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Teacher Outcomes of an Intensive STEM-Focused Professional Learning Initiative: An Examination of Their Beliefs, Practices, and Perceptions

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Abstract

The purpose of this paper is to describe teacher outcomes from participating in an intensive science, technology, engineering, and mathematics (STEM) professional learning (PL) initiative for middle school science teachers in the United States. The initiative included intensive summer coursework and ongoing support (e.g., individual coaching, professional learning communities), and focused on enhancing teachers' STEM instruction and their pedagogical content knowledge (PCK), with the ultimate goal of improving student outcomes.

In this mixed method study, we examine change across time in teachers' beliefs, use of STEM instruction, and PCK. In general, we did not observe statistically significant change in teachers' beliefs, use of STEM instruction, or PCK from the beginning to the end of Year 1. In follow-up focus groups, ten teachers described their perceptions of student outcomes of STEM instruction and identified tensions related to implementation. We offer implications intended to inform future work in the area of STEM PL.

Keywords: *middle school science, professional learning, STEM education, teacher beliefs*

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Introduction

The international emphasis on STEM education in K–12 settings has increased in the last two decades (Bryan & Guzey, 2020; Saw, 2019). This movement toward STEM education is encouraged by research identifying its positive effects on student outcomes (e.g., Hiğde & Aktamış, 2022; Lynch et al., 2019; Means et al., 2013). International educational policy initiatives (e.g., U.S. Department of Education, 2016; OECD, 2018; NRC, 2014) emphasize the importance of increasing students' ability to identify new, interdisciplinary STEM solutions in a rapidly changing world and to incorporate 21st-century skills in ways that benefit humanity and are ecologically sustainable (Donovan et al., 2014). This innovative thinking and problem-solving is known as STEM literacy (Bybee, 2013; Falloon et al., 2020; NRC, 2012). STEM instruction, which is defined to include instructional practices that support learning, has emerged as the vehicle for promoting STEM literacy in K–12 contexts worldwide.

In this paper, we describe teacher outcomes and perceptions associated with a STEM PL initiative (known as STEM PL) that was guided by prior research. We examined changes in teachers' beliefs (self-efficacy, confidence, and importance), use of STEM instruction, and PCK after participating in 1 year of intensive PL. We selected these outcomes as a focus of this paper because previous research, which we describe later, shows that they are responsive to STEM PL initiatives. In addition, we report on findings from focus groups conducted at the end of the school year highlighting themes about teachers' perceptions of student outcomes, as well as tensions related to implementation. Finally, we share overarching conclusions that inform future work in STEM PL initiatives.

Factors Influencing Teacher Implementation of STEM Instruction

Programmatic efforts to enact STEM instruction have been successful both in the United States and internationally (Freeman et al., 2019; Kayan-Fadlelmula et al., 2022; Lynch et al., 2018). Findings support positive outcomes for achievement and affective characteristics for students overall and when disaggregated by underrepresented groups (Bicer et al., 2014; Erdogan & Stuessy, 2015; Gourgey et al., 2010; Wiswall et al., 2014). However, STEM instruction is not always implemented as intended or with the desired outcomes (Ejiwale, 2013; Hu & Guo, 2024; Johnson, 2012).

As we focus on teacher factors identified in existing work, several characteristics emerge as contributors to teachers' willingness and ability to implement STEM instruction. These factors include but are not limited to teacher beliefs (i.e., self-efficacy, confidence, importance) and PCK. We expected to observe increases in participating teacher beliefs and PCK.

Teacher Self-Efficacy

Informed by Bandura's social learning theory, Bleicher (2004) found that self-efficacy relates to teachers' beliefs that an action will have a favorable result (outcome expectation) and that they can perform the action successfully (self-efficacy expectation). Teachers with higher self-efficacy for teaching are more likely to implement innovative, evidence-based instruction (Tschannen-Moran & McMaster, 2009). Existing research shows that teacher self-efficacy is responsive to discipline-specific PL (Nadelson et al., 2013; Ross & Bruce, 2007; Tschannen-Moran & McMaster, 2009). Students in classrooms with teachers who report higher self-efficacy demonstrate statistically significant higher achievement (Guo et al., 2012).

Teacher Confidence in Implementing STEM

In this study, we consider teacher *confidence* in implementing STEM instruction, whereas, we consider teacher *self-efficacy* as related more broadly to teaching science. Existing work supports that teacher confidence is an important factor in changing their instruction that ultimately influences student outcomes (Munck, 2007; Nadelson et al., 2013). Teachers who are more confident in their ability to implement STEM instruction are also more likely to incorporate inquiry-based instruction, whereas other teachers express hesitation and doubt (Nadelson et al., 2013). In addition, teacher confidence in teaching STEM is responsive to PL. Nadelson et al. (2013) observed a statistically significant increase in teacher confidence with an effect size of.48 following a 3-day PL experience focused on teacher STEM confidence.

