Impacting Preservice Teachers' Classroom Practice Through the Development of Coherent Science Teacher Education Experiences

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The release of the *Framework for K-12 Science Education* (NRC, 2012) and the Next Generation Science Standards (NGSS Lead States, 2013) over a decade ago marked a shift to the purpose of K-12 science education. Instead of treating science as a collection of facts to be memorized, science education is now conceived as a deliberate sensemaking process where students engage in scientific practices and construct science ideas to answer questions they have about the natural world (Edelson, 2001; Kanter, 2010; Odden & Russ, 2019). A growing body of research suggests that these reforms in science teaching are more effective in supporting student learning, motivation, and equity than traditional approaches (Beier et al., 2018; Geier et al., 2008; Harris et al., 2015; OECD, 2016; Schneider et al., 2020). However, despite the potential of this reform approach, the process of deliberate sensemaking remains uncommon in K-12 science classrooms (Banilower et al., 2018; Cherbow et al., 2020). One explanation for this trend is that new teachers often find it challenging to implement reform-based ideas and practices from their preservice science teacher education programs, often reverting to more traditional teaching approaches (Hutner & Markman, 2017; Fulton et al., 2005; Roehrig & Luft, 2004).

Preservice science teacher (PST) education serves as a crucial link between the goals, ideas, and practices outlined in the standards documents and research literature and those commonly implemented in schools (Darling-Hammond, 2014). As a result, it is imperative that science teacher education programs maintain coherence between the university courses promoting this reform vision of science education and the field-based experiences where this vision plays out in schools (Nordine et al., 2021). In general, Darling-Hammond and Oakes (2019) defined a coherent teacher education program as one with a consistent vision of effective

teaching that is revisited across a range of teacher education experiences including university coursework and clinical work in schools. However, efforts to seek coherence between university classrooms and field experiences have remained elusive due to limited connections between these settings and hierarchical relations where the university is positioned as the authoritative source on teaching (Canrinus et al., 2017; Zeichner, 2010; Grossman et al., 2008). As a result, PSTs often receive conflicting images of effective science teaching in their teacher education programs and struggle to bridge the gap between the ideas and practices advocated in their university courses and their practical enactment (Braaten, 2019; Hutner et al., 2021; Allen & Wright, 2014).

One promising strategy to enhance the coherence and effectiveness of science teacher education programs is the use of 'third spaces' (Daza et al., 2021; Zeichner, 2010). Zeichner (2010) described third spaces in teacher education as *hybrid spaces* that bring together university- and school-based teacher educators to equitably share their knowledge of teaching "in new ways to enhance the learning of prospective teachers" (p. 92). Recent research on third spaces, particularly in the context of research-practice partnerships (Coburn & Penuel, 2016), has demonstrated promising results in enhancing the coherence of teacher education programs (refer to Daza et al., 2021 for a scoping review). In this study, we invited interest holders involved in university-based preparation of PSTs (university education faculty, university science faculty, and mentor teachers) to engage in third spaces with the goal to enhance the coherence and effectiveness of their science teacher education programs for PSTs. In these spaces, we employed the Science Teachers Learning from Lesson Analysis (STeLLA) conceptual framework (Roth et al., 2017) to support each university team in fostering a shared vision and language to describe and implement effective science teaching strategies. Over the course of a six-year partnership,

interest holders used what they learned about the STeLLA strategies to improve their own classroom practices and revise their coursework and field experiences in ways that fit the unique needs and infrastructure of their PST program. In this study, we investigated the impact of these conceptual and structural changes on PSTs' classroom practices while student teaching. Further, we explored how the PSTs in each university perceived the effectiveness of their revised programs. Our research questions are:

1. How does preservice science teachers' participation in revised science teacher education programs impact their classroom practices?
2. How do preservice science teachers perceive the effectiveness of their revised science teacher education programs?

Theoretical Framework

Coherence in teacher education

Scholars in teacher education have long recognized coherence as a significant challenge and a vital pathway for improving teacher preparation (Richmond et al., 2019; Grossman et al., 2009; Hammerness, 2006; Darling-Hammond et al., 2005; Zeichner & Tabachnik, 1981). In a coherent program, both university coursework and field-based experiences consistently highlight the same vision and core ideas for effective teaching (Darling-Hammond & Oakes, 2019). In an effort to characterize coherence in teacher education, Hammerness (2006) argued that this construct could be broken down into conceptual and structural forms. Conceptual coherence involves cultivating a 'shared vision' among teacher educators regarding the knowledge, skills, and dispositions that PSTs must develop in their program to become effective teachers (Hammerness, 2006; Tatto, 1996). Conceptually coherent programs provide PSTs with repeated

exposure to a set of mutually reinforcing ideas on effective teaching (Hammerness & Klette, 2015). Structural coherence involves the organizational and logistical alignment of activities, assignments, and experiences across both university and school settings with the program's shared vision (Hammerness 2006; Tatto, 1996). The sequence of courses and the arrangement of field placements in a teacher education program constitute a plan to integrate conceptual and structural coherence in ways that 'deliberately build understanding of teaching over time' (Hammerness & Klette, 2015, p. 8).

In science teacher education, conceptual coherence revolves around a small set of core ideas about teaching and learning that can be used consistently across both university and school contexts (Nordine et al., 2021). The specific core ideas within any given program will differ, but typically involve ‘figuring out' phenomena and problems (e.g., Schneider et al., 2020; Odden & Russ, 2019), motivating a 'need-to-know' through connected storylines (e.g., Reiser et al., 2021; Sikorski & Hammer, 2017), and the incremental development of key explanatory science ideas over time (e.g., Alonzo & Gotwals, 2012; Fortus & Krajcik, 2012). These core ideas are not general commitments to effective pedagogy but rather represent critical aspects of science teaching that have been empirically shown to support student learning (Nordine et al., 2021). In science teacher education, achieving structural coherence requires organizational alignment between the learning of core ideas in university courses and the practical application of these ideas in field-based teaching experiences. In general, science education courses focus on imparting knowledge about reform science instruction, drawing from standards documents, curriculum, and research in the field (Sorge et al., 2019). Field experiences are where PSTs observe and practice reform science teaching through mentor observations, short-term teaching practicums, and long-term student teaching experiences (Alonzo et al., 2019). Ultimately, when

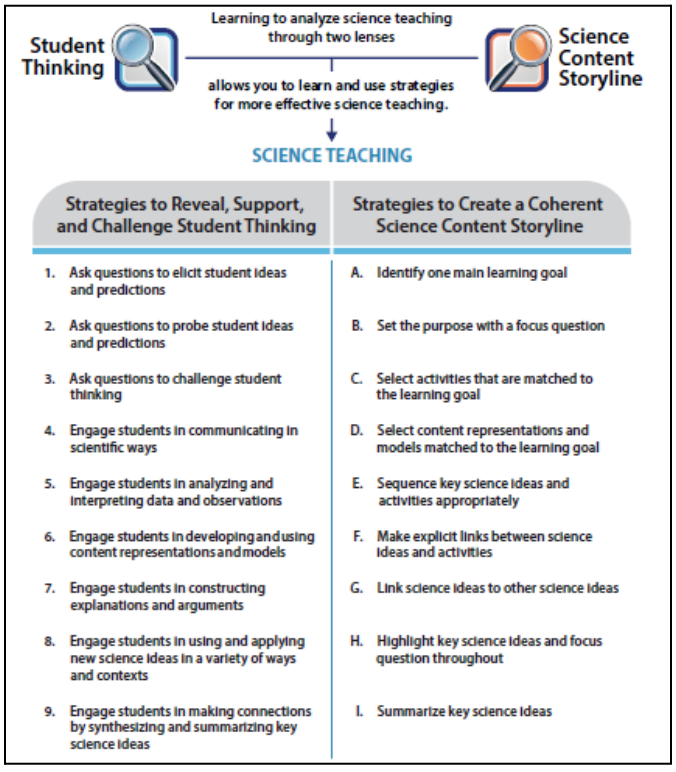
PSTs encounter a consistent set of core ideas about teaching across various contexts, they are more inclined to embody and apply these ideas in their own teaching upon completion of their PST program (Nordine et al., 2021; Hammerness, 2006).

STeLLA conceptual framework

In this project, we employed the Science Teachers Learning from Lesson Analysis (STeLLA) conceptual framework (Roth et al., 2017) to establish core ideas and common language to describe effective science teaching practices. Each university employed this framework to establish conceptual coherence within their program. In general, the STeLLA framework forms the core substance of the broader STeLLA professional development (PD) program. This framework (see Figure 1) consists of two analytical lenses that organize effective science teaching strategies: 1) the student thinking lens and 2) the science content storyline lens.

