Adapting and Scaling the STeLLA Program Conceptual Framework in Preservice Teacher Education Programs

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Adapting and Scaling the STeLLA Program Conceptual Framework in Preservice Teacher Education Programs

University science teacher educators face challenges bringing coherence to course and field-based aspects of **p**reservice **s**cience **t**eacher (PST) preparation and creating a common vision among the many individuals who play a role in developing PSTs' understanding of effective science instruction (Darling-Hammond, 2014; Zeichner, 2010). The STeLLA CO^2 project uses the STeLLA (**S**cience **Te**achers **L**earning from **L**esson **A**nalysis) program's proven framework of teaching strategies and video-based analysis of practice (Roth et al., 2017) to support a common vision of effective science teaching and enhance the coherence of PSTs' learning experience, which includes the PSTs' participation in university education and science courses and their field experiences. This goal is accomplished through a five-year partnership with three Mountain West region universities (pseudonyms: Universities A-C) that brings together faculty who teach undergraduate science courses, faculty who teach secondary science preservice education courses, and mentor teachers (MTs) who support PSTs' field experiences. All stakeholders learn about the lenses and strategies embodied in the STeLLA Conceptual Framework in preparation for developing a local plan to use what they have learned to enhance and bring coherence to their PSTs' learner experiences.

There is a long line of research that establishes the value of the STeLLA approach in improving teacher science content knowledge, pedagogical content knowledge and teaching practice, as well as improved science content knowledge outcomes for the students of teachers who have participated in the program (Roth et al., 2019; Taylor et al., 2017). The approach has also proven effective in preservice settings (Wilson et al., 2017). The STeLLA CO^2 project represents how we are scaling STeLLA program and applying it to new audiences and contexts. Different phases of the STeLLA CO^2 program required different types of scaling efforts (see Morel et al., 2019), from the BSCS staff *adapting* the STeLLA program in the early stages to meet the needs of the mixed participants (university science and education faculty and mentor teachers) to university team participants *reinventing* the program as each university designed innovative ways to use the STeLLA conceptual framework to meet the needs and bring coherence to their PST learning experiences in their particular context. STeLLA CO^2 is unique in that the ownership of the scaled innovation was with the university participants. The research presented in this paper focused on understanding how each team approached this scaling challenge, the impact on PST learning and practice at each site, and the successes and challenges that each site team faced during the first year of plan implementation. In this paper, we examine the factors that supported and challenged this scaling approach. Two questions guided the research addressed in this paper: 1) What successes and challenges did teams face as they developed and implemented their plans? 2) To what extent did university team plans enhance the coherence of PSTs' learner experience?

The STeLLA CO^2 Project: Description and Theory of Change

Facilitating Cross-stakeholder Collaborations to Realize the Vision

Figure 1 illustrates our Theory of Change for how the STeLLA CO^2 project can support PSTs and their students. The project involved three different phases: Phase 1: Developing a university-based community with shared vision and purpose; Phase 2: Operationalizing a vision of effective science teaching and learning; and Phase 3: Analyzing pre-service teacher outcomes.

