuff. And I think that'd be, kind of, an interesting way. So I definitely wanna incorporate the robots into a lesson like that. - Christine.

Taken together, these reflections show how teachers connected the workshop to their own practice in different ways. For some, the value lay in seeing how STEM concepts could be integrated across disciplinary boundaries; for others, it was in gaining access to curriculum resources or thinking about concrete adaptations. Across these perspectives, the workshop provided a space for teachers to see how NGSS practices could be enacted through interdisciplinary, hands-on activities. These varied perspectives illustrate that teachers engaged with the workshop in different ways, but all found elements they could carry forward into their own classrooms. Building on these curriculum-focused insights, the second theme highlights what teachers learned by experiencing the workshop as learners themselves and by working alongside students as co-learners.

Theme 2: Experiencing the curriculum as a learner and working with the students as co-learners provided valuable insights

Teachers also described how participating in the workshop as learners provided them with perspectives they might not have otherwise gained. Experiencing the curriculum firsthand helped them see what implementation might look like in practice and gave them greater confidence in bringing similar activities to their own students.

Kevin, a mid-career teacher, emphasized the value of observing the curriculum in action with students. He explained that seeing students work through the activities alongside teachers reassured him that the approach could be successful in a high school setting.

And I think one of the best things is being able to work with students in a workshop like this. Uh, and I put that on my feedback on the forms, is just that you actually get to see what this looks like in practice. More in situ than trying to visualize it in the company of like a handful of teachers…We know it can work this way because we've seen it work. And I think that's I think something that a lot of these programs, uh, I think could benefit from. So I think the model that they've adapted, having the school teachers and the students put together, it has a ton of upside. – Kevin.

His response illustrates how participating as a learner with students helped reinforce the feasibility of bringing similar activities into the classroom. Teachers also noted how being placed in the position of learners reminded them of the challenges their students face. For Kevin, this included recognizing the importance of giving “students an opportunity and time” for learning.

> *Um, so I think just understanding, um, just to give time and just allow people to work at kind of different paces and to know that a lot of the practices that are being adopted are-are leading more in that direction of like, “Really, let’s just get a-a few fewer things but have a higher degree of mastery and retention, um, rather than just like racing through stuff.”*

Similarly, Alex, an early-career chemistry teacher, described how the experience prompted him to reflect on pacing and patience:

> *I think I gained a lot of like, personal like, oh, my gosh, what it’s like to be in the students’ positions again! I think that was the biggest takeaway for me….I think it’s made me reflect a lot more about the digesting time, and just the time as a student was really shown to me in the program because I was a student. And so it’s just kind of like a very good reminder to me about how I need to take things slow and also be patient. (laughs) – Alex.*

Alex’s reflection highlights how the workshop reminded teachers of the importance of building in time for students to process new material. Both Kevin and Alex’s comments reinforce that teachers left the workshop not only with curriculum ideas but also with a deeper appreciation for the central role of time and pacing in the learning process.

For other teachers, participating as a learner reinforced the need to account for differences in how students prefer to learn. Shannon, for example, reflected on her own experiences with group work and how they shaped her awareness of student preferences:

> *It’s really interesting because it reminded me a lot of group work that when I was a student and I actually don’t like group work. I prefer independent work. A lot of my students that I teach now really prefer to work independently. It’s rare when they want to work as a group. So yeah, just kind of reminded me like, okay, this isn’t for everybody, but some students really thrive on it and need it. So just reminding myself as I set up my lessons to make sure I include both options for students. – Shannon.*

Her reflection emphasizes the importance of designing classroom activities that cater to both independent and collaborative learners.

Finally, several teachers emphasized the value of working as co-learners alongside students. Uma, a mid-career biology teacher, described being struck by the originality and logic of students’ approaches to problem-solving, which prompted her to step back and reconsider her own assumptions.

> *Sometimes students might have different perspectives of the same– of the problem that they’re solving, other than what you know, not just what you have, but other than what you know. And I was quite surprised several times at their knowledge, at their logical thinking, at the way how they think differently. So, I just– That’s why I said I had to tone down myself a little bit, tone down my voice or my approach just*

to see and just to be awestruck at how they can solve the problems differently. So, that's something very important I'm– I took from the program. – Uma.

Her reflection highlights how the co-learning format provided teachers with a new vantage point for observing students' reasoning and problem-solving.

These reflections suggest that teachers found value not only in experiencing the iSTEM curriculum as learners but also in sharing the learning space with the students. For some, this reinforced the feasibility of implementation; for others, it prompted renewed empathy for the learning process, a recognition of the importance of pacing and time, or a reminder of the need to account for diverse student learning preferences. Experiencing the workshop in this way provided teachers with insights that extended beyond curriculum content, shaping their perspective on student engagement and their own instructional approaches.