Teacher Perceptions of the Importance of STEM Instruction

Following STEM PL, teachers often experience unanticipated challenges in translating STEM practices to their specific contexts (Kelly et al., 2015). Teachers who believe in the importance of STEM tend to overcome those challenges more efficiently compared to other teachers (Allen et al., 2016). As such, viewing STEM as important is especially critical when teachers encounter colleagues, parents, or school leadership who are less knowledgeable about STEM. Because teachers tend to transfer their beliefs to students, those who view STEM as important are more likely to encourage their students to view STEM as important, as well (Deemer, 2004).

Teacher Pedagogical Content Knowledge (PCK)

Content knowledge (CK) is defined as content-specific knowledge about a discipline, whereas PCK is defined as the knowledge needed to integrate the CK and appropriate pedagogy for teaching that discipline (van Driel et al., 1998). This type of knowledge is necessary to make learning accessible to students. Existing research demonstrates a strong connection between teachers' science and mathematics PCK and student academic achievement (Baumert et al., 2010; Gess-Newsome, 2013; Keller et al., 2017). Teachers with stronger PCK are more likely to engage students in cognitively complex tasks during instruction, rather than focusing on lower-level procedural tasks (Baumert et al., 2010). A meta-analysis found that STEM PL, emphasizing both CK and PCK, increased student academic achievement (Lynch et al., 2019).

In the intensive STEM PL initiative we implemented, subsequently referred to as STEM Academy, we intentionally focused on intervening in the malleable factors of teacher beliefs (i.e., self-efficacy, confidence, and importance), PCK, and teachers' use of STEM instruction. The ultimate goal was to improve student achievement. We report on the teacher outcomes and perceptions in this manuscript, based on teachers' participation in STEM Academy.

About STEM Academy

This study focuses on science teachers for middle-grade students in a large southern city in the United States. The city's school district serves over 150,000 students—a majority of whom are economically disadvantaged (86%) and identify as students of color (95%). Despite the close proximity to high-paying STEM career opportunities, an alarming 14% of the school district's Grade 10 students expressed interest in pursuing STEM-related careers in 2015. District personnel recognized a need to increase middle school student interest in STEM.

With district personnel support, university educators designed and implemented STEM Academy, in which teachers participated for up to 3 years. As a part of STEM Academy, teachers engaged in (a) summer coursework; (b) individual coaching; and (c) school-based professional learning community (PLC) meetings. To support implementation at each participating school, a school-based STEM leader also engaged in (a) summer coursework; (b) individual leader coaching; and (c) school-based PLC meetings.

Summer Coursework for Teachers

STEM Academy included 90 hours of coursework each summer (20 hours of online coursework and 70 hours of face-to-face coursework). Teachers earned six university credit hours each year that they participated in the summer coursework.

STEM Academy online coursework was divided into "10 hours before" and "10 hours after" the face-to-face coursework. The initial 10 hours provided teachers with an introduction to STEM instruction with an emphasis on inquiry-based instructional approaches, including *project-based learning* (PBL; Capraro et al., 2013; LaForce et al., 2014) and *maker-based instruction* (MBI; Bevan et al., 2014; Krummeck & Rouse, 2017; Sang & Simpson, 2019). The 10 hours of online coursework after the face-to-face coursework provided teachers with an opportunity to collaborate virtually (e.g., sharing units and assessments).

During STEM Academy face-to-face coursework, teachers engaged in activities focused on PBL and MBI using the *BSCS 5E Instructional Model* (Bybee, 2015). University instructors facilitated teacher engagement with PBL and MBI units and materials in ways that teachers could modify and use with their students. For example, teachers developed solutions to traffic congestion in the city using an MBI sprint; that is, exploration, skill building, and challenge (Krummeck & Rouse, 2017). To encourage student risk-taking and entrepreneurial mindset, teachers engaged in engineering design and technology integration using tools such as Tinkercad™ (a free web app for 3D design, electronics, and coding), 3D printers, and laser cutters. Teachers collaboratively developed PBL units based on their grade level content standards, which also connected to student interests and their local communities. University instructors encouraged teachers to integrate collaborative real-world problem-solving (Freeman et al., 2019; LaForce et al., 2017; Sahin, 2019), and 21st-century skills, such as communication, critical thinking, cultural competence, and creativity (NRC, 2012, 2014).

University instructors and industry experts led STEM Academy face-to-face coursework. The university instructors emphasized accurate and rigorous disciplinary content knowledge. For example, a mechanical engineering professor facilitated a PBL unit focused on the physics of rocketry. Through this experience, teachers were exposed to detailed explanations of the underlying physics principles. Similarly, industry experts facilitated content-rich field experiences, emphasizing content knowledge and STEM career connections. During field experiences, which were part of the summer face-to-face coursework, teachers visited local STEM community resources such as the city zoo, a natural river sanctuary, an aeronautics museum, or the city transportation center.