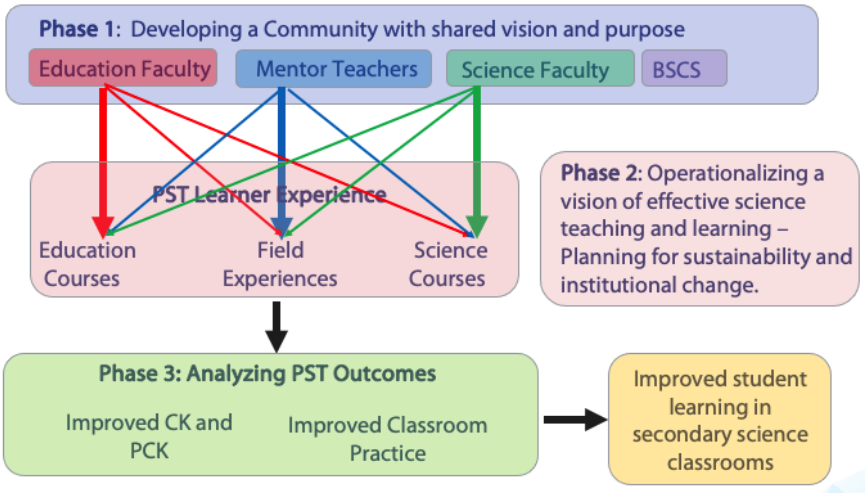


Figure 1. STeLLA CO^2 Project Theory of Change

Phase 1: Developing a community with shared vision and purpose. During Phase 1, university science and education faculty and MTs participated in BSCS STeLLA CO^2 staff-facilitated synchronous sessions and asynchronous work to co-develop a common vision for effective science teaching and learning using the STeLLA conceptual framework to prepare them for the reinvention of the program that would occur in Phase 2. The framework involves two lenses that teachers at any grade level can apply to their classroom practices to move students' science thinking forward: a *student thinking lens*, which includes pedagogical strategies for surfacing and building on student thinking, and a *science content storyline lens*, which involves pedagogical strategies for supporting students in constructing coherent science learning. This work involved the analysis of classroom video, including video from STeLLA CO^2 university or secondary science classrooms. In this phase of the program, we adhered closely to the traditional structure of the STeLLA PD program, while making adaptations that would meet the needs of our audience of faculty and secondary science teachers. For example, rather than having an intensive 2-week face-to-face summer institute, we structured our program to include face-to-face interactions interspersed by online asynchronous and synchronous sessions over a span of four months. In addition, we did not focus on deepening participants content in one or two science content areas, as is typical in the traditional STeLLA program, since science faculty and MT participants had expertise and teach in a range of disciplines. We used lessons and video examples to highlight our understanding of the STeLLA strategies that spanned all secondary science focus areas, from 7th through 12th grades in Biology, Chemistry, Earth Science and Physics. Participants then applied what they learned and found useful from STeLLA to their own teaching practice.

Phase 2: Operationalizing a vision of effective science teaching and learning. Phase 2 of STeLLA CO^2 involved university team participants reinventing the STeLLA program by co-developing a localized plan that was grounded in the STeLLA Lenses and Strategies to enhance the coherence of the PSTs' learner experience, meet the needs of their PST programs, and sustain changes beyond the scope of the grant period. Examples of plan components include the development or revision of university education courses to make explicit use of the STeLLA strategies. In addition to the foundation received during Phase 1, STeLLA CO^2 project staff conducted leadership institutes to prepare university team participants to implement aspects of

STeLLA at their sites. For example, participants practiced selecting video for use in the context of analysis of practice sessions with teachers.

Another important goal was to breakdown traditional stakeholder roles and responsibilities to facilitate collaborations across stakeholder groups. For example, two of our universities involved mentor teachers in co-planning and co-teaching class sessions related to the STeLLA strategies. In doing so, mentor teachers could inform the process by which PSTs developed their understanding of the strategies in the university classroom and reinforce and further develop understanding as PSTs used them to facilitate secondary science learning in MTs' classrooms. In our general theory of change (see Figure 1), we use bold, colored arrows to identify the primary stakeholder group responsible for key parts of the PST learner experience (Education courses, Field Experiences, and Science courses). When creating university team-specific models to understand what was happening at each university, we adjusted the arrow width to indicate the level of involvement of each stakeholder in informing each aspect of the PST learner experience. In the previous example of MTs co-teaching university education courses, we would use a bolder arrow between mentor teachers and education courses to represent the MTs' enhanced role. With this collaborative spirit, mentor teachers adopted leadership roles on their university teams, often leading work and initiatives.

In addition to the work being done at each university, STeLLA CO^2 staff invited PSTs and their MTs to a three-day institute prior to their student teaching semester to ensure that all participants had a common understanding of key STeLLA strategies and had the opportunity to plan together. The rationale was two-fold. Because Phase 2 involved the iterative implementation and revision of each university's plan, we wanted to ensure that all PSTs had a basic understanding of key STeLLA strategies to ascertain the effects of learning about and using STeLLA on PSTs and their students in Phase 3. Table 1 identifies the strategies that were emphasized during the institutes. Since it was not always possible for universities to place PSTs with a MT involved in the STeLLA CO^2 work, this 3-day institute provided the opportunity for MTs with no prior STeLLA experience to become familiar with the STeLLA strategies.

