

Article

Co-Learning: A Hybrid Model for Integrated STEM Teacher Professional Learning and Student Out-of-School Learning

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Abstract: Our paper presents a case for co-learning, a novel hybridization of teacher professional learning and student out-of-school learning wherein students and teachers collaborate and learn together. The benefits of collaborative learning are well documented in the literature; however, a co-learning approach to engaging teachers and students in integrated STEM activities is unexplored. This qualitative study was designed to unpack the co-learning experience from the perspectives of teachers and students to understand the opportunities and challenges of a co-learning model. We drew upon end-of-workshop semi-structured interviews with teacher and student participants, focusing specifically on participants' reflections and insights about their experience with co-learning. The findings of our study highlight that (1) co-learning can be a powerful model for learning STEM content for both teachers and students, (2) co-learning leads both teachers and students to develop new insights and perspectives about each other, (3) co-learning requires teachers to navigate multiple roles, and (4) challenging group dynamics can impact co-learning. This research provides a proof of concept that co-learning is a model with much potential and may serve as a valuable model for creating integrated STEM learning experiences that serve both teachers and underrepresented racially minoritized (URM) students.

Keywords: professional development; informal science learning; STEM learning; minoritized students



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1. Introduction

The Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) articulate a new vision of teaching, stressing the increasingly interdisciplinary nature of science and engineering. While the NGSS advocate for integrating engineering across all disciplines and levels of K-12, the majority of high school courses remain discipline-based (i.e., discrete courses in biology, physics, and chemistry), which encourages teachers to stay within their disciplinary silos (Boyd, 2017). Applying new pedagogical approaches and integrating multiple subject areas within this existing structure is challenging but important, and there is growing concern that teachers are not equipped to incorporate these less familiar practices into their teaching (Brown & Bogiages, 2019; Wang et al., 2020). In addition, most high school STEM teachers are trained within their discipline and thus may find it challenging to implement an integrated STEM teaching approach (Lo, 2021; Wang et al., 2020). Therefore, professional learning opportunities to help in-service teachers learn to teach STEM subjects using an integrated approach are critically needed (Brand, 2020; Lo, 2021).

Parallel to the need for teacher professional learning, there is a need to engage ethnically diverse and racially minoritized students in STEM learning and address long-standing disparities in participation. For example, within advanced STEM courses in high school,

Black, Latinx, Indigenous, and other minoritized youth remain significantly underrepresented (Neally, 2022). One strategy to address these disparities is to provide enriching STEM learning experiences outside of the formal school setting. Out-of-school STEM learning experiences can be an important site for youth to explore and nurture their interests and motivations in STEM. These informal learning environments can be especially beneficial for underrepresented racially minoritized (URM) students, as they can serve as a space to address educational inequities and increase STEM learning opportunities (King & Pringle, 2019). URM students may experience cultural barriers leading to a decreased motivation to persist in science (Jackson et al., 2016). However, out-of-school STEM spaces can provide opportunities for URM students to engage in authentic activities and connect with peers and role models from minoritized backgrounds, providing support and inspiration to persist in STEM (Koch et al., 2019; Milton et al., 2023). Out-of-school settings can also be ideal places to experience integrated STEM activities. Integrated approaches to STEM teaching and learning can promote interest and motivation in STEM (Thibaut et al., 2018) and persistence to science degrees among URM students (Jackson et al., 2016).

We have developed a hybrid teacher professional learning and student out-of-school STEM learning experience, the Cellular Construction Workshop (CCW), that models an integrated STEM learning environment. In the CCW, teachers and students experience biology as a problem-based discipline reframed through the lens of computational thinking and engineering. This combination underscores, for students and teachers, the convergent nature of science and the common toolkit engineers and scientists employ to solve real-world problems. Beyond CCW's integrated STEM learning experience, it is unique in that it brings high school science teachers and students together as co-learners. In this co-learning model, the roles of teacher and student are blurred, and all are engaged as active learners. This paper aims to (1) describe the teacher–student co-learning model and (2) provide evidence of the value of co-learning for both teachers and students. The following sections describe our conceptual framework, the teacher–student co-learning model, and the data collection and analysis methods. We then present key themes and findings and discuss their significance and implications.

2. Conceptual Framework

We draw from two distinct but complementary research literatures for our conceptual framework: (1) non-hierarchical learning and (2) collaborative learning.

2.1. Non-Hierarchical Learning

We draw upon prior work conducted by Kermish-Allen et al. (2015) and Kermish-Allen and Kastelein (2017, 2018), wherein they describe and develop a concept termed *non-hierarchical learning*. Kermish-Allen et al. (2015) defined non-hierarchical learning as

“...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; the boundaries between teacher and student, young and old are blurred into one cohesive community of actively-engaged learners.” (p. 3).

Kermish-Allen et al. (2015) investigated a non-hierarchical learning environment and found significant learning gains for both participating teachers and students in a summer workshop as well as for students in participating teachers' classrooms. However, Kermish-Allen et al. did not investigate how and why the non-hierarchical model worked.

Kermish-Allen and Kastelein (2017) expanded upon this concept of non-hierarchical learning and developed a framework for use in online learning environments: the Non-Hierarchical Online Learning Communities (NHOLC) conceptual framework. This frame-

work draws on [Vygotsky's \(1978\)](#) sociocultural theory, communities of practice ([Lave & Wenger, 1991](#)), knowledge building theory ([Scardamalia & Bereiter, 2006](#)), funds of knowledge ([Moll et al., 1992](#)), and place-based education ([Gruenewald & Smith, 2008](#)). The NHOLC framework proposes that collaborative online learning environments should place an emphasis on the following: (1) multi-directional learning opportunities for diverse participant groups, (2) real-world investigations that are driven by participants and are personally relevant to participants lives, (3) share goals and purpose of projects, (4) develop communication structures that foster relationships among diverse participants, and (5) utilize place-based data sharing across geographic boundaries.