Teacher Coaching Sessions

Teachers often need additional support during the school year to implement knowledge learned during summer PL (Kraft et al., 2018). Therefore, during each school year, teachers participated in up to *seven* one-on-one coaching sessions with one of five university-based instructional coaches. The coaches were either full-time university staff or graduate students—all of whom had experience as science or mathematics teachers and who engaged in intensive, ongoing coaching training facilitated by a lead coach. To maintain consistency, one instructional coach was assigned to support all of the teachers within a school. Teachers earned one additional university credit hour each year they participated in coaching.

During each coaching session, teachers engaged in a *pre-lesson conference*, an *observation*, and a *post-lesson conference*. The pre-lesson conference occurred before the coach conducted the observation. The post-lesson conference occurred after the observation. During the observation, coaches used a systematic tool called *STEM Teacher Observational Protocol* (STEM TOP; Adams et al., 2019). Researchers designed STEM TOP, based on the summer coursework, which they used to help provide structure to the observations. Additionally, coaches used a *pre-lesson conference* and *post-lesson conference* discussion framework to guide questioning and feedback. During these conferences, university-based instructional coaches emphasized the outcomes of this study. These outcomes included teacher beliefs (i.e., self-efficacy, confidence, and importance) and use of STEM instruction. To encourage consistent and high-quality coaching experiences for teachers, coaches met monthly as a group to re-calibrate STEM TOP, share feedback strategies that worked well, and problem-solve implementation issues.

Teacher and Leader PLCs

In addition to one-on-one coaching, the university instructional coach assigned to each school was responsible for facilitating up to seven PLCs—approximately monthly—with participating teachers and the school-based

STEM leader. School-based PLCs provided intensive and sustained opportunities for teacher collaboration and planning with the university instructional coach and the school leader. University instructional coaches designed the PLCs to extend the summer coursework in ways that connected to each school's needs.

Summer Coursework for Leaders

School-based STEM leaders—typically assistant principals—engaged in up to 35 hours of summer coursework, as well as seven one-on-one coaching sessions with one of the university instructional coaches. Combined, these PL experiences focused on (a) defining and supporting STEM education in middle schools; and (b) facilitating science PLCs.

In this study, the primary components of STEM Academy included summer coursework, one-on-one coaching, and school-based PLCs for both teachers and school-based leaders. Prior to the study, we hypothesized that the intensive summer coursework and coaching would support teachers in developing confidence and self-efficacy for implementing STEM instruction. We expected to observe increases in teacher PCK, given STEM Academy's intensive PBL and MBI coursework, led by academic professionals, as well as content-rich field experiences, led by industry professionals. During each of the 3 years of STEM Academy, the focus of the summer coursework and coaching increased in rigor and depth.

For this paper, we focus on teacher experiences during Year 1 of STEM Academy. As such, leader experiences and perceptions of STEM Academy are not within the scope of this paper.

Research Questions

In this paper, we report teacher outcomes and perceptions associated with participating in STEM Academy. These outcomes and perceptions include (a) teacher beliefs (i.e., self-efficacy, confidence, and importance), (b) use of STEM instruction, and (c) PCK. In addition, we wanted to understand teacher perceptions of student outcomes from participating in STEM Academy, as well as the tensions they experienced when implementing STEM instruction. For the purpose of this mixed methods study, our research questions (RQs) include:

RQ1. Are there statistically significant changes in teacher outcomes associated with participating in STEM Academy, including:

- Teacher beliefs (i.e., self-efficacy, confidence, and importance) based on teacher surveys;
- Use of STEM instruction, based on an observational measure and a teacher survey; and
- PCK, based on a teacher survey?

RQ2. What are teacher perceptions of student outcomes of STEM instruction?

RQ3. What tensions emerge in teacher implementation of STEM instruction?

Methods

We employed a simultaneous mixed methods research design. We collected quantitative and qualitative data simultaneously, and we used the qualitative data to help us understand the quantitative trends (Tashakkori & Teddlie, 1998).

Participants

Our study focuses on 44 middle school science teachers in 14 middle schools who participated in Year 1 of the 3-year STEM Academy. During 2017–2018, 15 middle school science teachers participated in Year 1 of STEM

Academy; during 2018–2019, an additional 29 middle school science teachers participated in Year 1 of STEM Academy. The Appendix shows descriptive characteristics for the teachers who engaged in STEM Academy. Teachers were mostly females (70%) of color (23% identified as White), and relatively evenly distributed across Grade 6 through Grade 8.