Participating in the CCW offered teachers both practical strategies for integrating iSTEM into their teaching and experiential insights gained from engaging as learners and co-learners. While teachers' experiences varied depending on their background and context, their reflections highlight ways in which professional learning opportunities that blend authentic curriculum engagement with collaboration alongside students can provide multiple entry points for teacher growth. Together, these experiences gave teachers practical and reflective insights into both the curriculum and the learning process. In the next section, we turn to the student participants' perspectives to consider how the workshop influenced their interest in STEM and their thinking about future career pathways.

4.2.2 Impact on students

In addition to supporting teachers, a central goal of the workshop was to foster students' interest in STEM. While the majority of students in the workshop already had some level of interest in STEM, we wanted to know if their experience would foster and sustain their interest in STEM. Drawing from students' post-workshop interviews, 16 of the 18 students (89%) reported that they were *more* interested in STEM as a result of their experience in the workshop. In comparison, two students said their level of interest remained unchanged.

Students pointed to two key features of the workshop as contributing to their increased interest in STEM: (a) opportunities to connect directly with scientists, and (b) participation in authentic, hands-on STEM activities. These aspects were highlighted as influential in shaping their views on STEM as a field of study and a potential career path. Meeting practicing scientists gave students a rare chance to hear personal stories, ask candid questions, and see the day-to-day realities of scientific work, which made STEM feel more accessible and relatable. At the same time, the workshop activities, including lab tours, provided concrete experiences that helped students envision themselves participating in similar work. Together, these two features underscore the importance of relevance, connection, and authenticity in cultivating students' sustained interest in STEM.

Theme 1: Connecting with scientists provides students with an authentic look into the real work of science/STEM

Students particularly valued meeting and hearing from scientists about their research and their path to science. Meeting scientists allowed students not only to learn about research projects but also to hear about personal journeys, day-to-day work, and the human side of scientific careers.

For some students, the most valuable aspect of meeting scientists was the personal connection. Savannah explained that she had no prior ties to anyone in a STEM field, so being able to ask candid questions about scientists' daily lives and career paths gave her a perspective she would not otherwise have had.

> *I would say like it [interest in STEM] has risen a lot since I was able to meet with the scientists there at [university name] and ask them about, you know, their day-to-day, and you know, how much hours they're working, you know, about their social life, and all these other questions that I wouldn't be able to ask because I don't really have that, like, connection to anyone in the STEM field right off the bat like that. Um, so I think it's definitely increased [my interest in STEM]. - Savannah.*

While Savannah emphasized the personal and relational aspects of these conversations, Anthony was especially drawn to the research itself. He described finding the guest talks and lab tours "cool," particularly when he learned about projects like epilepsy research in frogs. For him, hearing about scientists' projects firsthand made the work of science feel exciting and increased his interest.

> *I think it's increased a lot. Like, I heard the-the-the talk- the people who came to talk, like, I-I found the- I just found the work kinda, like, cool. And like, uh, Ava [a facilitator] did a presentation about, like, frogs and how she's studying epilepsy. I thought that was kinda cool. And when I was walking around, like, the lab tours, I just thought like, like, it was really interesting to see, like, all the equipment being used. Like, my interest has definitely been, like, risen. - Anthony.*

For Anna, the lab tours broadened her sense of what STEM could encompass. She noted that walking through the labs exposed her to the range of scientific questions being investigated and the diversity of work that scientists engage in, giving her a more expansive view of the field. Anna states:

> *I think it showed me new perspectives, definitely. When we went to like to the labs to look around, that was really cool because I could see like all the different things that you could do within science. So, like the research you get to conduct. - Anna.*

Across these reflections, students emphasized that hearing scientists' personal stories and observing authentic research environments gave them new insights into STEM careers. For some, this made the work of scientists feel more concrete and relatable, while for others it revealed possibilities they had not previously considered. Collectively, these reflections highlight that students valued different dimensions of their interactions with scientists, including the opportunity to connect personally, hear about cutting-edge research, and experience the variety of work environments and opportunities within the STEM field. While their emphases varied, each described these encounters as expanding their understanding of what scientists do.