Figure 1

STeLLA conceptual framework



The student thinking lens is supported by a set of 9 core strategies that help teachers to 'reveal, support, and challenge student thinking' about science ideas and the science content storyline lens consists of 9 strategies to 'create a coherent science content storyline'. In the STeLLA PD program, participants utilize this conceptual framework as they analyze lessons and video of science instruction (Roth et al., 2017). Extensive research underscores the effectiveness of the STeLLA approach in improving teacher science content knowledge, pedagogical content knowledge, and teaching practices. Notable gains in knowledge and practice have been observed for both in-service (Roth et al., 2019; Taylor et al., 2017) and preservice teachers (Wilson et al., 2018) who have participated in the program.

STeLLA CO^2 Project

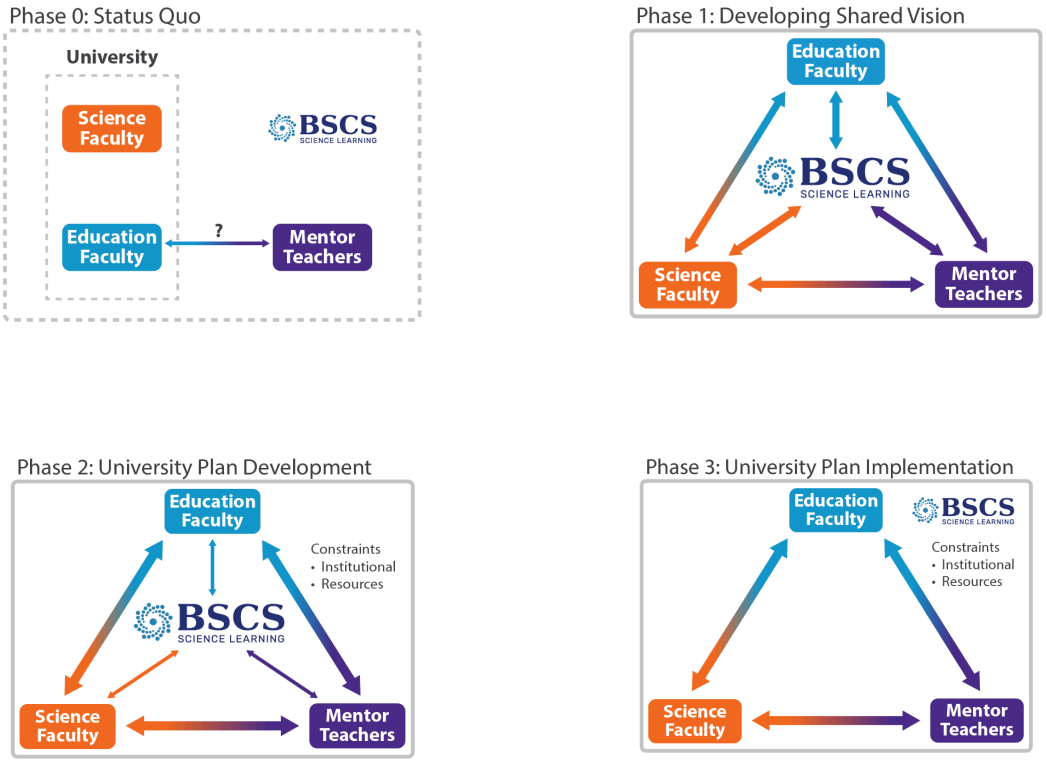
The STeLLA CO^2 project was developed to study how university education and science faculty and mentor teachers (MTs) can work together to improve the effectiveness and coherence of their science teacher education programs. This project fostered third spaces (Zeichner, 2010) for the faculty and MTs at three mountain west universities to equitably collaborate on conceptual and structural revisions to their programs. These teams comprised university science faculty, university education faculty, and MTs, each offering distinct perspectives on science instruction through their teaching. In general, university science faculty develop PSTs' science content knowledge, while university education faculty focus on PSTs' pedagogical content knowledge and use of instructional strategies (Nordine et al., 2021). MTs guide PSTs through their field experiences, providing valuable insights and practical experiences. The STeLLA CO^2 theory of change (see figure 2; Lo et al., 2024) delineates the process through which university faculty and MTs at each university cultivated a shared vision of effective science teaching,

formulated a plan to revise their teacher education program, and subsequently implemented this plan with PSTs.

Phase 0. Phase 0 illustrates the roles typically undertaken by various interest holders responsible for preparing preservice science teachers (PSTs), including those at these three universities. University education and science faculty are connected due to their university affiliation, yet often do not explicitly collaborate to provide coherent learning experiences for PSTs. MTs often work with education faculty or their designates as hosts for PSTs in their classrooms. However, this relationship may not always be equitable. University education faculty usually define the parameters for fieldwork, and MTs are responsible for implementing these parameters with PSTs in their classrooms. Additionally, MTs may lack insight into university-level activities or mechanisms to offer feedback on PST programs.

Figure 2

STeLLA CO² Theory of Change



Phase 1. In Phase 1, university faculty and MTs, engaged in synchronous and asynchronous professional learning (PL) facilitated by BSCS staff over a four-month period. The Phase 1 representation illustrates the crucial role played by BSCS staff in organizing each university team and cultivating a community of practice among interest holders who may have previously operated in isolation. Our collaborative professional learning aimed to cultivate a shared vision for effective science teaching and learning, leveraging the STeLLA conceptual framework. Participants engaged in video analysis, examining both their own and other teachers' teaching for the implementation of STeLLA strategies. They also explored how to integrate the STeLLA strategies into their own teaching practices. Ultimately, this phase strengthened the relationships between university faculty and mentor teachers, fostering a shared language and set of core ideas about effective science teaching that each university team could utilize in planning and implementing changes to their teacher education programs.

Phase 2. During Phase 2, BSCS staff facilitated discussions among university team members to assess the integration of their shared vision for effective science teaching throughout various aspects of their teacher education program. Each team developed plans to improve the effectiveness and coherence of their programs given institutional constraints and available resources at their university. A core feature of this phase was to establish all team members as equal partners, valuing their unique perspectives and expertise, and allowing for the adoption of new roles in teacher education. For example, MTs could help co-design revisions to university courses with faculty, or university science faculty might integrate more reform-based pedagogy into their courses to align with the team's vision of effective science teaching. The phase 2 representation illustrates the collaborative effort between university faculty and mentor teachers to develop a university plan. Each university team, led by one or more members, had the

autonomy to use their acquired knowledge to revise their programs according to their specific needs. Each team was allocated financial support from BSCS to develop, implement, and sustain their plans. Meanwhile, BSCS continued to play an important, albeit more limited, role in this planning process. Each team was assigned a BSCS staff member who served as an advisor. Their role was to ensure that all team members' contributions were heard and respected, and to guide the planned work toward developing more coherent learning experiences for PSTs.

Phase 3. In Phase 3, each university team implemented their plans to enhance the coherence and effectiveness of their science teacher education programs. Phase 3 unfolded over an extended period as teams translated their plans into action, revising them as they implemented their programmatic revisions with PSTs. BSCS staff continued to serve in an advisory capacity, monitoring the progress of each team, but did not take on a central role in implementing the plans of each university. The intended outcome of this phase was to enact plans that enhanced conceptual and structural coherence of each program, utilizing the STeLLA framework in university courses and field experiences. Additionally, sustainability was an important aspect of this phase as team members reflected on how their work impacted PSTs and considered how to continue the most important parts after the conclusion of the project. They considered how key decision-makers outside of their university teams, such as department chairs or school administrators, could be briefed on their work and allocate resources to sustain key components of the team's efforts in the future.

Methods

This study employed a mixed methods multiple case study design (Stake, 2013), in which each participating university (n = 3) is conceptualized as a 'case'. The purpose of a multi-case

study is to compare and contrast cases of the same phenomenon in order to identify emergent patterns and themes within and across cases (Yin, 2017). In this study, we investigated how the revisions made by each university team to their science PST program impacted their PSTs' use of STeLLA strategies in their classroom and their PSTs' perceptions of the effectiveness and coherence of their PST program. Each university team case included both a quantitative measure that characterized the quantity and quality of PSTs' use of the STeLLA strategies and a qualitative measure of PSTs' perceptions of their program, enabling us to compare and contrast the impact of each revised program. In what follows, we provide an overview of each team's intervention (see Lo et al. (2021) and (2024)), before sharing information on the participants, data sources, and means of analysis in this study.

Participants and university context

The three universities that participated in this study were located in the mountain west region of the United States. University A is a large R1 public research university, while Universities B and C are both midsized R2 public research universities. Universities A and B are partners with the UTeach institute. UTeach programs offer a distinctive pathway to secondary science teacher licensure, allowing undergraduate students to obtain a bachelor's degree and an initial teaching license within four years, while graduate students can earn a master's degree along with licensure within two years. These programs focus on ‘'research-based instructional practices' and include practicum components in the majority of courses. In contrast, University C's teacher preparation program entails post-baccalaureate students earning a master's degree and initial teaching licensure in the two years. This program still mandates both short-term practicum and long-term student teaching experiences.