On average, these teachers taught in schools attended by more students who identified as Hispanic (74%) or Black (22%) and fewer students who identified as White (3%). Across the schools, 50% of the students were identified as English Learners. Student proficiency, as measured by the state accountability test, was low. In 2016–2017, the year before the program started, 27% of Grade 6 through Grade 8 students met proficiency in reading; 27% of Grade 6 through Grade 8 students met proficiency in mathematics; and 31% of Grade 8 students met proficiency in science.

Student achievement as an outcome is beyond the scope of the current paper. Because STEM Academy was implemented in 14 of the 47 middle schools in the school district (i.e., not all of the middle schools in the district), it is not possible to use the district-level student achievement data as an outcome measure demonstrating the effectiveness of the program.

Teacher Survey Measures

Teachers completed surveys that focused on their beliefs about STEM. They self-reported frequency-of-use of STEM instruction at the beginning, middle, and end of STEM Academy Year 1, and a measure of PCK at the beginning and end of Year 1. Teachers completed surveys via an online platform (Qualtrics, Provo, UT).

The Science Teacher Efficacy Beliefs Inventory (STEBI; Bleicher, 2010; Riggs & Enochs, 1990) measured teachers' *self-efficacy* for science teaching. Teachers respond to 25 items on a 5-point Likert scale (i.e., strongly disagree, disagree, uncertain, agree, strongly agree). Developers of the survey identified two scales based on exploratory factor analysis. The two subscales included student–teacher outcome expectancy (STOE; α =.77) and personal science teaching self-efficacy (PSTE; α=.92). In this study, we used the overall score and the two subscales. Depending on timepoint, we calculated Cronbach's alphas (α) ranging from.65 to.85 for STOE and.81 to.89 for PSTE, supporting that teacher response patterns were consistent with previous work.

The STEM Perceptions, Practice, and Culture Survey (STEM PPC) measured teachers' perceived *confidence* in and the *importance* of STEM instruction and their self-reported *frequency* of use of STEM instruction in their classrooms. STEM PPC includes 27 commonly adopted STEM practices and builds on a previous measure of teacher STEM beliefs, as well as existing research on evidence-based instructional practices (White, 2015). Examples of these evidence-based instructional practices include "Instruction allows students to connect science concepts to real-life situations," and "Lessons expose students to information about STEM careers."

Teachers responded to each STEM PPC item on a 4-point Likert scale indicating the extent to which they (a) were confident implementing the practice (i.e., not confident at all, not confident, confident, very confident); and (b) believed that the practice is important (i.e., not important at all, not important, important, very important). In addition, teachers indicated the frequency with which they used the practice on a 6-point Likert scale (i.e., less than one time per month, one time per month, two to three times per month, one time per week, two to three times per week, every day). This researcher-developed tool was supported with a clustered confirmatory factor analysis and Cronbach's alphas (α =.94 for importance, α =.95 for confidence, and α =.93 for frequency).

The Pedagogy of Science Teaching Test (POSTT; Cobern et al., 2013) measured teachers' PCK. On each item, teachers read a vignette describing a classroom situation. Teachers responded by selecting the most appropriate instructional recommendation for the situation. The responses were categorized into four pedagogies, including didactic direct, active direct, guided inquiry, and open inquiry. Each response was scored on a 4-point Likert scale (1 for didactic direct to 4 for open inquiry). Cobern et al., (2013) conducted a pilot study, which did not identify outliers and indicated adequate variability in teachers' responses to the items. We selected 10 items for the pre-test and 10 items for the post-test, which focused on middle-grade science content.

Teacher Observational Measure

During each of the seven coaching cycles, coaches completed STEM TOP, which includes 22 items that are organized into two scales: STEM Instruction (α =.92) and Classroom Management (α =.90). A clustered exploratory factor analysis supported the use of the scales. Coaches rated each item on STEM TOP using a 4-point Likert scale (i.e., not observed, emerging, proficient, or exemplary).

We developed STEM TOP as a snapshot of teacher implementation of STEM instruction, based on STEM Academy PL and informed by existing observational measures, such as the UTeach Observation Protocol (UTOP; Walkington & Marder, 2015). A lead coach and a researcher trained the coaches on STEM TOP. The researcher monitored score reliability statistics following training and throughout the school year. Instructional coach scores matched the expert score exactly, or within one, 75% of the time following initial training and 98% of the time near the end of the school year.

We tested for significant changes across three time points on the STEBI and STEM PPC and six time points for STEM TOP using repeated-measures analysis of variance (ANOVA). We analyzed POSTT responses using a paired sample t-test across two time points. Post-hoc analyses were conducted.