Table 1. STeLLA strategies emphasized during PST/MT institutes

Student Thinking Lens	Science Content Storyline Lens
• Ask questions to elicit student ideas and predictions • Ask questions to probe student ideas and predictions • Ask questions to challenge student thinking • Engaging students in communicating in scientific ways	• Identify one main learning goal • Set the purpose with a focus question • Summarize key science ideas • Make explicit links between science ideas and activities. • Link science ideas to other science ideas • Highlight key science ideas and focus question throughout

Phase 3: Analyzing Pre-Service Teacher (PST) Outcomes. In Phase 3, we will analyze the effects of the STeLLA CO^2 intervention on PST outcomes and outcomes from their secondary students during student teaching. The composite treatment for PSTs combines their participation in the revised components of the PST learner experience, as guided by each university team's plan, and the STeLLA CO^2 PST/MT institute. In our general Theory of Change, we theorize that incorporating the STeLLA strategies in the context of university

instruction will improve PSTs' content and pedagogical content knowledge related to the use of the STeLLA strategies and improve secondary science learning.

Research Methods

We are currently in year 4 of the project, with universities continuing to implement and iteratively evaluate and improve on their locally-developed plans. This paper shares preliminary findings from the beginning of Phase 2 of the STeLLA CO^2 project, which involved analyzing the underlying rationales for components included in each university team's plan and the successes and challenges of developing and implementing the plan. The data from this study comes from 9 university faculty, 23 mentor teachers, and 9 PSTs across 3 universities. To understand the development and implementation of each university team's plan, we analyzed video recordings of two in-person institutes, during which each team developed their plan; administered monthly and year-end surveys; and conducted interviews with a representative sample of team participants (6 university faculty and 11 mentor teachers). See the Appendix for copies of year-end survey and interview protocols.

We used an inductive coding approach (Miles & Huberman, 1994) to identify themes in the university team plan components, the rationales for those components, and the stated roles of education faculty, science faculty, and mentor teachers when implementing the plan. We used survey and university team participant interview data to identify themes related to community and factors that hindered plan implementation. We used classroom observations and PST interviews to develop an understanding of the extent to which the STeLLA strategies were explicitly introduced and supported in the context of PSTs' university work, interactions with mentor teachers, and PSTs' perceptions of the role that the STeLLA strategies play in supporting student learning. Tables 2 and 3 summarize the categories of codes that emerged from analyzing the university team data and PST interviews respectively.

Table 2. University Team Codes

Category	Description
University Team Plan Components	This category of codes involved identifying the components of the university team plan. ● Course content ● Tools and protocols ● Professional Learning ● Additional STeLLA-related work that was not part of university plan
Underlying rationale for proposed plan	This category of codes examined the underlying rationales for each of the components of their plan. ● Use of STeLLA strategies ● Coherence ● Capacity-building for enacting university plan
University Team Participant Roles	This category of codes examined the planned and actual roles that each stakeholder group played in the university team plan implementation. ● Education faculty ● Science faculty ● Mentor Teachers

Ideas related to community	This code examined sentiments related to the extent to which university team participants felt like they ● shared a common vision for implementing what they learned about STeLLA in each university's PST program and ● were part of an inclusive community that honored their ideas and contributions.
Additional Factors that hindered plan implementation	This code examined additional factors from the university team's context that may have hindered implementation of the team's plan. Examples include departmental rotation of faculty scheduled to teach university courses or relationships with districts where mentor teachers are supporting PSTs.