To examine the effects of the program revisions, we recruited PSTs before and after each university team began implementing revisions to their PST programs. This data collection spanned from spring semester of 2018 to the spring semester of 2023. PSTs who completed the original versions of all courses and did not attend the STeLLA CO^2 MT/PST Institute were categorized as the business-as-usual (BAU) group. PSTs who experienced any part of revised versions of the courses and/or attended the institute were classified as the treatment group. In total, we recruited 22 PSTs from University A, 9 PSTs from University B, and 17 PSTs from University C (see Table 1). Due to challenges with low enrollment in PST programs statewide, there were no BAU PSTs at University B.

Table 1

University Teams and PSTs by treatment group

Group	**University A**	**University B**	**University C**	**Total**
University faculty	4	2	5	11
Mentor teachers	9	8	7	24
PSTs	22	9	17	48
BAU	5	0	3	8
Treatment	17	9	14	40

Intervention context

University A. The team members from University A stated that the ideas behind the STeLLA conceptual framework were not entirely new to them and were consistent with elements of their existing classroom practices. However, they found it helpful to develop a common language among interest holders to describe and support PSTs' enactment of effective science teaching practices. University education faculty and mentor teachers collaborated to integrate the

use of the STeLLA framework handbook into several university education courses, including *STEP 2, Classroom Interactions (CI), and Problem-Based Instruction (PBI)*. The team also integrated the STeLLA strategies into their lesson planning template and observation protocol to help PSTs focus on particular areas when planning and carrying out lessons and receive coherent feedback. The team also developed a tool that secondary science students, PSTs, MTs, and observers could use to assess the extent to which students were communicating in scientific ways.

University science faculty integrated what they learned into their undergraduate science teaching. In these classes, undergraduate learning assistants (LAs) provided peer support for fellow undergraduates. The science faculty revised the training for LAs to include an introduction to some of the STeLLA strategies that would help LAs better support student thinking and reasoning rather than merely providing the right answers. Additionally, science faculty and one of our mentor teachers revised a course, *Teaching and Learning Biology*, which was cross-listed in the Biology and Education departments and involved introducing the STeLLA strategies to students who might be interested in teaching biology at the secondary or university level. Lastly, as a team, mentor teachers and education and science faculty designed a three-day workshop to broaden the pool of mentor teachers to host and support PSTs.

Figure 3

University A intervention timeline

University A

Spring 2019	Fall 2019	Fall 2021	Spring 2022	Fall 2022
Pilot new CI, PBI, and STEP 2 courses • STeLLA strategies in Classroom Interactions (CI), Problem-based instruction (PBI), STEP 2 courses	**Pilot lesson planning template and observation protocol** • Infused STeLLA strategies in Lesson planning template (STEP 2, CI) and Observation protocol (PBI)	**Revise CI, PBI, and STEP 2 courses and pilot new T&L Bio course** • STeLLA handbook in STEP 2, CI, PBI courses • STeLLA strategies in Teaching and Learning Biology (T&L Bio)	**STeLLA workshop for Mentor Teachers (MT)** • 3-day STeLLA workshop to familiarize MTs with strategies	**Finalize CI, PBI, STEP 2, and T&L Bio courses** • STeLLA readings, lesson planning template, and observation protocol (STEP 2, CI, PBI) • STeLLA strategies in T&L Bio.

University B. The University B team integrated the STeLLA strategies into their science education courses, including STEP 1/2, Science Research Methods (SRM), Classroom Interactions (CI), and Problem-Based Instruction (PBI). In STEP ½, mentor teachers helped education faculty design and teach course sessions that supported PSTs in learning about the STeLLA strategies. In addition, mentor teachers designed new field experiences through which PSTs could practice using the STeLLA strategies with students in mentor teachers' classrooms. Dissemination of learned ideas was a critical feature of the University B plan, which fostered institutional buy-in and the invitation to integrate the STeLLA strategies into each of the science education courses at University B. The team developed a website to familiarize new mentor teachers with the STeLLA strategies and how to support PSTs.

Figure 4

University B intervention timeline

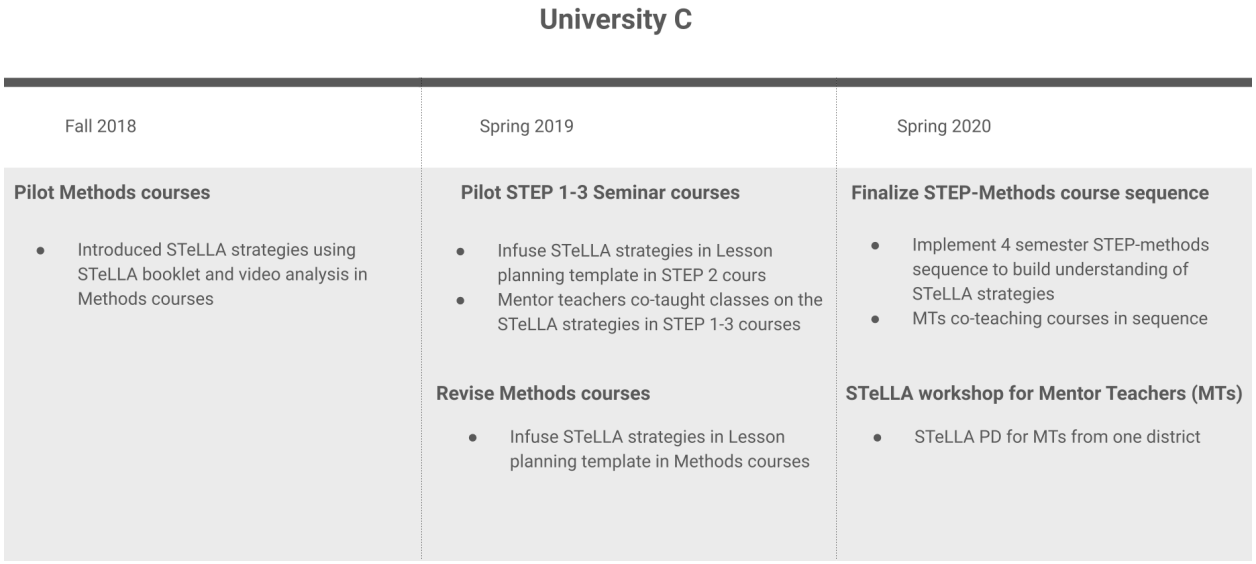
University B

Fall 2019	Fall 2020	Fall 2021	Spring 2022	Fall 2022
Pilot SRM course • Incorporate STeLLA questioning strategies into Science Research Methods (SRM) course	**Revise SRM course** • More integration of STeLLA strategies in SRM course **Pilot STEP 1 course** • Incorporate STeLLA video analysis in STEP 1 course.	**Finalize SRM course** • Integration of new STeLLA strategies (modeling) in SRM course **Revise STEP 1/2 Courses** • Observation, video analysis and classroom practice of STeLLA strategies STEP 1/2 courses	**Finalize STEP 1/2 Courses** • Finalized based on PST course experience in Fall 2021.	**Created Mentor Teacher (MT) website** • Website explaining STeLLA strategies to MTs **Pilot CI and PBI courses** • Incorporate STeLLA strategies In Classroom interactions (CI) and Problem- based instruction (PBI) courses

University C. Science-specific methods courses and practicum experiences at University C were taught and supervised by university science faculty, who specialized in discipline-based instruction and taught university science courses. Thus, University C science faculty shared similar roles as education faculty at Universities A and B. University C had a two-pronged approach for modifying their PST program. First, they redesigned the syllabi for three practicum seminars and the methods seminar course to introduce PSTs to the STeLLA conceptual framework in stages. Multiple rotating science faculty taught the practicum seminars at University C. The team included STeLLA CO^2 mentor teachers as guest instructors to introduce and facilitate discussions around the STeLLA strategies. This approach helped maintain fidelity to the team's vision of effective science teaching and learning while broadening multiple science faculty members' exposure to STeLLA and the video-based resources used to learn the STeLLA strategies. Additionally, University C desired to increase the pool of mentor teachers who were familiar with the STeLLA strategies and could support PSTs' use of the strategies. The mentor teachers designed a year-long professional learning program at a local, large district. However, the program was only partially implemented due to the pandemic.

Figure 5

University C intervention timeline



STeLLA CO^2 MT/PST Institute. In addition to each university's intervention, BSCS led a series of three-day professional learning events for PSTs and their MTs. The STeLLA CO^2 MT/PST Institute engaged PSTs and their assigned MTs in video analysis where they collectively learned about the STeLLA strategies. PSTs attended this institute with their MT at the onset of their student teaching semester. BSCS implemented this series of institutes to ensure that PSTs were paired with MTs during student teaching who were familiar with the STeLLA strategies.