2.2. Collaborative Learning

We also draw upon prior research on collaborative learning to understand the co-learning experiences of our teacher and student participants. While collaborative activities have been studied from various perspectives and in many disciplines ([Baker, 2015](#)), we draw upon the theoretical foundations of 'collaborative learning' from the computer-supported collaborative learning (CSCL) literature. According to [Roschelle and Teasley \(1995\)](#):

Collaboration is a coordinate, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem. We make a distinction between 'collaborative' versus 'cooperative' problem solving. Cooperative work is accomplished by the division of labour among participants, as an activity where each person is responsible for a portion of the problem solving. We focus on collaboration as the mutual engagement of participants in a coordinated effort to solve the problem together (p. 70).

[Baker \(2015\)](#) outlines six underlying assumptions of collaborative learning situations. The first is that all participants in collaborative learning are considered equal in terms of their status and right to participate in the interaction (but not necessarily with prior knowledge or other relevant social and cognitive characteristics). Baker states that this would effectively "exclude from consideration as 'collaboration' many interactions between teacher and student" (p. 3) due to the power differential between teacher and student.

The second assumption is that groups work on tasks requiring individuals to work together to solve the problem and that a single shared product or solution is the end goal. Third, "not all 'group work' is either cooperative or collaborative" ([Baker, 2015](#), p. 3). During a group work situation over an extended duration, there may be periods in which the group members are working individually on a related subtask—in which case, they are not collaborating.

The fourth assumption relates to the extent to which there is a clear or known solution path to the problem. Ideally, collaborative situations involve tasks that allow participants to explore the problem space and gain deeper conceptual knowledge. This directly leads to the fifth assumption, namely, that collaboration is intimately related to the process of 'co-elaboration'. That is, participants will come to develop knowledge and a conceptual understanding of the joint problem space.

Finally, the sixth assumption of collaborative learning situations, specifically ones that occur in a classroom, is that a teacher primarily oversees the collaborative learning process (e.g., forming groups, providing task instructions, evaluating group work). When a collaborative learning situation occurs outside a classroom (e.g., in an informal learning context), it would be fair to assume that the role of the teacher could be filled by someone else (e.g., a workshop facilitator or educator).

3. Co-Learning as a Model for Professional Learning and Out-of-School STEM Learning

Non-hierarchical and collaborative learning provides a solid theoretical foundation for the co-learning model. In our CCW, student and teacher participants are engaged in collaborative learning that meets the six criteria outlined by [Baker \(2015\)](#). Although Baker notes that most collaborative learning would exclude many of the interactions between teachers and students, we consider the co-learning model used in our CCW to be a distinct form of collaborative learning. From Kermish-Allen and Kastelein's NHOLC model, we view the relationship between teachers and students during co-learning situations as non-hierarchical. Students and teachers are equals during co-learning and are engaged in co-elaboration during the integrated STEM activities organized and led by the workshop facilitators. In these settings, knowledge is co-constructed, multi-directional, and can negate the hierarchical structures commonly found in educational settings ([Macias et al., 2022](#)). The co-learning model acknowledges that all participants (students and teachers) have different expertise and backgrounds and that each has something to learn from and teach others ([Kermish-Allen & Kastelein, 2017, 2018](#)).

As such, there are several potential benefits for participating teachers and students. Co-learning allows teachers to experience the pedagogy as learners, which can provide insights into the joys and challenges of learning in an integrated STEM project-based learning environment. By participating in integrated STEM tasks as students, teachers can develop a deeper and more critical grasp of what STEM integration entails ([Fitzpatrick & Leavy, 2025](#)). Such hands-on, learner-mode experiences also serve as powerful mastery experiences that boost teachers' confidence and self-efficacy in teaching STEM, as they generate emotional excitement about STEM learning and foster an appreciation of learners' capabilities ([O'Dwyer et al., 2023](#)). Co-learning also allows teachers to observe students' thinking, their struggles, and how they learn in real time. From this experience, teachers may better understand where and how students struggle in a classroom setting, promoting deeper empathy with their students. Moreover, the opportunity to interact with students in a non-hierarchical learning environment may help teachers better understand their students' cultural expression of and perspectives on learning and gain insights on how to teach students from backgrounds different than their own. For example, teachers may come to see how even historically underperforming students can become motivated, engaged, and successful in using scientific, mathematical, and engineering practices when given rich STEM challenges ([Lesseig et al., 2016](#)). These insights in turn shift teachers' beliefs about student potential and help them refine their own conceptions of STEM education ([O'Dwyer et al., 2023](#)).

Co-learning may also help teachers gain confidence to bring new pedagogies into their classrooms to engage students in more authentic practice. The NGSS articulates a new vision of science teaching but provides little pedagogical guidance on integrating the Engineering DCIs and Practices into science courses ([Larkin, 2019](#); [Williams et al., 2019](#)). The NGSS requires thoughtful choices about pedagogy. For many teachers, this work requires a re-conceptualization of their role, shifting to helping students investigate to gain understanding rather than simply providing answers, as well as furthering their knowledge of the importance of "minds-on" learning ([Furtak & Penuel, 2019](#); [Holthuis et al., 2018](#)). Co-learning gives teachers insights and experiences that make them feel comfortable and confident about integrating new pedagogy and curricula into their practice.