Table 3. PST Interview Codes

Category	Description
Use of STeLLA strategies in university courses	This code described the extent to which the STeLLA strategies were explicitly or implicitly used in PSTs' university courses.
Perceived usefulness of the STeLLA strategies for supporting student learning	This code described PSTs' use of the STeLLA strategies and their perceived usefulness for supporting student learning.
Coherence of PST Learner Experience	This category of codes described the extent to which PSTs believed that their PST experience was coherent. ● Alignment of PST Learner Experience with Vision of Effective Science Teaching and Learning ● Coherence of feedback from key stakeholders

University Team Plans

Each university took a unique approach to scaling the STeLLA program at their university. The variation in approaches reflects differences in the structure and course sequence at each preservice science teacher program, the make-up of the university teams and their ability to distribute leadership and shift traditional roles, and the agency available within each program context to make significant changes. In this section, we describe each university team's plan and the intended benefits for improving the PST learner experience.

University A

University A team participants stated that the ideas behind the STeLLA Lenses and Strategies were not entirely new to them and were consistent with elements of their existing classroom practices. However, they found it helpful to explicitly name the STeLLA strategies to ensure a common language was used among university faculty, MTs, and PSTs to describe a set of desired practices. For example, one university education faculty member shared that having a common language would minimize confusion for the PSTs, "I think we all had shared goals and perspectives, but I don't know if we were all using the consistent language. And so, I think that STeLLA really helped with that" (University Faculty Member, 5/20/20). By developing and using these shared tools among stakeholders, the team hoped that it would contribute to PSTs receiving more objective and coherent feedback that the PST could act on to improve their

classroom practice. For example, rather than evaluating a lesson in general terms, a MT could use common language to articulate how using the STeLLA strategies could help PSTs better achieve their goals. One mentor teacher shared

> It is nice, I think, using the stuff that we've done in the STeLLA that where we can have some common language, and this is how we go about structuring a lesson. And so, one of the things that I really wanted, and have come out of it with is a lesson planning design of like, "This is how we're going to go about making the lesson. These are the things that are good in a lesson. And that's what we're shooting for." (Mentor Teacher Interview, 6/3/20)

In response, the University A team plan (see Figure 2) involved university faculty and mentor teachers working together to use the STeLLA strategies as a common language to revise lesson planning templates and observation protocols used in education courses to help PSTs focus on particular areas when planning and carrying out lessons. Prior observation tools placed a focus on what the teacher was doing or saying rather than analyzing student discourse, a key shift found in NGSS-aligned instruction and the STeLLA student thinking lens strategies. In response, the lesson planning template included educative features to support PSTs, such as questions to guide the development of questions to elicit, probe, and challenge student thinking (STeLLA *student thinking lens strategies*). Furthermore, the team 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 (STeLLA *student thinking lens* strategy). The development of these tools was primarily the work of a collaboration between university education and mentor teachers to enhance PSTs' experience in their university education courses and field experiences.

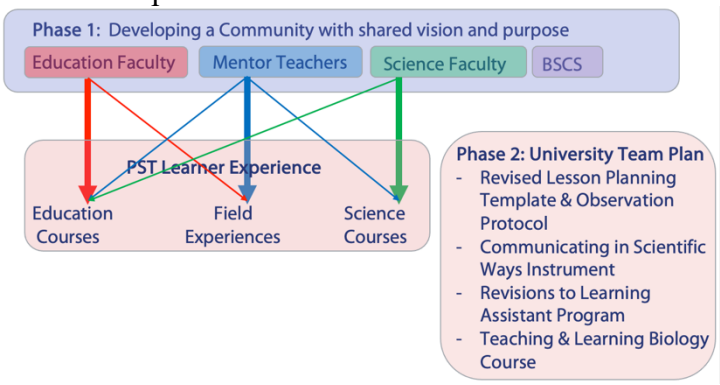


Figure 2. University A's Theory of Change

Along a parallel track, science faculty at University A began integrating STeLLA strategies in their own classroom instruction, modifying their use in the context of large undergraduate science classes. In these classes, undergraduate learning assistants (LA) provide 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 telling peers the right answers. One of our PSTs was a participant in this program in one of her science courses, and shared that it was an example of a science course that reflected her vision of effective science teaching and learning (PST Interview, 4/23/20). In addition, science faculty and one of our mentor teachers co-developed a new course cross-listed in Biology and Education, Biology for Teachers, in which STeLLA strategies are both introduced and modeled during instruction. These modifications to the university program appear in the Theory of Change as arrows showing the science faculty's influence on education courses (the cross listed course), as well as the mentor teacher's influence

on the science courses. Post-COVID, the university team hopes that additional mentor teachers will be able to contribute to revising this course and participate in facilitating discussions with PSTs.