Focus Groups

Following Year 1 of STEM Academy, 10 of the 15 STEM Academy teachers (in 2017–2018) returned the following summer in 2018. These teachers participated in semi-structured focus groups, which were designed to elicit their perceptions of STEM Academy. This sampling method resulted in a purposive sample (Teddlie & Yu, 2007). This sample may have introduced bias because returning teachers were likely more engaged in STEM Academy than non-returning teachers.

During Year 2 of STEM Academy, three to four teachers participated in one of three 1-hour focus groups, which were audio recorded and transcribed. Two interviewers with knowledge of the program, but who were not directly involved in the implementation during Year 1, conducted the focus groups using a semi-structured protocol. The focus group protocol included questions focused on teachers' general perceptions of STEM Academy, such as "In general, how would you describe STEM Academy?" and "What aspects of the program stand out most as the most helpful to you?" The protocol also inquired about teachers' specific experiences implementing PBL or MBI. Following the focus groups, each interviewer completed a memo outlining possible themes and emerging ideas.

Two of the study's authors analyzed the transcribed focus groups using multiple case study analysis—viewing each focus group as a case (Stake, 2006). This framework was selected to link together several cases in STEM Academy across a common experience. The first coder is a former elementary school teacher with a PhD in educational evaluation. The second coder has experience in higher education administration with an MEd in higher education. As such, the coders bring different perspectives to data analysis.

Four steps were used for analysis, including coding, writing focus group summaries, conducting cross-group analysis, and generating themes. The two researchers coded transcripts using a priori and emerging codes using NVivo 12 (QSR International, 2018). The average kappa (κ) coefficient was.42 with an average of 95% agreement. Agreement rates ranged from 77% to 100% depending on the code. During coding, the researchers generated annotations and memos pertaining to possible themes.

Results

The quantitative results focus on 34 of the 44 teachers who completed the survey measures across three time points during Year 1 of STEM Academy. We tested for significant changes across three time points on STEBI, STEM PPC, and STEM TOP using repeated-measures ANOVA. We analyzed POSTT responses using a paired sample *t*-test across two time points. Post-hoc analyses were conducted. Because we were missing responses from some teachers on the POSTT, the sample size for the *t*-test sample (n = 22) is smaller than the ANOVA sample (n = 34). We collected data using STEM TOP starting in the 2018–2019 school year; as such, STEM TOP data are only available for 23 of the 44 teachers. The qualitative results focus on 10 of the 44 teachers, who were purposively selected to participate in focus groups.

Changes in Teachers Beliefs, Implementation, and PCK

To address RQ1, the Appendix shows the results of an ANOVA for teacher beliefs (i.e., self-efficacy, confidence, importance), self-reported frequency of use of STEM instruction, and a paired sample *t*-test for PCK. We hypothesized that participating teachers would increase across time in their beliefs, frequency of use of STEM instruction, and PCK. The results of the ANOVA were statistically significant for importance, confidence, and frequency of use based on teacher self-report; however, post-hoc Tukey pairwise comparisons of the means indicated that the changes in scores between time points were *not* statistically significant at p <.05 after correcting p-values for multiple comparisons. The results of the *t*-test indicate that teachers did not increase their PCK. Contrary to our hypothesis, changes in teacher beliefs, self-reported frequency of use of STEM instruction, and PCK did not change significantly.

The Appendix also shows the results of statistical significance testing using an ANOVA based on STEM TOP across six observations, which were available for all teachers. Similar to the results for the other measures, the results of the ANOVA for STEM TOP showed no significant changes in scores. We examined teacher responses during focus groups to better understand these findings.

Teacher Perceptions of STEM Instruction

Related to RQ2, we examined teacher perceptions of STEM instruction. Three themes emerged based on an analysis of teachers' focus group responses.

Most Teachers Noted Increased Student Engagement During STEM Instruction

Seven of 10 teachers emphasized that STEM instruction encouraged student engagement in the learning process and contextualized problem-solving. These observations are consistent with the intended outcomes of STEM instruction. In general, teachers discussed the fun and engaging aspects of STEM instruction, using words like "enjoyable," "interesting," and "inspiring." One teacher described a PBL lesson saying,

> I took the kids outside. We were learning about micro-habitats and seeing these little ants in their schoolyard outside. ... We went outside with field equipment. We had thermometers. ... I was open to them just learning and experiencing and coming to their own conclusions and critically thinking. [Before participating in STEM Academy], I probably would have never taken them to the schoolyard. I thought they'd all run away. They didn't run away. Only a couple did, and I caught them. It made me more open to letting them learn in an informal learning area.

Not only does this quote point to the teacher's perception of the increased engagement but also to the role of student-centered inquiry instruction in fostering students' ability to make meaning of their learning experiences and deeply engage in the learning process.

Although teachers emphasized student engagement, their explicit reference to student understanding of the content standards was notably absent. Focus group teachers did not specifically reference the content standards, nor did they describe a benefit as improving students' content knowledge. Although teachers likely made connections to content during STEM instruction, they did not emphasize those connections during the focus groups.