Theme 2: Authentic and engaging STEM activities can foster student interest in STEM

In addition to valuing their interactions with scientists, students also pointed to the workshop's design of hands-on, inquiry-driven activities as central to their interest in

STEM. Students contrasted these experiences with the more passive, lecture-based approaches they encountered in school, noting that the opportunity to actively engage, collaborate with peers, and apply STEM concepts to real-world contexts made the workshop both more enjoyable and more meaningful. Overall, students' reflections underscored how active learning and authentic practice can motivate interest in STEM, particularly among those from groups that have been historically underrepresented in these fields.

A few students noted that their interest in STEM grew because they were actively involved in the activities rather than passively listening. Emma explained that having the chance to do the work herself, rather than just hearing about it, made the experience much more engaging and increased her interest.

> *Um, it's definitely increased more now that I got like, actual experience with it, and like, no, like, I'm not just sitting there listening the entire time. So it's definitely-definitely the interest has risen a lot, and yeah. – Emma.*

Ella echoed the importance of active engagement but emphasized a different dimension: the balance between autonomy and collaboration. She explained that too much explanation left her disengaged, whereas the opportunity to work with peers to figure things out for themselves encouraged her to invest more deeply in the activities.

> *I feel like when things are over-explained to me, I become disinterested in it, but since it was like a good amount of you doing it yourself and trying to figure it out with your group, it encouraged me a lot more to really get into it.*

For Ian, the most significant factor was the real-world applicability of what he was learning. He contrasted the workshop with his school experiences, noting that the programming and biology activities in the workshop helped him see how STEM could be applied in tangible, meaningful ways. As he explained:

> *I think it would– it increased a bit because it showed me what you can actually do with, uh, real-life programming and, like, actual biology, since, like, in school, most of the time, I didn't really get to do that. – Ian.*

Together, these comments highlight different yet complementary aspects of why authentic, hands-on activities are important for sustaining student interest. For some, it was the opportunity to be actively engaged, for others, the balance of autonomy and collaboration, and for still others, the relevance of connecting STEM to real-world contexts.

Theme 3: Exposure to scientist role models and iSTEM activities can support STEM career aspirations

A majority of students also reported being interested in pursuing a career in STEM in the future. Ten of the 18 students (56%) reported that they were definitely interested in pursuing a career in STEM in the future, while five students (28%) said they were maybe interested in pursuing a career in STEM, and only three (17%) students said they were definitely not interested in pursuing a career in STEM. Of the three students not interested in STEM careers, two indicated that it was unlikely, but that, because of their experience in the workshop, they could see it as a possibility now, while the third student indicated that they already had a different career path in mind.

Of the 15 students who were *maybe* or *definitely* interested in pursuing a STEM career, 13 (87%) indicated that their experience in the workshop positively influenced their thinking about pursuing a STEM career. Similar to their expressed views on why the workshop increased their interest in STEM, students stated that key features of the workshop, such as the scientist guest speakers, lab tours, and the programming and biology activities, were instrumental in inspiring them to continue to pursue their STEM interests as a possible future career path.

For some students, hearing directly from scientists about their career journeys was especially influential. Anthony explained that listening to guest speakers who had followed varied and non-linear paths into science shifted his perspective and strengthened his interest in pursuing STEM.

> *I definitely want to pursue something in STEM, or if that doesn't work out, I'll prob- I really- I wanna probably like do something with English…I think it [the workshop] influenced– I think it, like, pushed me over, like, more to the side of STEM hearing all those speakers talk about their experiences and how they like- they-they, like, went from just like community college, they transfer out, and then they just found, like-like– It was like a lot of- like, a lot of roads, like, after, um, high school. I thought that was really interesting. - Anthony.*

His reflection illustrates how exposure to scientists' diverse pathways made a STEM career feel more attainable and relevant.

While Anthony emphasized career pathways, Maria highlighted the combination of inspiration from the speakers and skill-building through the activities. She explained that hearing scientists' stories gave her a sense of what a STEM career might involve, while the hands-on biology and programming activities provided her with concrete skills to support that vision.

> *I don't really know what to do for my future, although I have been l learning– I mean looking more into like the medical field, but I definitely really like some– To do something that's similar, or that involves science….Like the [workshop] activities definitely like helped me like do– Like learn more about how to do things, while the speakers like made me realize what goes on when you're in like a STEM type of career. – Maria.*

Her response highlights how the combination of inspiration and authentic practice influenced her thoughts about her potential future in science.

For Raj, an influential aspect of the workshop was seeing the lab environments firsthand. He explained that visiting labs and observing the equipment and atmosphere deepened his interest in biochemistry and helped him picture what working in such a space might be like.