University B

University B team's first year of implementation work involved the design and implementation of a single pilot activity in which PSTs applied what they learned about the STeLLA questioning strategies to design an inquiry activity that MTs then implemented with their secondary science students. PSTs received videos of the classroom enactments, student work, and feedback from the MTs and students. From this experience, MTs shared with the university education faculty the need for PSTs to develop a better understanding of the STeLLA questioning strategies and receive additional support through their university course work. Furthermore, MTs pressed education faculty members for PSTs to have the opportunity to teach the lab themselves so that PSTs could develop their understanding for how to use the STeLLA strategies to support student learning. In response, the team decided to enhance education courses to meet these perceived needs.

Work scheduled to revise the team's plan during Spring 2020 was pushed to the summer due to COVID-19. During the Fall 2020 semester, the team modified two education courses to introduce and support PSTs' use of the STeLLA strategies, including the course in which the inquiry activity was a capstone project for PSTs. MTs co-planned and co-taught class sessions involving the use of the STeLLA strategies with education faculty. MTs used video and other professional learning resources from STeLLA CO^2 institutes to facilitate PST learning. The MTs, in turn, would support the PSTs' efforts to use the STeLLA strategies. In addition, MTs plan to design and facilitate after school workshops to support PSTs with the practical aspects of using the STeLLA strategies in their classroom and complement what PSTs are learning in their education courses. However, this plan has been delayed due to COVID-19. The team implemented the revised inquiry lab activity, during which MTs adopted more of a coaching role to support the PSTs' use of the STeLLA strategies rather than enacting and filming the activity.

The collaborations between education faculty and MTs to modify the university education courses and reinforce PST learning in the context of their field experiences are represented in the University B Theory of Change (see Figure 3). Note that there are no similar arrows for University B indicating collaborative work with the science faculty. We will discuss in more detail the implications of this when discussing the successes and challenges of implementing the university team's plan.

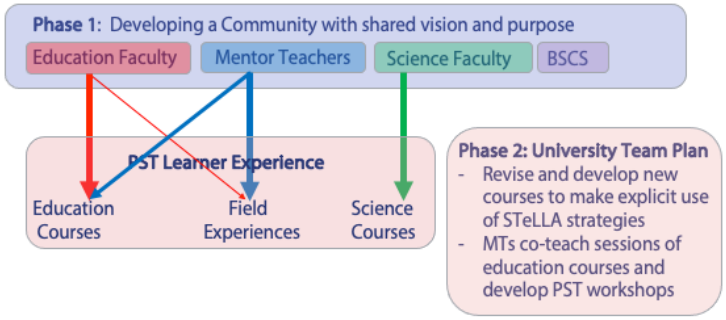


Figure 3. University B's Theory of Change

University C

While University C PSTs enroll in foundational education courses taught by education faculty, there are no science education-specific courses in the education department. Science-specific methods courses and practicum experiences are taught and supervised by science faculty, who specialize in discipline-based instruction and teach university science courses. Thus, University C science faculty share similar roles as education faculty and science faculty at Universities A and B. Since non-science-specific education courses continue to be an important part of the PST learner experience, we include education faculty in the University C's theory of change diagram (see Figure 4), but they are not part of the STeLLA CO^2 project.