Co-learning also offers great promise as an out-of-school STEM experience for students. Co-learning allows participating students to work closely with teachers in a non-hierarchical relationship as equal contributors and knowledge generators to complete project-based challenges. This may make students more confident in their abilities to

participate in STEM activities competently, as has been found in prior research examining students' experiences in out-of-school STEM programs (Zhao et al., 2023). Developing a strong sense of competence is tightly coupled with an increase in self-confidence and STEM identity (Mercier & Carlone, 2021, 2022). Bringing science-interested students together in an out-of-school STEM co-learning experience can shift students' science identities and future trajectories. Multiple studies have demonstrated that out-of-school STEM co-learning environments can positively shape students' science identities and future aspirations. Students who engage in these collaborative, authentic STEM experiences often report stronger identification with science and a greater sense of belonging in the scientific community (Hill et al., 2024; Ludwig et al., 2024). Such programs allow youth to see themselves as 'science people' and even envision working in STEM careers alongside like-minded peers and mentors (Hammerness et al., 2024; Ludwig et al., 2024). In addition, out-of-school STEM programs can be an important space for URM students to explore and nurture their interest in STEM. Youth that participate in informal STEM learning experiences show increased interest in STEM and are more likely to pursue STEM majors and careers (Zhao et al., 2023). Finally, co-learning allows students to observe and interact with teachers in an out-of-school setting, which may alter or shift their perceptions of teachers.

4. Research Goals and Questions

Because of its novelty, questions and skepticism exist about co-learning as a hybrid professional and out-of-school learning model. We suggest it offers great promise and is worthy of systematic study to define better its strengths and limitations. This study was designed to unpack the co-learning experience from the views of teachers and students to understand the strengths and limitations of a co-learning model for teacher professional learning and out-of-school STEM experiences. The research question of primary interest in this study is as follows: What opportunities and challenges does co-learning present for teachers and students?

5. Methodology

This exploratory qualitative study includes data from end-of-workshop semi-structured interviews with teacher and student participants. The data for this paper include findings that focus specifically on participants' reflections and insights about their experience with co-learning.

5.1. The Cellular Construction Workshop (CCW)

The CCW is a 10-day (60 h) summer workshop that was held in June 2023 on the campus of the University of California San Francisco. The CCW focuses on the interdisciplinary domain of cellular engineering. This discipline leverages a growing understanding of controlling cellular structure and function to solve environmental, medical, and industrial problems. Cellular engineers 'reprogram' cells to take on new functions, and this work is at the interface of biology, physics, chemistry, engineering, and computer science. The workshop curriculum centers on the 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 the wet lab to programming and robotics through the cells-as-robots analogy adds a unique dimension to the workshop's biology content. 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 codes (either genetic or computer) play 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 and computational thinking skills, as outlined by Wing (2006) and the National Research Council (2010). These modeling activities allow for a comparison of how cells and robots sense and respond to their environments and help participants to understand that cells are dynamic and readily adapt to alter their function and behavior. See Table 1 for a sample schedule of a day in the CCW program.

Table 1. Sample schedule (Day 3) in the CCW program.

Time	Focus: Biology or Robot Modeling	Activity	Activity Description
9:00 a.m.–9:15 a.m.	N/A	Icebreaker/ Warm-Up Activity	Community-building activity to get participants engaged and ready to participate.
9:15 a.m.–10:30 a.m.	Biology	Did Physarum find its way?	This activity is designed as an open-ended exploration into Physarum (slime mold) preferences by observing its chemotaxis. Participants first observe that Physarum will move towards oats, and then design experiments to determine its preference by observing its chemotactic behavior.
10:30 a.m.–10:45 a.m.			Break
10:45 a.m.–11:45 a.m.	Robot Modeling	Phototaxis Mystery Program	This is an open-ended programming lesson that models cell movement towards light. In this lesson, participants are introduced to the idea of outlining a program as a series of scenarios and responses. They are also exposed to the engineering method (like the scientific method, but for engineers). They are given a program called Phototaxis_Prog that has 2 to 3 code blocks offered for each scenario. Each group is asked to build their own phototaxis program by assembling the code blocks into a functioning program. The groups are then asked to improve upon the program in any way they would like, provided they use the engineering method to improve on their program.
11:45 a.m.–12:30 p.m.			Lunch
12:30 p.m.–12:45 p.m.	N/A	Icebreaker/ Warm-Up Activity	Community-building activity to get participants engaged and ready to participate.
12:45 p.m.–1:45 p.m.	Robot Modeling	Chemotaxis Programming	This is a programming lesson that models cell movement up a chemical gradient. In this lesson, participants build on the idea of outlining a program as a series of scenarios and responses. This program is a bit more complex than the phototaxis program lesson as groups will need to build their chemotaxis program from scratch. 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.

Table 1. Cont.

Time	Focus: Biology or Robot Modeling	Activity	Activity Description
1:45 p.m.–2:15 p.m.	Biology	Observe Physarum Experiments and Shareout	Participants check on Physarum growth from experiments started earlier in the day. Groups should 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 p.m.–3:00 p.m.	Biology	Lab Tour	Throughout the workshop, participants are given the opportunity to tour a number of 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.

5.2. Participants

Workshop participants were recruited from local public or public charter schools. Student participants needed to be 10th or 11th graders, identify as individuals from backgrounds historically marginalized in the sciences, and ideally have taken at least one biology course. Teacher participants needed to teach a STEM subject at a public or public charter school. Workshop participants received a small stipend for completing the workshop (USD 1000/student and USD 1350/teacher); however, there was no additional compensation for agreeing to participate in the research study.