Some Teachers Emphasized Student 21st-Century Skills Development

Six of 10 teachers described implementing lessons where they incorporated STEM instruction. Through these lessons, teachers promoted 21st-century student skills development in collaborative learning and increased communication. These STEM instruction outcomes help students develop behaviors and characteristics that are consistent with STEM professionals in developmentally appropriate ways.

Teachers noted that collaborative learning makes their students "better people and helps them grow" in nonacademic ways. For example, one teacher said, "We can block out everything that's going on outside of here. Even if you don't love science, I want you to love being curious about life." Two teachers specifically described an activity where students provided one another with feedback on a project using "I like" (a compliment), "I wish" (a critique), and "I wonder" (a recommendation), which was an instructional strategy recommended by the university instructional coach. One of the teachers said that she was impressed that students who usually speak "aggressively" were encouraging of others and provided positive feedback.

Some Teachers Described Student Question and Explanation Role Changes

Five of the 10 teachers described a shift in the role of student questions and explanations as a result of implementing STEM instruction. Teachers wanted to see and hear more student thinking, which illustrates the teachers' revised role as facilitators of learning. One teacher said she used student explanations to monitor understanding because: "You're able to see I know this child got it because he can explain this better than I can … in his own words or to his peers."

Teachers also said that questioning and explaining allowed students to take "responsibility" and "ownership of their learning." One teacher said:

> We've been trained and we're being untrained [by STEM Academy] from providing students with knowledge and then watching them process that knowledge to regurgitate what we've told them. This [STEM instruction] is flipping that on its head and saying let's find out what our students know. Let's see what they can learn when we give them certain materials and tools, we can guide them along the way.

This teacher's perspectives exemplify the role of facilitator and point to the benefits of student learning and engagement.

Tensions Related to Teacher Implementation of STEM Instruction

Related to RQ3, we observed three primary themes that underlie the tensions teachers experienced in relation to their ability to implement STEM instruction, which include teacher beliefs about students, differences in ideologies and instructional visions, and access to resources. We looked at the focus group responses to understand why quantitative evidence indicated that teachers did not increase their use of STEM instruction.

Teacher Tension/Uncertainty About STEM Instruction: Is it Appropriate for Students?

In response to various questions during the focus groups, six of 10 teachers grappled with their beliefs about student capabilities and their desire to implement STEM instruction. Several teachers were not convinced that STEM instruction was appropriate in their classrooms with their students. Specifically, teachers expressed concerns that their students could not be successful in a STEM classroom due to challenges such as lack of motivation. One teacher explained:

> My students have a lot of other things to deal with. They don't care. They're here because they have to be, so how do you foster that curiosity? Too often, confusion [related to using PBL] inevitably leads to defeat, and then they just don't want to do it.

This response illustrates teacher perceptions of a lack of interest by students. It also implies that the teacher was hesitant to implement STEM instruction because of her beliefs about her students' capabilities.

Other teachers noted changes in their perceptions of students based on their use of STEM instruction. For example, one teacher described an "ah-ha" moment regarding her beliefs about students she had during the school year:

> [Using STEM instruction] made my faith in my students greater, and my belief in their abilities has improved especially with the lower socio-economic demographic we work with. We have language barriers, reading skill levels can be low. There are so many challenges that statistically tell us that they can't do it. Then to give them the tools and the structured freedom to do it, to see them succeed, even incrementally succeed is mind-blowing. Oh my Gosh, I've underestimated what they're capable of doing.

This response illustrates the teacher's willingness to implement STEM instruction in her classroom even when she was not sure that her students would be successful.

Teacher Thoughts on STEM Instruction Illustrate Contrasting Perspectives

The responses to the research questions highlight teachers' initial low expectations about student behavior and performance. The teacher's low expectations in the first example were confirmed by her experiences. In the last example, students exceeded the teacher's expectations, and she ultimately recognized that she had been underestimating their capabilities.

Previous teacher responses also illustrate the tension between their beliefs about their students and their own ability to implement STEM instruction with success. For example, when describing experience teaching about micro-habitats on the schoolyard, the teacher expected students to run away and was initially hesitant to allow them to learn in informal settings. Similarly, another teacher noted her surprise when students who usually spoke "aggressively" were encouraging of others.

Teacher and Administration Tensions Related to Instructional Vision Misalignment

Teachers struggled with tensions between their educational ideologies and the vision of high-quality STEM instruction espoused by STEM Academy. These tensions focused on the role of state accountability tests and support from school administrators.

Regarding teachers' philosophy of teaching, some struggled to reconcile STEM instruction focused on inquiry with their preference for teacher-directed instruction. Five of 10 teachers noted tensions with school administrators, saying their school administrators' priorities were not aligned with STEM Academy.