> *I-I am thinking about, um, biochem. Working in labs seems really fun. We also went to labs, and it looked really fun in there. A lot of machines, and all that stuff…Um, I had something in mind in STEM, but this workshop also helped me. – Raj.*

Raj's experience illustrates how authentic exposure to professional settings gave him a clearer and more exciting sense of what a STEM career could look like.

Together, these reflections highlight the various ways in which exposure to role models and authentic practice shaped students' thinking about STEM careers. For some, hearing about diverse and non-linear career pathways broadened their sense of what was possible. For others, the combination of inspiration from scientists and the opportunity to build concrete skills reinforced their interest in pursuing science-related fields. Still others emphasized the value of seeing professional lab environments firsthand, which made the idea of working in STEM feel more vivid and tangible.

For students, the CCW experience provided new perspectives on both the realities and the possibilities of pursuing a STEM career. Students greatly valued hearing from scientists, from similar demographic backgrounds as their own, about their path to careers in science, their day-to-day work, and their research interests. Students also described how the authentic, hands-on iSTEM activities provided them with insight into the real-world applicability of the science and engineering skills they were learning, which, as one student noted, was in direct contrast to their experience of school science.

Across the three themes, students described how the workshop deepened their interest in STEM and influenced their perspective on future possibilities. Meeting scientists provided personal insights into career pathways, making STEM feel more approachable. Participating in authentic, hands-on activities sustained engagement by allowing students to be active learners, collaborate with peers, and connect STEM concepts to real-world contexts. Finally, the combination of role models and authentic practice influenced how many students envisioned STEM as part of their future careers. Together, these perspectives suggest that students experienced the workshop as both engaging in the moment and influential in shaping their longer-term relationship with STEM.

5 Conclusion

Building on these student and teacher perspectives, this paper describes the design and implementation of a hybrid workshop model that simultaneously serves as a professional learning experience for high school STEM teachers and an out-of-school learning opportunity for racially and ethnically diverse high school students. Anchored in the integration of situated learning theory, research-based principles of effective professional development, and culturally inclusive and responsive pedagogy, the workshop offers a unique and synergistic approach to addressing persistent challenges in STEM education. It prepares educators to teach integrated and inclusive STEM content and broadens participation among underrepresented student populations.

The findings indicate that teachers and students described meaningful benefits from their participation. Teachers highlighted new ways of connecting disciplinary content to NGSS science and engineering practices, valued curriculum resources they could adapt to their own classrooms, and reflected on the experience of being both learners and co-learners with students. Students reported increased interest in STEM, valued opportunities to connect with scientists, and emphasized the importance of authentic, hands-on activities that contrasted with more traditional school science experiences. Several participants also noted that the workshop influenced their thinking about future career possibilities in STEM.

While the findings highlight the promise of this approach, several limitations should be noted. The study drew on a small, self-selected sample of teachers and students from two workshop cohorts, which constrains the generalizability of the results. Because participants self-selected into the program, their experiences may not reflect the perspectives of broader teacher or student populations. In addition, the reliance on post-workshop interviews means that findings capture immediate reflections rather than longer-term impacts, and the absence of a control or comparison group limits the ability to attribute changes directly to the workshop design. These limitations suggest caution in interpreting the findings while pointing to important directions for future research that could incorporate larger and more diverse samples, multiple data sources, comparison groups, and longer-term follow-up.

Taken together, these findings suggest the potential of hybrid models that bring teachers and students together in shared STEM learning environments, providing valuable insights for both groups. By bridging professional learning and student enrichment in a shared, responsive space, this workshop model may contribute to efforts to make STEM education more inclusive and empowering. Further studies could explore the longer-term impacts of such co-learning experiences, examine the effects of such integrated models on both teacher practice and student interest and identity development in STEM, and consider how they might be scaled or adapted across different educational settings. Based on these reflections, the CCW workshop illustrates how creating spaces where teachers and students learn together can generate insights that inform both classroom practice and efforts to broaden participation in STEM.

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Author contributions
Study conception and design was performed by X.A. and K.N. Material preparation and data analysis was performed by X.A. The first draft of the manuscript was written by X.A., K.N., R.S., and J.A. All authors (X.A., K.N., R.S., J.A., S.A. & J.K.) reviewed and edited previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability
The datasets generated during and/or analyzed during the current study are not publicly available in order to protect participants' privacy, but anonymized data are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This research received ethical approval from the Institutional Review Board for the Protection of Human Subjects (IRBPHS) at the University of San Francisco (IRB Protocol #1945) and the Institutional Review Board (IRB) at the University of California San Francisco (19-28078). All participants provided written informed consent prior to participating in the study, and all identifiable details have been anonymized to protect their privacy.

Consent for publication
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