Data sources and analysis

Classroom video. We analyzed videos of PSTs' science instruction from their student teaching to measure changes in PSTs' classroom practice due to revisions to their PST programs.. We collected one full class period of science instruction on one occasion from each treatment PST. The videos were coded using a coding scheme employed in prior STeLLA projects (Roth & Kowalski, 2015; Roth et al., 2019). This scheme documented PSTs' utilization of the STeLLA strategies and assessed the quality of their implementation with students. The

coders involved in this study were the same individuals who participated in prior STeLLA projects, ensuring consistency in coding practices. These coders have achieved interrater agreement with master coders ranging between 0.829 and 0.947 (Roth et al., 2019).

A Rasch measurement model was used to estimate person measures of classroom practice (Bond & Fox, 2013; Boone, et al., 2013). The Rasch model is a probabilistic model commonly employed in educational settings for developing tests and scoring test results. It yields a sample-invariant scale of the construct being tested. In our study, Rasch analysis was utilized to convert the non-linear ratings from the video coding rubric into a linear scale of classroom practice. The "person measure" refers to a scale number representing an individual's performance on the targeted construct, namely the use of STeLLA strategies and the quality of their implementation. Data fit to the model is crucial in Rasch modeling. Due to the small sample size in this study (n=38), we added data from 116 in-service teachers who took part in a previous project. This enhanced the data's fit to the model and facilitated more precise measures of classroom practice. The data were analyzed using Winsteps software (Linacre, 2023). Person measures of classroom practice were reported in logits, with zero indicating the average item measure. Person measures greater than zero signify classroom practices more aligned with STeLLA strategies, while measures less than zero indicate lower-quality implementation of these strategies. The data exhibited a very good fit to the Rasch model, with person and item separation indices of 4.39 and 6.33, respectively, and corresponding reliabilities of 0.95 and 0.98, respectively. Separation indices above 2 and reliabilities above 0.70 are considered desirable.

Preservice teacher interviews. PSTs were interviewed after the completion of their student teaching about their learning experiences, including the sense of coherence in their teacher education program and the extent to which STeLLA strategies were incorporated into

their courses and student teaching. All interviews were recorded and transcribed. To initiate the analysis, we subdivided the treatment category into partial and full dosage levels to gain deeper insights into PSTs' experiences within their teacher education programs. The partial dosage level was assigned to PSTs who received any piloted versions of university courses, while the full dosage level was assigned to PSTs who received fully revised versions of each course (Table 2).

Table 2

PSTs by dosage level

University	**Partial dosage**	**Full dosage**	**Total (Treatment)**
University A	14	3	17
University B	2	7	9
University C	11	3	14

We developed an inductive coding scheme to categorize PSTs' perceptions regarding the effectiveness and coherence of their program, as well as their exposure to the STeLLA strategies. Utilizing thematic analysis, we crafted analytical memos for each university to describe PSTs' perceptions regarding various facets of their program. This included their exposure to and utilization of the STeLLA strategies, the efficacy of their university program and courses, and their experiences with mentor teachers during practicum and student teaching experiences. We conducted cross-case analysis of these memos to identify similarities and differences among the three programs concerning PSTs' perceptions. Finally, when documenting the findings, we made sure to specify the student teaching semester when including quotes from each PST. This approach allows the reader to consider the intervention timeline while examining the interview findings from each university.

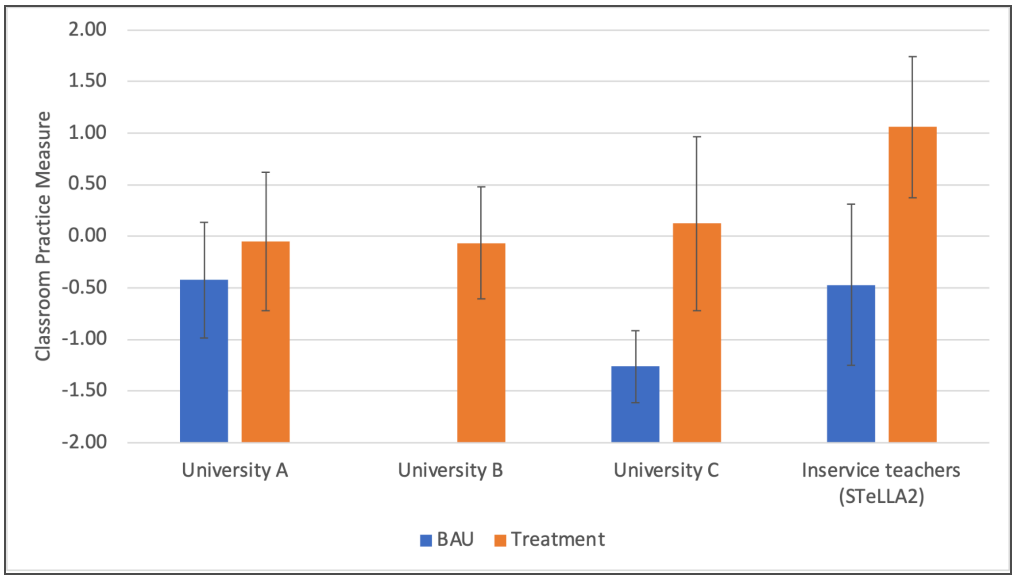
Findings

Classroom practice (RQ 1)

Figure 6 below presents the findings from the classroom practice analysis. There are three sets of bars representing the average classroom practice measure of the BAU and treatment PSTs at each university and one set of bars representing the average classroom practice measure of the BAU and treatment in-service teachers who participated in a previous STeLLA project. University C had the biggest difference in classroom practice measure between the BAU and treatment groups (1.55 logits). A t-test confirmed that this difference was statistically significant ($t = -3.86$, $p < 0.01$). This suggests that the implementation of the university plan impacted PSTs' classroom practice. While University A showed a positive difference between BAU and treatment, it was not statistically significant. We included the average measures of the in-service teachers to contextualize the findings from the PSTs and give more context to University B who did not have any BAU PSTs.

Figure 6

Classroom practice measure bar graph



On average, the PSTs in our study had more aligned classroom practices than the BAU in-service teachers, but less aligned classroom practices than the treatment in-service teachers. We would not expect the PSTs in the current study to have classroom practice measures as high as the treatment in-service teachers because the in-service teachers experienced significantly more STeLLA-related professional learning than the STeLLA CO^2 PSTs. However, it is interesting to note that they are scoring higher than the BAU in- service teachers, even though the difference is not statistically significant.

Perceptions of teacher education program (RQ 2)

University A. At University A, there was an initial focus on inquiry-based teaching and learning in the program. Throughout the intervention, PSTs reported having minimal exposure to the STeLLA strategies during their university coursework and field experiences. However, they were able to identify strategies that were aligned with the STeLLA framework. In the final stages of the intervention, the STeLLA strategies were more explicitly and coherently integrated into education coursework. The level of coherence in feedback that PSTs received from university faculty and MTs remained varied across the duration of the intervention.

Initial emphasis on inquiry. Early in the university team's intervention, the PSTs in this program already expressed a strong focus on inquiry-based approaches to teaching and learning in their course work. For example, PST A1 participated in the program before the intervention (BAU) and expressed her views on the program as follows:

> "*They did a really incredible job of giving us a philosophy that I still carry with me, that students should be engaged in inquiry, students should be doing science in my science classroom.*" (PST A1, Spring 2019)

Similarly, PST A2 shared that the program as a whole "*really does harp a lot on inquiry-based learning and that exploratory learning, which I think is definitely the biggest thing that CU helped prepare me for*" (PST A2, Fall 2019). PST A3 added further nuance to the idea of inquiry in science teaching when he expressed that the primary takeaway from the program was its emphasis on "*phenomena-based learning, and sort of the scientific practices and inquiry that we learned at University A*" (PST A3, Spring 2020). All three PSTs either received no (A1) or piloted portions (A2 & A3) of the university team's intervention plan. However, the programmatic focus outlined by these PSTs had some conceptual coherence with aspects of the STeLLA conceptual framework, such as phenomena-based learning and the utilization of scientific practices.

In particular, PSTs expressed that their Problem-Based Instruction (PBI) and Classroom Interactions (CI) courses were particularly valuable to learn about scientific inquiry and see instructors model these practices in their teaching. For example, PST A4 shared that her PBI instructor "*did a really nice job demonstrating both lesson-planning and questioning strategies, especially with that phenomena-based learning*" (PST A4, Spring 2021). These courses were an initial target for revisions to incorporate the STeLLA strategies, including the use of questioning strategies (elicit, probe, challenge). However, the PSTs described the pedagogical approach used

in these courses as incoherent with the approaches used in their university science and engineering courses. For example, PST A3 described his engineering courses as being in stark contrast to his experiences in his science education courses:

> *"It would just be some grad student with a sack of notes that's been passed down the past 20 years. That he's just like copying on the board. And you're like, wait a minute. Like, we know how to do this. Why isn't there any transfer between the School of Ed and [the School of] Engineering?"* (PST A3, Spring 2020)

In this quote, PST A3 wondered why there was a disconnect between his education courses that modeled inquiry and the traditional and ineffective pedagogy present in his engineering courses. While PSTs uniformly expressed a disconnect between their university education and science courses, their opinions were more varied regarding their field experiences. The extent of coherence between university- and school-based experiences often depended on the level of connection between their mentor teacher (MT) and the PST program. For example, PST A1 had multiple field experiences, and shared that some of her MTs were "*super keyed into the program*" (PST A1, Spring 2019), while others were not as connected to the university. As a result, she often observed conflicting images of science teaching at her field sites. Taken together, there was a strong initial emphasis on scientific inquiry in many of the education courses within the program. However, this focus did not extend consistently to PSTs' university science courses and PSTs' field placements and student teaching experiences.