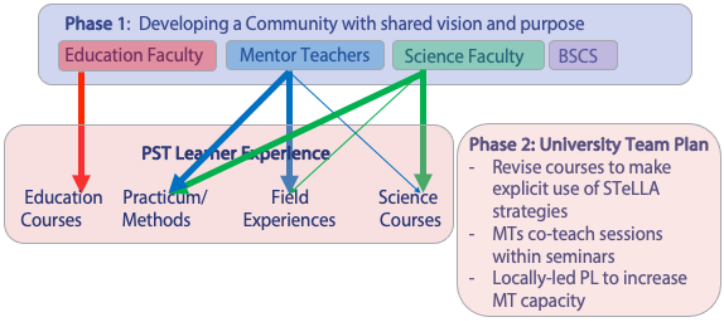


Figure 4. University C's Theory of Change

University C had a two-pronged approach for modifying their PST program. First, they redesigned three practicum seminars and the methods seminar course to introduce PSTs to the STeLLA conceptual framework in stages and used the STeLLA strategy booklet as a course text. The first seminar course, which focused on classroom observation, introduced Student Thinking Lens strategies that focused on classroom discourse. The second seminar course, which focused on lesson planning, introduced the Science Content Storyline Strategies. The third seminar course introduced Student Thinking Lens Strategies that support students in engaging in the science practices, including developing and using models, analyzing and interpreting data, and developing explanations and arguments. The methods course involved apply what PSTs had learned about the STeLLA Conceptual Framework.

Multiple, rotating science faculty teach the practicum seminars at University C. To support coherence, the team redesigned each course syllabus to include STeLLA CO^2 MTs as guest instructors to introduce and facilitate discussions around the STeLLA strategies using the analysis of video showing the strategies in action. This approach was designed to 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. Because science faculty (rather than education faculty) are the instructors for these seminars and MTs cross-over as guest instructors of seminar courses, University C's theory of change diagram has a bold arrow from the science faculty and MTs to the practicum courses.

Second, the team recognized the need to recruit additional MTs to model the STeLLA strategies and maintain a consistent vision and language for describing and improving effective science instruction. To meet this need, STeLLA CO^2 MTs designed and implemented a year-long professional learning program at a local, large district to introduce STeLLA to any secondary science teacher interested in hosting PSTs in their classrooms. Since most PST classroom observations and interactions prior to student teaching occurred in this local district, it was critical from a coherence perspective that PSTs observed teachers using the STeLLA

strategies in meaningful ways. In the coming year, they plan to expand this learning opportunity to MTs in neighboring districts.

Findings

In this section, we describe the successes and challenges that each university team faced when implementing their plans as a community. When examining the initial successes and challenges of this scaling work, we examined coherence in two areas: 1) the extent to which the STeLLA strategies were incorporated into the university coursework and 2) PSTs' perceptions of the alignment of components of their learner experience. Then, we examined the extent to which each university team was able to develop a common vision and work together to implement their plans to enhance the coherence of the PST learner experience using the STeLLA framework.

Coherence of PST Learner Experience

A central goal of the STeLLA CO^2 program is to use the STeLLA framework to support the development of a common vision of effective science teaching and learning and a common language to talk about that vision. In doing so, PSTs would experience classroom teaching that was aligned with this vision and hear a common message their university education courses, university science courses, and field experiences and experience. We used interview and observational data as evidence for determining the extent to which university faculty and MTs used the common language in the STeLLA Conceptual framework to support this coherence.

University A. When sharing about the coherence of university education and science courses with their vision of effective science teaching and learning, PSTs universally described their education courses as being aligned with their vision, whereas their science and engineering courses as being more lecture-based. The science faculty's efforts to incorporate the STeLLA strategies in their own science courses and engage in collaborations with education faculty could contribute towards enhancing the alignment of science courses with PSTs' vision of effective science teaching and learning.