There were 15 student participants in the workshop, 14 of whom agreed to participate in the larger study. This paper focuses on data from the eight student participants who completed the post-workshop interviews (see Table 2 for their demographic profiles). Five teacher participants, all identified as teachers of color, agreed to participate in the study (see Table 3 for their demographic profiles).

Co-learning teams comprised three students and one teacher. Team membership varied across activities, so teachers and students had the opportunity to collaborate with different individuals throughout the workshop. Within the co-learning teams, teachers and students participated as learners, working together to complete the learning activities.

Table 2. Participating student demographics.

Student (Pseudonym)	Gender	Race/Ethnicity	Grade	Languages Spoken
Anna	Woman	Asian	10	Cantonese; English; Mandarin
Andy	Man	Hispanic or Latine	11	English; Spanish
Emma	Woman	Asian	10	English; Vietnamese
Ella	Woman	Hispanic or Latine	10	English; Spanish
Isaiah	Man	Hispanic or Latine	10	English; Spanish
Lily	Woman	Asian	10	Cantonese; English; Farsi; German; Italian; Mandarin
Nora	Woman	Hispanic or Latine	11	English; Italian; Spanish
Savannah	Woman	Black or African American	11	English

Table 3. Participating teacher demographics.

Teacher (Pseudonym)	Gender	Age Range	Race/Ethnicity	Years Teaching	Subject(s) Taught
Francine	Woman	31–35	Asian	5	Biology and Chemistry
Janet	Woman	36–45	Black or African American	10	AP Biology, Biotechnology, and Health
Shannon	Woman	36–45	Hispanic or Latine	10.5	Biology
Alex	Man	31–35	Asian	4	Chemistry
Michael	Man	31–35	Asian	2	Physics

5.3. Data Collection

Teacher and student participants were emailed following the workshop to request their participation in a short (30 min) one-on-one interview conducted via Zoom. Interviews were conducted with all five teachers and eight of the fourteen students. The interviews covered a range of topics, including participants' reflections on their (a) overall workshop experience, (b) conceptions of science and STEM, and (c) experiences with co-learning. Interviews with teachers included questions about their school and their approach to teaching, while interviews with students included questions designed to probe their STEM identity. This paper focuses on participants' responses to the questions related to their overall experiences in the workshop and co-learning experiences. The semi-structured interviews allowed us to understand the participants' experiences with co-learning and how they made sense of their co-learning experiences, prompting for additional details based on the participants' responses when necessary.

5.4. Data Analysis

Interviews were transcribed and then imported into *ATLAS.ti* for analysis. 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 (Braun & Clarke, 2006). We relied on Braun and Clarke's (2006) six-step approach to thematic analysis to guide our process. We (the first and second authors) began by familiarizing ourselves with the data, performing multiple readings of the interview transcripts, and developing an initial set of codes, focusing specifically on anything relevant to co-learning. Initially, we coded one transcript (teacher interview) together and then worked alone to code the remaining teacher interview transcripts. We then met to compare and share our coding and clarify definitions of codes. We then coded all the student interview transcripts, using codes developed while coding the teachers' transcripts and identifying new codes. We once again met to share and compare our codes and reached a consensus. We then collated the codes into potential themes (categories) and reviewed these initial themes against the coded extracts to determine whether they fit. We then defined and named the themes, selected compelling examples (quotes), and related these quotes to the research question and the literature. See Table 4 for an example of the codes and subthemes developed during data analysis.

Table 4. Example of codes, subtheme, and theme developed during data analysis.

Theme	Subtheme	Codes	Example Quotes
Co-learning requires teachers to navigate multiple roles in their co-learning groups	Teacher purposefully played a role in the group	team player	"I basically just did the things they didn't want to do. I did like, I presented when a lot of them were pretty shy about presenting. I would work on slides if they wanted to work on the code. I would work on code if they want to work on slides. I would mainly just fill in the roles they didn't want to do."—Michael
		step back or step forward	"So I was always trying to. . . because I was trying to step back because, not that I had the answer, but because I could give them the answer right off the bat, but I purposely caught myself not wanting to answer it and just saying, 'What do you think?' Or, 'Hey, can you explain?' 'You don't understand. Okay, that's no problem.' 'So-and-so, can you explain the idea?'"—Francine
		facilitator	"I found myself using my teacher comments when I noticed that students to students collaboration could have been better. So I would say. . . What did I say? There was an instance where the student would only talk to me because they saw me as the adult, but then I caught myself saying just, "Oh, I think so-and-so has an idea as well. Have you asked them?" And then I would very explicitly say, "I'm not going to answer that because I know you're looking at me because I'm the adult, but I'm pretty sure they both know too."—Francine
		put on teacher hat	"There were some students that you know, I took. I put my teacher hat on. And you know, some students just didn't want to work, but I would call them out And so I think that that was that was it, was what I would notice students slacking off."—Alex

6. Findings and Discussion

Six distinct themes emerged from analyzing responses from both teacher and student participants. The six themes are as follows: (1) co-learning is enjoyable and provides opportunities to connect with others, (2) co-learning is helpful for learning (STEM content), (3) co-learning requires teachers to navigate multiple roles, (4) co-learning provides teachers with valuable insights about students and teaching, (5) co-learning provides students with new perspectives on teachers, and (6) challenging group dynamics can impact co-learning. We present and describe these themes in more detail below, interweaving discussion of previous findings from the research literature.