Exposure to STeLLA-aligned strategies. Throughout most of the intervention, PSTs described learning about instructional strategies that aligned with the STeLLA framework but that were not explicitly labeled as such. PSTs from the initial stages of the intervention expressed that they were largely not taught about the STeLLA strategies. For example, PST A3 shared:

> *"We were never explicitly taught what the STeLLA strategies were. Like I think it was a day. Well, we were... We never sat down with the STeLLA handbook and was like, okay,*

> *this is strategy number one, this is strategy number two, to my knowledge."* (PST A3, Spring 2020)

PSTs like A3 ostensibly received piloted versions of the PBI and CI courses with the integration of STeLLA strategies. However, these PSTs described these courses as having minimal explicit exposure to these strategies. Instead, when reflecting retrospectively on their program, the PSTs identified strategies that were aligned with the STeLLA framework. For example, PST A4 expressed the following about his education courses and instructors:

> *"They didn't say, "These are the STeLLA strategies," but pretty much all of them I had heard before… it felt very much like this is a lot like what [instructor] was talking about in PBI or this was what [instructor] was talking about in CI, or this is what they're talking about even as early as my freshman year when I took Step 1 and sophomore year when I took Step 2, these are ideas that are being floated around for new teachers."* (PST A4, Fall 2020)

In this quote, PST A4 recollected learning about STeLLA-aligned strategies as early as his freshman year in his program. However, he felt that these strategies were not explicitly called out as STeLLA strategies, even as he experienced courses, like PBI and CI, that were revised to integrate these strategies. Even later in the intervention (2021-2022), PSTs still often expressed confusion about which strategies were explicitly STeLLA and which ones were merely STeLLA-aligned. For instance, PST A5 felt she received exposure to STeLLA strategies but was not sure '*what was a STeLLA strategy versus just a strategy*.' Ultimately, she felt the STeLLA strategies were not established as a '*common language and coherency*' across her program. She explained:

> *"We heard a lot about STeLLA strategies, in a lot of our university classes. And they weren't always explicitly called out, as STeLLA strategies, so we weren't having that common language, and coherency throughout all of our courses. Although it felt sprinkled in, around everything. And I think making it more explicit, and making those connections more explicit, and making sure that the mentor teachers, that we're working with, also know that that's explicit, will be something that the university's focusing on, going forward."* (PST A5, Fall 2021)

In this quote, PST A5 shared that the STeLLA strategies were not coherently integrated as common language across her education courses and field experiences. As a result, she described the integration of these strategies into her program as '*disjointed*' and '*ineffective*' (PST A5, Fall 2021). Taken together, for most of the intervention, PSTs expressed learning about inquiry-based teaching strategies that only aligned with STeLLA framework. Over the intervention, PSTs identified more STeLLA strategies in their program, but felt they were not consistently integrated across their education coursework and field-based experiences.

Explicit exposure to STeLLA strategies. In the final stages of the university team's intervention, PSTs expressed more explicit and rigorous exposure to the STeLLA strategies in their program. In particular, several PSTs noted the use of the STeLLA strategies booklet in their PBI and CI courses. For example, PST A6 highlighted specific STeLLA strategies that he learned about in these courses:

> *"I would say there were specific sections that some of my teachers actually did have assigned for readings, and then we did some class discussions on some of those specific topics...like identifying a main learning goal, focus questions. There was a lot on asking questions to get students' ideas"* (PST A6, Spring 2023)

In this quote, PST A6 noted explicit exposure to STeLLA strategies in his education coursework rather than only STeLLA-aligned exposure. Similarly, PST A7 mentioned learning about specific STeLLA strategies in her PBI and CI courses. She shared that she learned "*a lot about elicit, probe and challenge. And the main learning goal and the focus question was all used to plan these lessons*" (PST A7, Spring 2023). Both PSTs noted the focus question and main learning goal strategies as ones they explicitly learned about. These strategies, along with the questioning strategies, were explicit targets in the revisions made by the university team.

In addition to education courses, several PSTs noted exposure to STeLLA strategies in university science courses as well. In particular, PSTs identified the Teaching and Learning

Biology course, which underwent revisions in the Fall semester of 2019 to incorporate the STeLLA strategies. For instance, PST A8 shared that his instructor in his Teaching & Learning Biology course *"basically showed us how to do STeLLA*" and that he "*hammered in a lot of the STeLLA stuff into the teaching itself*" as he taught using "*storyline or a lot of group-based learning, where it's student-led*" (PST A8, Spring 2023). Here, PST A8 noted that his instructor both taught about the STeLLA strategies and modeled them as they engaged in the course. Taken together, PSTs who experienced the final iteration of the intervention expressed explicit exposure to the STeLLA strategies across multiple education and science courses. As a result, they described more cohesive exposure to these strategies in their university coursework.

Varied coherence in feedback. Throughout the intervention, PSTs described varying levels of coherence between the feedback they received from university education faculty and their MTs. Early in the intervention, several PSTs also identified a gap between theory and practice, exemplified in feedback from the university- and school-settings. For example, PST A2 felt that there was "*a little bit of disconnect*" between the *"more progressive, idealistic teaching, ideal scenario"* ((PST A2, Fall 2019), type of feedback he received from university education faculty and the more practical feedback he got from his MT. Similarly, PST A3 expressed the need for more support with the practical aspects of teaching like '*time management in lesson planning*' and '*supporting students with IEPs'* in the feedback he received from university faculty (PST A3, Spring 2020). However, other PSTs, whose MTs were more integrated into the program, described more coherent sources of feedback. PST A9, who experienced some aspects of the intervention, still felt her MT was "*really for implementing more effective science teaching strategies*". As a result, she felt that her practicum-based courses "*worked really well*" and the

feedback she received was "*pretty seamless because everyone was on the same page*" (PST A9, Spring 2021).

Later in the intervention, several PSTs continued to note incoherence in feedback. However, some PSTs were able to use the STeLLA strategies to interpret and mobilize the feedback they received on their instruction. For example, PST A5 felt she was able to use her knowledge of the STeLLA strategies to establish coherence between the feedback she received from university faculty and mentor teachers.

> *"There wasn't a lot of coherence, between my mentor teacher and the university, at this point. I went through the program during COVID, so there was obviously some lack of communication on everyone's part. But knowing the strategies myself, and having the language myself, I could pretty easily reframe whatever my mentors were saying, in a way that made sense in the framework that I had been taught."* (PST A5, Fall 2021)

Here, PST A5 described mobilizing the STeLLA strategies to 'reframe' the feedback from her MTs to be more aligned with the feedback from her faculty. However, her quote implies that she established coherence between feedback sources rather than receiving already coherent feedback. Taken together, PSTs noted varied levels of coherence in feedback based on the experiences of their MTs and their own exposure to and understanding of the STeLLA framework. Those with MTs who were more integrated with the university or who had more knowledge of STeLLA found or made more coherence in feedback between university faculty and MTs.

University B. Early in the intervention, PSTs typically described their education coursework as emphasizing more general ideas about inquiry. As the intervention progressed, PSTs initially described exposure to the STeLLA questioning strategies in one science education course, which was limited to those strategies. Over time, PSTs identified exposure to the strategies in other education courses but described this exposure as fragmented. Generally, PSTs

felt that learning about the STeLLA strategies spurred discussions and use of these strategies in their practicum and student teaching experiences.

General ideas about inquiry. In the initial stages of the intervention, PSTs often described their science education coursework as inquiry-based, but they characterized this work in content-neutral terms. For example, PST B1 described her program as teaching *'a variety of things*', in order "*to reach students, whether it's on technology or hands-on activities or inquiry, or things like that*" (PST B1, Spring 2020). Similarly, PST B1 noted her PBI courses' focus on inquiry through project-based learning was valuable. She explained that she and a partner teacher spent three weeks in a classroom, *"we basically just led students through a project that would teach them some things, but mostly teach them how to show their learning more than actually teach them something"* (PST B1, Spring 2020). In these quotes, the PST noted the benefit of inquiry-based learning in the education course but did not identify any science-specific aspects of inquiry they have learned, such as student engagement with natural phenomena or the use of scientific practices.