Teachers also described pressures from school administrators to teach what students "need to [know to] pass the state test," rather than implement innovative instruction. Teachers adjusted their priorities to align with their school administration, regardless of their personal vision for their classroom.

Teachers described feeling that they had to "fend for themselves" or that the administrator "didn't know what was going on" with STEM Academy. Another teacher described her school administration's engagement as superficial, saying that her administrator viewed STEM Academy as a "school resume builder" and that the administrator's overall engagement was "not serious." She went on to say:

> STEM Academy was a cute feather in their cap, not realizing this is a big deal for us ... rather than taking this seriously. It felt like a little pat on the head and saying that's cute that y'all are doing that, have fun with that.

In contrast, at least three teachers described administrative support. One teacher said that her school's administrator encouraged "freedom, creativity to kind of do what we want to do. ... I think it's important to have a leader who is involved and dedicated to that."

Tension About Needed Resources to Implement STEM

While some teachers expressed optimism and valued the planning tools provided by STEM Academy, some teachers expressed concerns about the resources (e.g., technology, time) needed to implement STEM instruction. Five of 10 teachers identified resources such as technology, availability of curricular materials, and limited time, as preventing them from implementing STEM instruction.

In general, teachers expressed a preference *not* to have students use technology. This preference was due, in part, to issues related to limited access to devices. In addition, some teachers did not feel confident in their ability to integrate technology. One teacher described using technology as "time-consuming" because access to the technology is limited (e.g., a classroom with one laser cutter), which results in students having to wait their turn. Two teachers preferred hands-on activities for students with "tangible objects" to technology because they believed tangible materials were better suited for encouraging creativity and imagination. Others noted a lack of resources. One teacher said:

> The availability of resources is critical. ... If teachers want to facilitate, but don't have the stuff in place, what are you going to be facilitating? ... We don't even know how to get all these resources, but [STEM Academy] is pointing us in the right direction.

Finally, four teachers described limited planning and implementation time. Some teachers were able to overcome implementation barriers by using planning tools (e.g., 5E Model) introduced during STEM Academy. Teachers said that the 5E Model was "accessible and realistic." Teachers liked that they could partially, rather than fully, integrate inquiry into their lessons using the 5E Model, with one teacher expressing relief saying, "Okay, now I can squeeze [PBL] in little places. It don't have to be a long, drawn out thing."

Discussion

In this paper, we focus on three research questions and highlight important considerations related teacher outcomes that we hope inform the work of others who are interested in designing, implementing, and evaluating STEM PL initiatives. After compiling data, the following observations were made using participant RQ responses:

- Related to RQ1: We did not observe statistically significant changes in teacher outcomes associated with participating in STEM Academy. Notably, after participating in 1 year of an intensive PL that included summer coursework, ongoing individual coaching, and school-based PLCs, changes were not observed in teacher self-efficacy, confidence, importance, use of STEM instruction, or PCK. There was some fluctuation mid-year, but by year end, teachers responded similarly to when they entered the program.
- Related to RQ2: Focus group findings point to positive student outcomes as perceived by the teachers. These student outcomes include increased engagement, development of 21st-century skills, and expansion of students' question and explanation skills.

- Related to RQ3: Findings from the focus groups highlight several tensions, which include: uncertainty about whether STEM instruction was appropriate for their students; misaligned instructional visions across stakeholders; and teacher perceived lack of resources.

In this discussion, we unpack questions about how we can design programs to affect teacher outcomes and ultimately change student outcomes. This study contributes to literature focused on how we affect teacher outcomes and why intended outcomes are sometimes not observed.

Intervening Factors

As a part RQ1, we targeted research-based factors that support implementation of STEM instruction, including teacher beliefs (i.e., self-efficacy, confidence, importance) and PCK. Although not a focus of this paper, STEM Academy also targeted school leaders' understanding about STEM instruction. In our findings, two factors emerged that were not targeted in this study nor as a part of STEM Academy: teacher beliefs about students and school administrator beliefs about STEM instruction.

Our findings suggest that teacher beliefs about students are important for changing their instruction and ultimately their students' outcomes. Teachers expressed uncertainty about whether STEM instruction was appropriate for their students, suggesting low student expectations due to a high percentage of economically disadvantaged, low-performing students of color in an urban setting. Student sociodemographic factors can negatively influence teachers' collective belief that they can change student outcomes (Cherng, 2017; Liou & Rotheram-Fuller, 2019; Papageorge et al., 2020).

Existing research supports that teacher beliefs about their students are malleable with targeted and intensive intervention, but that these beliefs are often dependent on the contexts in which teachers work (Brault et al., 2014). *We recommend that future programs focus on confronting systemic biases and integrating an assets-oriented framing to understand what students uniquely contribute to the classroom* (García & Guerra, 2004; Gonzalez et al., 1995).