6.1. Co-Learning Is Enjoyable and Provides Opportunities to Connect with Others

All of the teachers described their co-learning experience as enjoyable. Teachers said it was fun, enjoyable, and that they found it rewarding when they saw students' excitement. The collaboration and interaction were noted as a salient aspect of the teachers' enjoyment. As one teacher, Michael, stated, *"I really liked the collaboration between students and teachers."* Likewise, students often enjoy opportunities to interact with one another (O'Donnell & Hmelo-Silver, 2013), and here, students noted that they also enjoyed working with teachers. Emma (a student) stated, *"I think after a while, once you warm up to each other, it's really fun to*

work as a group with a teacher.” Another student, Lily, stated, “I really liked the way it was laid out and the way that there were teachers with students working together.”

Participants consistently referred to the *connections and relationships* they developed during the co-learning experience. Thus, there appeared to be a high level of social cohesion amongst the CCW participants. Social cohesion is the extent to which individuals feel a sense of belonging and commitment to the group and can be thought of as the ‘glue’ that connects the group (Sasson et al., 2022). Collaborative learning can positively impact social cohesion (Sasson et al., 2022), as appeared to be the case here.

The program’s size overall (fifteen students and five teachers) was intimate enough that participants could connect with others, while the co-learning group size (one teacher and three students) also allowed for a more personal, one-on-one connection to build. Students said they enjoyed learning about the other participants and their lives and interests and felt this helped create authentic bonds with them.

I think what I enjoyed most was, like, getting to hear about, like, their lives [chuckles] in a way. Like, it was fun working with them as a team, but what really made it fun was, like, learning about each other’s stories and, like, how-how they lived, how they were-- like, funny stories about their lives, which, like, helped us connect together as a team and made it funner [sic] for everyone. And it was like, sometimes the stories were weird, but [chuckles] it was still-- Like, we connected in a way, and because of that, we worked it better, um, better as a team together.—Emma (student)

The *community* built within the workshop amongst participants also contributed to participants’ enjoyment of the co-learning experience. Participants discussed the icebreakers, games, and time allotted for developing relationships (teacher to student and student to student) as a critical component of their enjoyment of the workshop. Participants described the welcoming atmosphere, the openness and friendliness of other participants, and that even for a more introverted or shy individual, the safe community was encouraging and allowed them to open up too. Alex (a teacher) stated, “*There were a lot of times for gamebreaker or icebreakers and stuff like that, so games, and I think that was a key essential thing to open people up.*” Similarly, students Isaiah and Ella stated

They were really open and understanding with like, us having breaks, and also getting to know each other and stuff before we started doing like the work. . . it was really good because they gave us the time to get to know each other, and I feel like I get to- I got to know everyone pretty well and, um, yeah, everyone was really kind.—Isaiah

Um, I’m a really not so social person, so finding out that a lot of the teachers and kids were really social, it really helped me a lot because I like when-when people are really social; it helps me talk a lot more. And seeing as how a lot of students and teachers were really open, it encouraged me to-to be the same way.—Ella

6.2. Co-Learning Is Helpful for Learning (STEM Content)

As Baker (2015) outlined, one of the assumptions of collaborative learning is that the goal of group work is for students to learn through co-elaboration and develop a conceptual understanding of the problem space. Learning with others provides opportunities to extend one’s thinking, share ideas, and draw on the expertise of others (Krajcik et al., 1994). In collaborative learning, participants work together to maximize the learning of each group member (Cen et al., 2016). Participants found that working with their group members was beneficial for solving the design challenges and understanding the content. Andy (a student) described how one of his group members helped him solve problems:

Sometimes when I didn't have a solution, my partner will have it. And we would just discuss about the problems we had and possible solutions we could do for the next day.

Another student, Lily, described how co-learning allowed her to co-construct knowledge with her group members: *"I was definitely being [sic] able to build off of their ideas. And I think that we were definitely better together than, um, on our own."*

For co-learning to be an effective collaborative learning model, the participants must be equal in terms of their status and rights in the interaction (Baker, 2015), and the lines between teacher and student must be blurred (Kermish-Allen et al., 2015). The participating teachers found it exciting and challenging to have this type of learning experience. While there were varying levels of expertise with the biology content amongst the teachers (though all had more expertise than the students), four out of the five teachers stated that the programming content was new to them. This lack of knowledge of the programming content meant that teachers could learn with and from the student members of their co-learning group.

I love that I was able to learn something new. And so it was, stretching my brain in a new way, and like learning how the commands go. . . But then, yeah, just kind of being in a new position again, where it's like I'm starting from square one with the students. I think that was very challenging.—Alex (teacher)

There was a couple places where we had to, there was that big poster, and we were trying to connect how is a robot like a cell? And for some of them, they're going to be seniors this coming year, and biology was a long time ago, and they didn't remember all the steps of protein synthesis and all those details, so I helped them out with that. But otherwise, I really might drop a helpful hint or two if I had one about the biology content. But with the programming, I really was learning with them and from them.—Shannon (teacher)

A potential benefit of collaborative learning is that group members can bring diverse ideas and perspectives to the learning process, possibly contributing to greater understanding (Feltovich et al., 1996). Indeed, student participants recognized the diversity of ideas and perspectives their group members brought to the co-learning experience as valuable. Savannah describes how her group members were able to help her see thinking from a different perspective: *"Um, I re—I, like, liked all of, like, the different perspectives because, like I would be thinking one thing and then somebody would interpret it another way or somebody would challenge the idea."* Another student, Lily, describes how the diversity of ideas helped accomplish the project goals.