As the intervention progressed, PSTs began to discuss more science-specific tools for supporting inquiry with students. However, their description of these tools sometimes still described inquiry practice in general terms. For instance, PST B2 expressed that her use of the 5E lesson plan template facilitated her inquiry work during student teaching:

> *"I think the 5E lesson plan helped a lot to think about engaging them and having them actually... What's the word, what am I thinking? Having them actually do it themselves. So, very inquiry-based. I think that helped tremendously because I never got that when I was in high school or at any grade. So, I feel like that helped me a lot"*
> (PST B2, Fall 2020)

In this quote, the PST described the use of the 5E template, explicitly designed to engage students in scientific inquiry, using content-neutral terms like 'do it themselves'. However, it is

important to note that not all PSTs describe inquiry in such terms, and those who did so likely did not learn about these strategies in content-neutral and general ways.

Limited exposure to STeLLA strategies. As the intervention progressed, PSTs described exposure to the STeLLA strategies primarily in one science education course, Science Research Methods (SRM), which was the last course prior to student teaching. This exposure was mostly limited to the questioning strategies (i.e. elicit, probe, challenge questions). For example, PSTs B3 described learning about the STeLLA strategies exclusively in their SRM course. She shared that they only spent a limited time on these strategies in the course. PST B4 felt that she "*didn't really learn about the strategies at all, besides the questioning strategies*". She elaborated that "*we've spent some time on this differences between eliciting, probing and challenging questions. But that's about the extent that we did"* (PST B4, Spring 2021). Similarly, PST B5 also remembered being exposed to the STeLLA strategies in her SRM course, where they would "*refer back to the STeLLA strategy poster*" (PST B5, Spring 2023). However, she argued this exposure was *'not as in-depth*' as when she attended the STeLLA CO^2 PST/MT institute to learn about the strategies with her MT.

While these PSTs noted limited STeLLA exposure, they still described some rigor to these learning experiences. For example, PST B4 learned about the STeLLA strategies in her SRM course through video analysis.

> *"He presented just a definition of what it was. And then we learned it or reinforced it through looking at videos. And we were given transcripts, very similar to what we did with your training at the very beginning. We would watch videos and we would circle this is a challenging, this is a probing. And then we just have discussions of what type of question do you think it is? And that's what we did for the questioning. And that's all we have learned from the STeLLA strategies."* (PST B4, Spring 2021)

Here, PST B4 is describing exposure to the STeLLA strategies in a way that aligns with the video analysis practices in the validated STeLLA professional development program. Therefore,

despite being limited and lacking coherence within the course, this STeLLA exposure still reflected certain rigorous practices found in the broader professional development program.

Fragmented exposure to STeLLA strategies. In the final iteration of the university team's intervention, PSTs still perceived that their exposure to the STeLLA strategies was inconsistently integrated within and across their education courses. For instance, PST B6 recognized exposure to the STeLLA strategies in several university courses, including her PBI course. In PBI, she recalled learning about the STeLLA strategies at the beginning and end of the course. At the outset, she mentioned learning about the STeLLA strategies poster. She explained that they spent one lesson at the beginning of the course learning about the STeLLA framework. However, she felt they did not revisit *"until the end when we had to go through, "Well, did your question strategies work? How was your final project? How was the final end project?"* She argued, "*it would've been more beneficial probably to revisit throughout if we had to make adjustments, we could have.*" (PST B6, Spring 2023). Relatedly, PST B6 felt that her initial introduction to STeLLA strategies in PBI was not science-specific or connected to the final project she was developing.

> *"We went through the diagram for sure. We spent a whole day talking about it and then we came up with... We're coming up with random question examples, so totally not related to anything science or math, but just trying to get good at asking questions. We just did mini kind of fun, goofy activities related around those questions but I think revisiting it throughout our project unit would've helped."* (PST B6, Spring 2023)

In these quotes, PST B6 highlighted how the STeLLA strategies were incorporated in a fragmented and incoherent way to her PBI course. By addressing these strategies only at the beginning and end of the course, she felt she was not able to learn about them effectively or incorporate them into her project-based unit. Similarly, PST B7 felt she learned '*a little bit*' about the STeLLA strategies during her program but explained that '*they were secondary*' to

other instructional strategies covered in these education courses (PST B7, Spring 2023) . Together, these PSTs who experienced the fully revised program still felt that the STeLLA strategies were not coherently integrated within and across courses.

STeLLA language between PST and MT. Throughout the intervention, PSTs expressed that learning about the STeLLA strategies prompted them to engage in conversations with their MTs about these strategies. Consequently, these conversations often led to increased utilization of these strategies in their practicum and student teaching experiences. For example, PST B4 felt that the STeLLA strategies provided her and her MT with a 'common language' to discuss teaching in their field site. Specifically, her MT attended the STeLLA CO^2 PST/MT institute with her, ensuring her MT had some familiarity with the STeLLA strategies. She explained:

> *"My mentor did know BSCS and so she went for [STeLLA CO^2 PST/MT institute] with me. She went to all the same ones I did. So that was kind of nice when we could build in a language because I feel like it just gave a word to some pedagogy that we've been talking about. So then I could say it and she understand what I'm talking about compared to having to explain everything and then think we're on the same page when we're not. So I think that was helpful is just kind of giving a common language."* (PST B4, Spring 2021)

In this quote, PST B4 described the benefit of having a shared language to name particular instructional strategies that emerge in their discussion together. Similarly, PST B6 felt the STeLLA CO^2 PST/MT institute spurred valuable conversations between her and her MT about teaching.

> *"We had talked about questioning, but it was easier, I guess not easier, but it's more relatable and maybe easier to incorporate it into student teaching after going to that PD with you guys with my mentor teacher, because it was like, "Okay, right away, let's figure out how to do this for the lesson that we're going to do this week." It was just being able to apply it immediately has been a huge help."* (PST B6, Spring 2023)

Here, PST B6 highlighted how these conversations with her MTs ultimately supported her to incorporate the questioning strategies into her own student teaching with the guidance of her MT. Throughout the intervention, the PSTs emphasized the value of the STeLLA strategies in

establishing a 'common language' for PSTs to observe MTs' instruction and receive feedback on their own teaching from MTs. In particular, the STeLLA CO^2 PST/MT institute served as an important venue for STeLLA exposure because it brought both PSTs and MTs to the table to learn about and discuss the strategies.

University C. Before the intervention, PSTs often identified a gap between the concepts taught in their university education courses, the strategies modeled in their science courses, and the experiences in their field-based work. Early in the intervention, PSTs expressed learning about the STeLLA strategies in one course through extensive video analysis and discussion. As the intervention progressed, PSTs noted sustained exposure to the STeLLA strategies across multiple courses. At each stage of the intervention, PSTs felt that MTs had varying degrees of familiarity and capacity to support them with STeLLA strategies in their own teaching.

Incoherences between university courses and field work. Before the intervention began, each PST noted incoherences between their university education courses, their university science courses, and their field-based experiences. For example, PST C1 highlighted the traditional nature of her science courses and the absence of practical examples illustrating reform strategies she learned about in her education courses. She stated:

> *"You either had really old school like, 'This is kind of how you're going to teach. Science is its own thing where we do labs.' Or you had like, 'You are going to be approaching this new type of teaching, but never really fleshing it out.' And then the science courses themselves, I mean, I feel like it was just really traditional lecture-based. Your only group stuff was with the lab and it was terrible."* (PST C1, Fall 2018)

As a consequence, she articulated that she "*felt pretty lost, pretty much until now with the new standards and the storyline teaching*." In these quotes, PST C1 noted the incoherence between the reform ideas she was learning in her education course about science teaching and learning and the manner in which she was being taught in her science courses. This lack of

alignment caused issues for her in her own teaching because she did not observe many examples of effective science teaching that matched what she learned about in her education courses.

On the other hand, PST C2 noted the disconnect between his university education courses and his field experiences with his MT. Early in his program, he engaged in short-term practicum experiences as part of several education courses. While he underscored the practical value of these practicum experiences, he expressed that his observations of his MT during these experiences could have been more intentional. He suggested that the university faculty from the course come into the classroom with the PSTs to scaffold their initial observations of the MT.

> *"I feel like when I was just doing my first STEP observations, I was just kind of there looking and just watching and seeing what they did, which is helpful. But I think it would've been nice, too, to have them with me to say, "Do you see them doing this? We talked about this in class. This is what it actually looks like."* (PST C2, Fall 2018)

In this quote, he noted that these initial observations were not grounded in specific ideas from his education course, which might have made these observations more specific and impactful. Overall, both PSTs expressed concerns about the traditional instructional methods in their science courses and perceived a gap between their university courses and their application in the classroom.