Teachers need systemic support from school administrators to change their instruction (Camburn et al., 2003). Our findings suggest that teachers may be more likely to see the benefits of STEM instruction for their students if their school administration is supportive. Half of the teachers in this study did not perceive their school administrators as genuinely supportive of STEM Academy. Teachers who felt supported by their administrators described freedom to implement innovative instruction. Our findings are consistent with existing work demonstrating the importance of school administration in implementing STEM instruction (e.g., Lessing et al., 2019).

Given the variability in administrator support, it follows that their implementation of STEM instruction also varies. Moreover, several teachers expressed disparate views about teaching from those that are espoused in STEM instruction. In instances where these teachers were in schools that lacked strong administrator support, their implementation of STEM instruction was likely further diminished. *We recommend that future programs consider involving school administrators in participatory co-design during the program development phase* (Fishman et al., 2007). This process equitably involves school administrators in the development of the program.

Related to RQ2, teachers described improved student engagement, student questioning, and student explanation, but overall implementation of STEM instruction did not increase across the school year. We observed evidence that teachers adopted STEM instruction focused on 21st-century skills, such as critical thinking and communication, more quickly than PBL or MBI. These skills might be a good entry point for teachers as they explore implementing STEM instruction in their classrooms.

STEM TOP may not have been sensitive to the ways in which teachers used 21st-century skills in their classrooms. This may explain why we did not observe changes related to RQ1. The measure focused more on implementing PBL and MBI, which seemed to be a large leap from the type of instruction teachers typically implemented prior to STEM Academy. *We recommend including classroom observational measures that capture a wide variety of STEM instruction with an emphasis on 21st-century skills.*

Teacher and School Readiness

Our findings related to RQ3, which focused on tensions in implementation, suggest that some teachers may be more ready to change their instruction than others. Six of 10 focus group teachers were hesitant to implement new instructional practices unless they were certain that the practices would result in improved student outcomes. Five of 10 focus group teachers were concerned that STEM instruction would not translate to high performance on the state accountability test. We recommend future programs consider including a measure of teacher readiness for STEM instruction, which might be a baseline observation. Moreover, *we recommend including measures of school culture to understand the extent to which teachers feel supported by school administrators in implementing innovative practices and taking instructional risks.* Results from these types of instruments may provide program developers with information about teacher and school readiness to implement STEM instruction. Program developers can then scaffold teachers' entry to STEM instruction and provide targeted intervention, as needed.

COVID-19 presented challenges for educators who were implementing STEM education. Teachers were forced to rapidly shift to online or hybrid learning environments. Upon returning to the classroom, educators have faced low student attendance rates (Kearney et al., 2022) and other challenges (e.g., high rates of student and teacher depression; Correa & First, 2021). In addition, the nature of STEM is changing with the introduction of neural network artificial intelligence (Tantawi & Aschcorft, 2022).

STEM Academy offers a model of professional learning that could support teachers who have administrator support and demonstrate readiness to implement STEM education in their classrooms. We found that qualitative evidence may contribute to increased student school engagement, as well as 21st-century skills, including collaboration and communication, all of which are critical to promoting STEM literacy in a post-pandemic context.

Limitations

This study includes a small sample size during Year 1 of STEM Academy. These results may not generalize to other contexts. A limitation of this study is that we do not know if STEM Academy affected the ultimate outcomes, including student achievement and interest. It is possible that STEM Academy affected students positively, even though teacher beliefs, implementation, and PCK did not change significantly. It is also possible that the measures we included in this study were not sensitive to the changes in teacher instruction and beliefs that contributed to changes in students' outcomes. There were likely pockets of success that these aggregated teacher outcomes did not capture.

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Appendix

Table A1. *STEM Academy Teacher Descriptive Characteristics*

Characteristic	2017–2018 # (%)	2018–2019 # (%)	All # (%)
Female	12 (80%)	19 (66%)	31 (70%)
Male	3 (20%)	10 (34%)	13 (30%)
Black	8 (53%)	14 (48%)	22 (50%)
Hispanic	4 (27%)	3 (10%)	7 (16%)
White	3 (20%)	7 (24%)	10 (23%)
Multi-Racial	0 (0%)	3 (10%)	3 (7%)
Asian	0 (0%)	2 (7%)	2 (5%)
Grade 6	1 (7%)	16 (55%)	17 (39%)
Grade 7	9 (60%)	11 (38%)	20 (45%)
Grade 8	9 (60%)	6 (21%)	15 (34%)
All	15 (34%)	29 (66%)	44 (100%)

Note: Eight teachers taught more than one grade level, resulting in percentages above 100% for grade level.

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