I like that there are other people around and that everyone has their own ideas. You know, and I definitely would not be able to do anything on my own with my own ideas, because sometimes it's just not enough to be on your own. So, I like collaborating with everyone and hearing their ideas.

When thinking about how the students learned with the teachers, students saw great value in having the teachers as part of their group. Because the students saw the teachers as equal members of the group, they valued the unique perspectives that the teachers brought to the co-learning groups. Andy stated, *"With teachers, it was nice because, like, you learned that when there's something new, they're also like students, but they have different ways of solving stuff."* Another student, Savannah, stated, *"And it was usually the teachers challenging the idea, so like, you know, they can get, um, more ideas. . . and different perspectives."*

6.3. Co-Learning Requires Teachers to Navigate Multiple Roles in Their Co-Learning Groups

In some collaborative learning situations, *scripted roles* are assigned to group members, defining each individual's expected duties and responsibilities (Stahl & Hakkarainen, 2021). Alternatively, roles for group members can emerge during the collaborative process, and these can be adaptive to the task demands and needs of the group members (Saqr et al., 2024). While the concept of co-learning suggests that all participants in the group would adopt the role of 'learners', it turned out that the teacher participants felt the need to play multiple roles during the co-learning experience. The central theme identified across teacher and student responses was that co-learning required teachers to navigate multiple roles in their co-learning groups. Within this theme, three smaller subthemes were identified: (a) the teacher as a student, (b) the teacher purposefully played a role in the group, and (c) the student's view of the teacher's role.

Teachers were quick to say that their primary role was to be a student in the workshop while perhaps not always acting entirely as a student in the group. Teachers acknowledged that the workshop setup was such that they could sit back and be students, participating as learners would. They were not in charge of leading or organizing the activities so that they could take their teacher hats off.

I really liked that we were 100% as students. The actual facilitators and the leaders were the teachers, and the moment we sat down and were with our group, we were the students. And so being able to put the student hat on was pretty cool.—Francine

However, at times, the teacher purposefully played a role other than that of a learner within the group. Teachers described taking on roles within their groups that they felt would help the group make progress toward their goals. The roles depended on the group and the particular teacher and spanned the spectrum from mentor to facilitator to team player.

I guess more as a facilitator, just being like, "Okay, well do you want to try to do this part of it, and do you want to try to do that part?" Or, "Hey, maybe we should start with this thing." Because otherwise it was just we're all sitting there and as crickets.—Shannon

I think, you know, I would try to show what a leader would do, and then I would hand it off to another student that would then just lead, and then delegate, or whatever, do the same thing that I was trying to do. I think that was how I tried to interact and do the group work.—Alex

I basically just did the things they didn't want to do. I did like, I presented when a lot of them were pretty shy about presenting. I would work on slides if they wanted to work on the code. I would work on code if they want[ed] to work on slides. I would mainly just fill in the roles they didn't want to do.—Michael

Students seemed aware of teachers' multiple roles in the co-learning groups. From the student perspective, teachers were viewed as co-learners; students felt they were on equal footing in the co-learning groups and understood that the teacher participants did not know everything. To this point, Emma (a student) stated, "*They had the same experiences as-as we had. And especially now since we're all learning new stuff, we're all basically students in a way.*" Another student echoed Emma's view of the teachers as equal learners:

There was a point where I didn't really like still think there were teachers. Like for- for me, it was still like we're all just here learning the same thing. This is new to all of us, so, yeah.—Isaiah (student)

Yet, students also viewed the teacher participants as having an essential role within the groups as they could explain content, encourage group discussion, and facilitate group dynamics. In other words, students recognized that teachers took on a *relational leadership* role, wherein they were able to promote and foster relationships and empower and motivate group members (Burke et al., 2006).

And it was nice, because, like, if you didn't understand something, even though it was new to the teachers, they could also explain it to you. . . Like, if you had a question, they could answer it very easily, or, in Michael's case, they could like try to talk it out with, like, talk it out in the group. —Andy (student)

Teachers are like always encouraging discussion. 'Cause in the groups that I was in, like the teachers would always be the one that would keep the discussion going, or just like randomly ask the questions. Always trying to engage the people in our groups. —Savannah (student)

6.4. Co-Learning Provides Teachers with Insights About Students and Teaching

Similar to findings from Christian et al.'s (2021) study of an NGSS-based teacher professional development program, the teachers' experience with co-learning allowed them to develop a sense of the student learning experience. A critical insight for teachers was the importance of building community and offering collaboration and group work opportunities for the students in their classrooms. Janet (a teacher) reflects on the importance of community and connection building before or as part of collaborative learning: *"Seeing that they're definitely quiet in the beginning if you don't build community, or if . . . they don't know each other, it's hard."* Another teacher, Francine, recognized the power of collaborative learning to draw quieter students into the learning mix: *"The desire for students to collaborate with one another, even with the shyest students. You can tell that even with the least social student that was there, wanted to be a part of the group."* As exemplified by the following statement by a third teacher, Shannon, an implication of this for teaching is the need to consider incorporating more of these opportunities in her future lesson planning.

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.

Prior research has shown that teachers may encounter challenges when implementing collaborative classroom activities, such as composing appropriate groups or designing effective group tasks (Gillies & Boyle, 2010; Le et al., 2018). Janet describes how her experience with co-learning made her more cognizant of the student dynamics within groups and the need to think more carefully about student groupings in her future teaching:

Just to think about my teams more or my student grouping more. Yes, make sure I'm strategizing and seeing not necessarily friend groups but who is strong in certain areas than others, based on what activity we're doing. Yes, and then just building, to build community and have groups, even if it's just through working on a challenge.