Initial STeLLA exposure through video analysis. As the intervention progressed, PSTs noted the presence of the STeLLA strategies in their methods course. For instance, PST C3 expressed learning about the STeLLA strategies through video analysis in her methods course. She shared that:

> *"a lot of his [instructor] teaching and preparing us was focused on STeLLA strategies. So, we had watched videos and he'd be like, "What do you notice about the questioning? What do you notice about the style of the lesson?" Which definitely helped us prepare us for what STeLLA strategies were."* (PST C3, Spring 2020)

In this quote, PST C3 noted learning about the questioning strategies through video analysis that resembled practices in the broader STeLLA PD program. Similarly, PST C4 also engaged in video analysis to learn about the STeLLA strategies in her methods course. Additionally, she highlighted how she was prompted by her instructor to utilize these strategies in her own lesson planning.

> *"In our methods class, we would always go over the strategies during the day or in a lesson. And we would watch videos. Sometimes he'd ask us, "Did the person ask elicit questions or probing questions or challenging questions?" And he'd always want us to make our lesson plans have the main learning goal and have the focus question."* (PST C4, Spring 2020)

In this quote, the PST identified both rigorous and sustained exposure to the STeLLA strategies, as she learned about the strategies through video and lesson analysis and would ultimately apply what she learned to her own practice. This notion of sustained exposure and use of STeLLA strategies was also raised by PST C5. He explained that his methods instructor "*showed videos with it [STeLLA strategies], but we were then also able to see it and connect that to our own situations*." In his approximation, this sequence of learning about and using the strategies "*seemed to be really effective*" (PST C5, Spring 2021) Taken together, these PSTs identified rigorous and continual exposure to STeLLA strategies in their methods course.This course was an early and important target for revision by the university team.

Sustained exposure to STeLLA strategies. By the end of the intervention, PSTs noted exposure to the STeLLA strategies across multiple science education courses. For instance, PST C6 mentioned learning about and practicing the STeLLA strategies across his teacher education program.

> *"I mean he taught the STeLLA strategies. He gave us time to talk about them with other people, try them out with other people, and actually do stuff. And then we talked about it and how it could be effective. But we already saw how it could be effective because he was already implementing them. So that was super important was just learning about*

> *these, and being introduced to these. Then we practiced them every single semester."* (PST C6, Fall 2021)

In this quote, the PST noted that his instructor both taught and modeled the STeLLA strategies, providing him with the opportunity to discuss and practice these strategies with his peers. He also mentioned practicing these strategies '*every single semester*' throughout their teacher education program.

PST C7 similarly recounted learning about the STeLLA strategies across their program. Specifically, the noted STeLLA exposure in three sequential courses, during which PSTs participated in seminars and observed secondary science teachers.

> *"I think we started off with them super early on. So, it's been, what? Three years since I've been introduced to all of that stuff. But, they took it and they gave the booklet and we talked about a couple of the different strategies, and then I think we did some kind of practice with it or wrote a little reflection on those things and how to use them, and we had a big group discussion about that stuff. That was pretty consistent throughout the three classes I did that stuff in."* (PST C7, Fall 2022)

In this quote, the PST mentioned learning about, practicing, and reflecting on their use of the STeLLA strategies throughout this three-course sequence. Furthermore, she remarked that this exposure to STeLLA "was pretty consistent" across these science education courses. While PSTs C6 and C7 noted consistent exposure, other PSTs felt that their courses had varied emphasis on the STeLLA strategies. PST C8 mentioned that all his courses "*mentioned STeLLA strategies*" but some of these courses '*focused entirely on them*' while other courses *"just mentioned them as we learned about other aspects of education*" (PST C8, Fall 2021). Taken together, these PSTs noted both sustained and varied exposure to the strategies in their education coursework. They did not just learn about the strategies; they also put them into practice during their practicum and student teaching work, followed by reflection on their application.

MTs had varied STeLLA familiarity and capacity. Throughout the intervention, PSTs expressed encountering MTs with varying levels of familiarity and capacity to support them with the STeLLA strategies. For example, PST C8 expressed that his practicum experiences with mentor teachers were incoherent with his STeLLA-focused courses. He noted difficulty using the STeLLA strategies in his student teaching when his MTs lacked an understanding of the STeLLA strategies.

> *"I started to notice was unless you ended up with a mentor teacher that was a part of the STeLLA program, the heavily focused STeLLA aspects of University C's program were a little rougher to transfer over to the real world because none of my mentor teachers ended up using STeLLA. I don't know if any of them had even heard of it by the time I ended up in their classroom."* (PST C8, Fall 2021)

In this quote, PST C8 concluded that transferring knowledge about the STeLLA strategies from their science education courses into their field-based experiences was challenging when their MT was not involved in the '*STeLLA program*'. He explained that none of his mentor teachers used the strategies, preventing him from observing these strategies in their MTs' practice or discussing the use of these strategies in their own practice.

In contrast to PST C8's experience, PST C7 described feeling supported by her MT regarding the STeLLA strategies. Specifically, she recalled having conversations with her MT about using the science content storyline strategies during co-planning work.

> *"And so going into my student teaching, that's a big thing that [MT] and I talked about frequently when we were designing units, because I would write them all out on the board, because I'm a big picture person. How do I plan this in a way that makes sense in a story that makes sense? We're going to start here. We're going to build some background. We're going to go this way. Then we're going to come down here. How do I make this make sense for the kids, and not just like, "Okay, we're talking about genetics. Here's this part, here's this part, here's this part."* (PST C7, Fall 2022)

PST C7's quote demonstrated an understanding of the Science Content Storyline lens, as she described co-planning a unit in a manner where science ideas were sequenced and linked to form a coherent 'story' that made sense to students.

Across universities. Across each program's intervention, PSTs reported increased use of specific STeLLA strategies, including questioning strategies, as well as the focus question and main learning goal strategies. Additionally, PSTs at each university acknowledged the significance of MTs who were well-versed in these strategies and capable of providing support for their implementation during the PSTs' student teaching. Finally, PSTs observed that courses in the science department remained predominantly lecture-focused and traditional.

Increased use of particular STeLLA strategies. PSTs at each university noted the use of the same specific STeLLA strategies in their field experiences. For example, PSTs identified the value of the questioning strategies (elicit, probe, challenge) and highlighted using them in their own teaching. For example, PST A6 explained that he tried to incorporate the eliciting question strategies "*as much as possible at the beginning, definitely at the beginning, and throughout the whole lesson*" (PST A6, Spring 2023). Similarly, PST C6 explained that she tried "*to implement these strategies, especially the questioning strategies during my student teaching*" (PST C6, Fall 2021). In addition to utilizing these strategies, PST B4 also explained how the questioning strategies were supportive of her students' thinking.

> *"I think the questioning strategies have been super helpful to know, okay, I am very surface level at this point. I can kind of sense that I have way too many eliciting questions. If I'm getting just simple yeses and nos, I can say no, "Okay. I got to probe them." Or through the timeline as well, through an activity, I feel like the types of questioning has really helped me know of how can I fit in a challenging question here."* (PST B4, Spring 2021)

In this quote, she noted the value of these strategies and identified how she would use eliciting, probing, and challenging questions based on her students' responses and the trajectory of the activity.

The focus question and main learning goals strategies were also consistently highlighted across universities. For example, PST A7 discussed the use of the main learning goal and focus question strategies. She also noted other STeLLA strategies, such as making explicit links between science ideas and activities, and connecting science ideas to one another. She emphasized how these key strategies were useful in establishing coherence for students in their learning:

> *"Writing a main learning goal and a focus question was useful in seeing what I want them to get out of a lesson and the connecting science ideas to activities and stringing that together to connect science ideas to other science ideas."* (PST A7, Spring 2023)

PST B4 also saw value in the focus question and felt it aligned with an instructional practice she already utilized in her student teaching, stating *"so, the focus question is a big one that I ended up using and taking to my classroom. My school makes us call it an essential question, but it's just the same thing*" (PST B4, Spring 2021). Similarly, PST C8 shared that the main learning goal and focus question translated well to his classroom practice:

> *"The ideas of main learning goals, focus questions, science ideas, all of those, I feel, translated the best in the classroom. Regardless of what I was teaching or how I was teaching it, those ones always stayed consistent. You always had to pick a main learning goal. We call them a learning intention or you had to do focus questions, which kind of morphed into what I use as my school's success criteria."* (PST C8, Fall 2021)

Both PSTs B4 and C8 highlighted how these content storyline strategies seamlessly integrated with the existing language (i.e. *essential question*, *success criteria*) in their field settings, making them more easily applicable to their own teaching than other STeLLA strategies.

Importance of STeLLA-familiar MTs. Across universities, PSTs noted the value of having MTs in their field settings who were familiar with the STeLLA strategies. For example, PST A5 described having issues with her MT because they were not familiar with the strategies, despite implicitly modeling them in their practice.

> *"I actually do think that my mentor teacher, even without the STeLLA strategies, had a similar idea to STeLLA, on how science teaching should be done, and how to be most effective. And really, the only layer that was missing, was that common language."* (PST A4, Spring 2021)

She expressed a desire for her MT to undergo some professional learning on STeLLA to facilitate their discussions about her science teaching, stating, "*anything to set them up with a common language before student teaching definitely would have made some of those conversations easier*." This sentiment was echoed by PST C8, who felt that the STeLLA strategies were "*little rougher to transfer over to the real world because none of my mentor teachers ended up using STeLLA [strategies]*" (PST C8, Fall 2021). Here, the PST expressed challenges in implementing the strategies due to their MT's lack of familiarity with STeLLA strategies and the absence of a shared language for discussing effective science teaching.

On a positive note, PST B4 emphasized the importance of a shared STeLLA language, underscoring its value for effective communication and collaboration in teaching practices. Her MT was familiar with STeLLA and was able to note these strategies in her observations and feedback:

> *"Especially when we had to do your lesson, we were using it a ton then, which was very helpful to be like, okay, what focus question or how are student talking like scientists? How are we linking prior knowledge or new science ideas to old science ideas? We definitely did use it. And I would say the language is pretty... We have a very coherent language with that, which I think is helpful, because she has been a part of the program for so long. The language is very, very similar. And we've been able to use the language throughout the whole semester."* (PST B4, Spring 2021)

In this quote, PST B4 highlighted the significance of focus questions and scientific communication strategies in her field site, noting the coherence in language between herself and her MT regarding instructional approaches. She attributed this alignment to her MT's sustained engagement in professional learning concerning the STeLLA strategies.

Science courses remained traditional. Throughout each program's intervention, PSTs consistently observed that science courses remained lecture-focused, diverging from the pedagogical approaches they were taught in their science education courses. For example, PST A5 viewed their science courses as "*so much lecture and it was just lecture the whole time*" and felt that these courses were "*not great models for how to teach*" (PST A5, Fall 2021). Similarly, PST B3 was critical of her experiences in her science courses. She also felt that these courses did not model effective science teaching. She explained that her physics courses "*were just lecture. It was my teachers sitting at the board writing notes, and I wrote them on my notebook.*" However, she felt that these courses had some benefit because they *"opened up my eyes to what I don't want to do as a physics teacher*" (PST B3, Spring 2021). PST C1 likewise expressed that her science course instructors did not engage in storyline teaching. Her interest in science motivated her to make connections among science ideas in these courses, but the instructors did not explicitly design for coherence:

> *"I don't think it was the storyline teaching that it should be, it was a lot of just moving through the different units. I definitely saw how they connected. But I'm wondering if that's because it was just such a focused class. I mean, all my classes were lecture-based."* (PST C1, Fall 2018)

In each quote, the PSTs highlighted how their science courses, regardless of the stage in the intervention, remained predominantly lecture-based and failed to align with the vision of effective teaching advocated in their university science education coursework.

Discussion

While the value of coherence in teacher education has long been documented (e.g. Darling-Hammond et al., 2005; Richmond et al., 2019; Smeby & Heggen, 2014), the connections between university- and school-based settings have remained limited (Canrinus, et al,, 2019; Southgate, et al., 2013; Grossman et al., 2008). Universities have traditionally been resistant to large-scale changes due to the presence of multiple interest holders, their traditional silos, and the complexities of working with schools, districts, and university departments (Canrinus et al., 2017; Korthagen, 2010; Darling-Hammond, 2006). In this study, three university teams, consisting of university faculty and mentor teachers, mobilized the STeLLA conceptual framework to develop a common vision for effective science teaching. Using this vision, the teams went about developing and implementing unique plans to enhance the coherence of their science teacher education programs. The impact of these programmatic revisions on PSTs' classroom practice and perceptions varied across the three universities but was overall positive. In what follows, we will discuss some potential explanations for this variation and highlight some of the successes and challenges of engaging in this work to improve the coherence and effectiveness of science teacher education.

Coherence as negotiation. Recent research in teacher education has framed coherence as a process of ongoing negotiation between relevant interest holders (Levine et al., 2023; Richmond et al., 2019). In this conception, conflict between interest holders is not something to be avoided in the negotiation of coherence (Mikkelsen & Clegg, 2019). Instead, teacher educators' differing views and commitments concerning teacher preparation should be surfaced and discussed in the process of developing and enacting a coherent teacher education program (Hammerness, 2006). In the context of this study, the three universities went about revising their

science teacher education programs at different paces. University C started revising their program earliest in the study and made more cycles of revision to their program over time. As a result, they had more opportunities to surface conflict and negotiate coherence around their program revisions. Furthermore, University C had one interest holder at the university who served as a champion for the bulk of revisions to the program. This interest holder was motivated to surface and work through conflict with other university team members concerning the conceptual and structural coherence embedded in these revisions. While University C may have had more opportunities to negotiate coherence in their program, this does not mean that Universities A and B did not engage in such negotiation. However, these efforts started later in the study when these university teams decided to make more substantial revisions to their coursework and field experiences. These differences may account for why University C had a significant difference in classroom practice between BAU and treatment PSTs and positive perceptions about the coherence of their program.

Mentor teachers and coherence. Mentor teachers (MTs) play a key role in developing preservice teachers and maintaining coherence across university and school settings in teacher education programs (Nordine et al., 2015; Thompson & Larkin, 2020). However, opportunities for university faculty to gain direct insight into the mentoring and teaching practices of MTs remain limited (Marciano et al., 2019). To tap into MTs' expertise in teacher preparation, researchers have advocated for third spaces where university faculty can gain insight into what MTs consider valuable for preservice teachers (PSTs) to learn, how they should learn it, and why (Floden et al., 2021; Orland-Barak & Wang, 2021). Further, efforts to have MTs teach university courses have been shown to benefit PSTs' learning and improve the coherence of teacher education programs (Tan, 2021). In this study, we utilized third spaces to bring MTs to the table

to revise their science teacher education programs. From this collaborative work, all three universities made efforts to incorporate MTs more meaningfully into their programs. For example, Universities B and C brought in MTs to teach about the STeLLA strategies in their science education courses. Furthermore, each university team developed professional learning for additional MTs to gain familiarity with the STeLLA strategies. The PSTs at each university noted that STeLLA-familiar MTs, both in their field sites and university classrooms, were important to their development as science teachers. Additionally, PSTs expressed issues with their program when there was conceptual incoherence between their STeLLA-focused coursework and their practicum and student teaching experiences that were not aligned with the STeLLA framework.

Explicit core ideas for science teaching. Science teacher education programs should be organized around a core set of ideas about effective science teaching that can be used consistently across both university and school contexts (Nordine et al., 2021). These core ideas should not only inform the design and enactment of coursework and field experiences but should also be made explicit to PSTs across these contexts (Hutner et al., 2021; McDonald et al., 2013). However, PSTs often do not experience the same core ideas about teaching across these contexts (Canrinus et al., 2017; Fazio & Volante, 2011). In this study, each university team mobilized the STeLLA conceptual framework (Roth et al., 2017) to develop a shared vision of effective science teaching and subsequently incorporated that vision and language into their program revisions. While the STeLLA framework informed the redesign of courses, tools, and field experiences at each university, these universities differed in how explicitly they presented the STeLLA framework to PSTs in these experiences. From the onset of their intervention, University C made the STeLLA framework explicit for their PSTs in their redesigned courses. On the other hand,

University A and B engaged in program revisions using the STeLLA framework but did not initially make the STeLLA strategies explicit to PSTs through these revisions. Instead, they incorporated the STeLLA strategies implicitly, focusing on the strategies which overlapped with existing instructional strategies they already taught about. As a result, PSTs at University C, even early in the intervention, identified exposure to the STeLLA strategies in both university and school contexts. However, as their interventions progressed, Universities A and B moved toward making the STeLLA framework more explicit to PSTs. This was reflected in PSTs' interviews from later in the intervention, as they noted a more explicit and coherent integration of the STeLLA strategies into their programs.

Conclusion

In this study, we engaged university faculty and mentor teachers from three Mountain West universities in third spaces with the goal of enhancing the coherence and effectiveness of their science teacher education programs for PSTs. Over the course of a six-year partnership, these universities revised their coursework and field experiences to integrate the STeLLA framework in a manner that fits their unique science teacher education programs. The impact of these revisions on PSTs' classroom practices and perceptions of their programs was varied but positive overall. PSTs from each university showed positive shifts in classroom practice and identified more positively with their program as each intervention progressed. University C differed from the other universities in terms of the onset of their program revisions, as well as the explicit and sustained nature of these changes for PSTs. Lastly, sustainability was a consideration for each university. As each intervention progressed, each team navigated challenges such as staff turnover and onboarding, and had to negotiate both ideological and practical conflicts

related to the effective preparation of PSTs. Each university made efforts to address sustainability, such as providing training and materials for new faculty teaching STeLLA-revised courses, but sustainability beyond the scope of this study remains a challenge for each program.

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