Echoing Baker's (2015) claim that a collaborative learning task should require working with others to reach a solution, Michael states

There's definitely challenges to group work always, just like in terms of, do people feel like they have enough work to do, or the roles that they're given suits them? I think just in general, it just gives me insight as, like, I think something Charles [a facilitator] told me. It was just like, "Is this work worthy of having groups?" Because there's a lot of times when you're given work that is just

basically individual work that you work on together with other people. I think something that I was thinking of is, if I make group work, is it worthy of the amount of groups that I make? Does it actually allow them to split the work effectively? Or is it just like one person doing work for four people?

Similarly, prior research has documented challenges that teachers face related to monitoring and facilitating productive collaboration when implementing group work in their classrooms (Hämäläinen & Vähäsantanen, 2011; van Leeuwen et al., 2013). Alex describes how his co-learning experience highlighted the importance of addressing this issue when considering implementing collaborative learning in his classroom.

Working together, I think it's really important to delegate roles and then, as the teacher, then to be the one to enforce it. I think I really kind of learned that because what I've realized is that a person will like, keep, will do all the work for the group. . . I saw that happen a lot at this program also. And so being more intentful [sic] with roles.

6.5. Co-Learning Changes Students' Perspectives on Teachers

The co-learning experience led students to have a different perspective on teachers. Students described teachers with phrases such as "fun to talk to," "a friend", and "human". Below we have chosen to share several quotes from students in order to illuminate the consistency and strength of students' reactions to working with teachers.

And just like, 'cause even though they're teachers, they're, like, still fun to talk to and, like, they're not that scary as you, like, imagined it. And like, they're actually pretty fun to talk to, even though it kind of sounds weird. [chuckles] It's, like, you need to experience [it] at first, and then you'd understand.—Emma

To be honest, working with teachers, like it made me see them like, not as teachers like, also, like, I guess someone you can like to like as a friend, I guess, like it's kind of weird. But it's also kind of cool.—Anna

I learned that they were more human, I guess, because. . . I'd never really worked with them, and it was always just them teaching in front of a whiteboard. So, I think my overall view of them just changed a bit. . . Also, the teachers were really kind, and they were really open to also sharing their ideas. And also some were also struggling with the coding or like the construction. So, I guess. . . it was just really nice to see them be human.—Lily

Students deepened their understanding of teachers as individuals with different strengths and weaknesses versus having a more monolithic vision of teachers. Students also realized that teachers do not know everything (i.e., they are students too) and that they, as students, could help the teachers learn.

That they sort of do have a stressful life, and that there are some nice teachers because they actually want to teach students, not like other teachers that just teach because they teach and not because they actually enjoy teaching subjects to other students.—Andy

There are really good teachers who know how to explain things because I told you how at my school, um, since it's science, some teachers don't really know how to explain it, but they know how to model things. So, it's more like you have to be a visual learner to understand it. And I feel like working with, uh, teachers in a group actually really helped me see that. Not all teachers are like that, but there are like a good amount of teachers who do know how to explain things.—Ella

They [teachers] helped us with things that we didn't understand, but I also kind of, um, was able to help them. So that was really new. I guess it was because, like in school, it's not- it's not really like that; the teachers are the one teaching us. So, it was really nice to see just a change because I didn't really, um-- there was a point where I didn't really like still think there were teachers. Like for- for me, it was still like we're all just here learning the same thing. This is new to all of us, so, yeah.—Isaiah

The co-learning experience humanized the teachers for the students. The students came to recognize that the teachers could not only be people that they could build a bond with, but also that the teachers did not have all the answers and that they could learn with and from the students too. Prior research suggests that the social and emotional interactions between teachers and students (and among students) are consistent predictors of students' attitudes towards studying and careers in STEM (McLure et al., 2022). It is clear that these students had positive social and emotional interactions with these teachers, which highlights the potential of a co-learning experience such as this one.

6.6. Challenging Group Dynamics Can Impact Co-Learning

As might be expected in any collaborative learning situation, issues related to group dynamics arose. In particular, participants mentioned two issues. The first challenge, from the students' perspective, was the initial awkward social dynamics in terms of working with teachers as peers. As mentioned earlier, social cohesion in groups is an important factor in collaborative learning. Group cohesion positively affects task participation and may improve group consensus (Xie et al., 2019).

And so I wasn't expecting anything from the students; I just thought they would be like me, but for the teachers, it was really awkward 'cause we had—'cause we were calling them by their first names. Usually, we don't do that. But it was like awkward like talking to a teacher as if they were like my classmates. But in the program, they were like, it wasn't try—they weren't trying to make it like a classroom environment almost, it's like a- like a lab environment. So that was pretty—it was pretty weird.—Savannah (Student)

The second challenge was related to the tension that may have sometimes risen between group members when someone's idea was disregarded or not taken up. Disregarding others' opinions and rejecting alternative suggestions during collaborative learning is a problem documented in prior research (e.g., Barron, 2003). When this happens, it can inhibit learning and group functioning (Le et al., 2018). This theme was found in both student and teacher experiences during co-learning:

Um, let's see, when they didn't pay attention to me, [chuckles] with the programming, I was like, "I have this one idea, and I'm sure." I'm like, "It might work, and I'm pretty sure it will." Um, but they were like, "No, let's try this." Um, yeah, so when they didn't listen to me, I guess.—Nora (student)

I guess I had a hard time. I was talking about the very last challenge. Charles [a facilitator] came by and made several suggestions, and I kept repeating them to encourage my students [group members] to try those changes out in the program because they were stuck and they kept just ignoring it and doing their own thing. And I kind of had to disconnect a little bit because I didn't want to come out and be really forceful and be like, you need to do this because I didn't even know how or if it would work, but that was a little hard for me to just be like, they're not listening to me. But I wasn't in teacher mode, so I had to let that go.—Shannon (teacher)

Another challenge revolved around group leadership. During collaborative learning, participants often take on different leadership roles, such as leaders and followers (Xie et al., 2019). Teachers expressed uncertainty about when and how much to step up and lead during co-learning. Three teachers (Janet, Francine, and Shannon) discussed how they encouraged or liked to see student leadership in the groups and did not mind following. However, they were unsure about maybe stepping back too much or when to challenge where the group was going, overstepping, and imposing undue authority.

Some of the teams had students that were really comfortable taking on a leadership role. And in those teams, I let them do that and I asked, “What do you want me to do?” Or, “Can I contribute this or that?” And they would let me know.—Shannon

Maybe sitting back too much, I don’t know, and not letting the kids-- The last group, there was some issues with deciding what robot, and basically, the person who was going to be the leader didn’t step up. I’m just like, “Do I do it? Do I not?” Yes, that was challenging.—Janet

Students also experienced issues with what is referred to in the research literature as *task leadership*. Task leadership includes assigning and coordinating tasks and facilitating good communication among the group to accomplish the task (Xie et al., 2019). Students expressed that one challenging issue during co-learning was when there was no clear direction for the group.

Well, sometimes it’s hard to cooperate with some people. So, it was like when they didn’t like when some people don’t know like what to do. And you also don’t know what to do, you just sit there, and you’re like, Okay, what are we supposed to do, and you had to, like, figure out a way so that you can get the work done. I think that was the hardest part.—Anna (student)

Group cohesion, disregard for others’ ideas, and group/task leadership are all issues in the collaborative learning literature that also presented themselves as issues for our participants during co-learning.

7. Conclusions

The benefits of collaborative learning are well documented in the literature; however, this non-hierarchical, co-learning approach to engaging teachers and students in integrated STEM activities is unexplored. These findings provide valuable insight into the teacher–student co-learning experience, identifying the opportunities and challenges a co-learning model presents.

Co-learning provided both teacher and student participants with opportunities to develop connections (teacher-to-teacher, student-to-student, and student-to-teacher) that were authentic and meaningful. The workshop facilitators fostered these connections by incorporating social activities such as icebreakers and games. The social cohesion felt by the participants fostered the co-elaboration that occurred in the co-learning groups, which led to deep content learning. Teachers and students also gained valuable insights about one another, which may impact their future teaching and learning experiences. Teachers gained insight into the importance of community, the value of group-worthy tasks, and the tricky dynamics of collaborative groups. Students developed new perspectives on teachers, which may help them create stronger connections with teachers and other adults in the future.

Alongside the abundance of opportunities, the co-learning experience presented a few challenges for participants. For teachers, navigating multiple roles within their co-learning groups was a challenge that elicited feelings of uncertainty and sometimes frustration. At

various points throughout the experience, teacher participants' roles could be characterized as learners, facilitators, leaders, team players, task leaders, and relational leaders. It was not always clear for teachers when it was best to assume what role or if they should assume any role other than learner. Navigating complex group dynamics was also a challenge for participants. Group dynamic issues were noted when there was not strong social cohesion (i.e., awkwardness among group members), lack of leadership (task or relational), or a disregard for someone's ideas, which inhibited co-elaboration and learning within the group.

This hybrid teacher professional learning and student out-of-school learning STEM learning model provides an innovative and synergistic strategy for tackling enduring challenges in STEM education, specifically by equipping educators to deliver integrated, inclusive STEM instruction and by expanding engagement among underrepresented student groups. Recent research emphasizes two complementary priorities for advancing equity in STEM: equipping teachers with robust support for integrated instruction and providing underrepresented learners with inclusive, hands-on STEM experiences beyond school. Sustained professional development and collaborative learning communities build teachers' content knowledge and pedagogical skills for innovative STEM teaching (Rehman et al., 2025) while culturally responsive after-school and informal STEM programs significantly boost engagement, self-efficacy, and STEM identity among minoritized students (Xia et al., 2025). Together, these strands suggest that effective reform requires an integrated approach linking formal and informal learning. By simultaneously preparing teachers and inspiring diverse students, such holistic STEM initiatives can create classrooms that are both pedagogically innovative and socially inclusive. This co-learning workshop model presents a compelling approach to transforming STEM education into a more inclusive and empowering experience for all participants.

This study was meant to be just a first step in exploring co-learning as a hybrid teacher professional and student out-of-school STEM learning model. We recognize that a limitation of this work is that it involves a small group of teachers located in an area steeped in STEM innovation. In addition, the participating students opted into the 10-day summer workshop, indicating a strong interest in STEM, and thus, their engagement in co-learning may not be typical of other youth their age. We do not presume that the findings from this study are generalizable to different populations of teachers and students; however, this research provides a proof of concept that co-learning is a model with much potential.

Future research directions could include additional qualitative research studies, such as this one, that examine co-learning in a different area of integrated STEM. This would provide insight into the integrated STEM activity design factors that can support participants' co-learning. Studies that explore and describe the co-learning process within a group(s) would help provide a clearer picture of what co-elaboration looks like within the group and give some insight into factors related to group dynamics (i.e., leadership, teacher roles, etc.). Finally, future research should continue to explore how to best structure and facilitate this type of co-learning experience to be a fruitful learning experience for both teachers and students.

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