University A's plan involved using the strategies as a common language to talk about and provide feedback on desired classroom practices. When asked about the extent to which PSTs had learned about the strategies in their university coursework, PSTs mentioned that they had not heard of them. After attending the PST-MT workshop or hearing a verbal description of the STeLLA strategies, they recognized alignment between what they had learned in their university courses and several of the STeLLA strategies, such as identifying a main learning goal, setting the purpose of a lesson with a focus question, and summarizing key science ideas at the end of class. PSTs desired to better support their students in surfacing and building on one another's ideas about phenomena and communicating with one another in scientific ways. After learning more about the strategies, PSTs described ways in which the STeLLA strategies could provide concrete ways to help achieve their goals. For example, one PST, who was able to attend the PST-MT workshop with her MT prior to student teaching, recognized the value of the using the STeLLA Communicating in Scientific Ways poster in her classroom (see Appendix), which contains sentence frames that students can use to mediate conversations around particular goals. For example, if a student were to want to clarify another student's idea, they could use frames, such as "What do you mean when you say…?" or "Are you saying that…?". Thus, having more

PSTs engage with STeLLA through their coursework and using the developed tools could provide PSTs with the strategies to needed to address their needs in the classroom.

PSTs reported receiving coherent feedback from their education faculty, science supervisors, and MTs. Although each stakeholder provided a different lens to their feedback, the PSTs found their advice to be helpful for supporting their teaching. One PST described the feedback received from their mentor teacher and education faculty member as two sides of an arch that support each other (PST Interview, 4/22/20). Although the PSTs described their science supervisor's feedback as not content-specific, PSTs reported that their needs were met through all relevant stakeholders.

University B. As with University A PSTs, University B PSTs reported that the pedagogy used by university education faculty was aligned with their vision of effective science teaching and learning. However, there were mixed reviews for university science courses, with some described as "not inquiry based," whereas others, particularly biology courses taught by faculty affiliated with the pre-service science program, were aligned (PST Interviews, 4/20/20 and 5/18/20).

University B team's plan involved revising their education courses to better support PSTs' use of the STeLLA strategies. However, University B's PSTs reported differences in the extent to which the STeLLA strategies were explicitly discussed as part of their university pre-service program. One PST described familiarity with the STeLLA questioning strategies, which was the focus of the inquiry lab pilot work, and a focus on designing lessons around main learning goals (PST Interview, 5/4/20). However, another PST described an unfamiliarity with the STeLLA strategies prior to attending the BSCS-led PST-MT institute (PST Interview, 4/20/20). Despite the lack of familiarity, PSTs recognized the value of the STeLLA strategies for supporting student learning. For example, one PST reported the desire to use "open-ended thinking questions and activities" to elicit student ideas, while another used the strategies to support students who were afraid of being wrong (PST Interview, 4/20/20). PSTs described alignment in the feedback provided by education faculty and MTs, which they attribute to faculty's status as "master teachers," who are still active with or not far removed from classroom teaching, which may enhance their ability to provide relevant feedback to PSTs (PST Interview, 4/20/20).

With the delay in implementation of University B's plan, we posit that future PSTs will benefit from an enhanced uniformity in their PST experience, both in terms of familiarity with the STeLLA strategies and the support provided for using them to support student learning during their field experiences. These findings also suggest that the ability for science faculty to collaborate with education faculty may facilitate the cross-pollination of ideas and strategies that could enhance the pedagogy used in university science courses.

University C. PSTs at University C commented that the instruction they received in their seminar courses that highlighted STeLLA strategies was very different from what they saw modeled in either their university educational foundations or science content courses. One PST noted that in educational foundations courses, they might learn about effective teaching strategies, but while the instructors were informed on relevant practices – they did not teach in a manner consistent with those practices, they "didn't walk the talk" (PST Interview, 4/23/20). Similarly, when describing highly impactful science courses, they discussed the teachers' enthusiasm for the subject or ability to create relationships with students – rather than their

teaching effectiveness – that made the course interesting and motivating (PST Interviews, 5/1/2020, 4/23/20).

University C introduced the STeLLA strategies explicitly in the four seminar courses associated with classroom observations and practicum experiences. PST described learning about the strategies and seeing them in action in classroom videos. One PST described an early seminar course in which he was introduced to the STeLLA strategies, but as important, the faculty instructor modeled them in his own instruction. "[My first seminar instructor was highly influential] not only because he teaches it, but he models it while he teaches it, which is something that doesn't really happen a ton, so that's pretty impressive" (PST Interview, 4/23/20). Other PSTs noted the impact of revisiting the STeLLA strategies in the methods course, taught the semester prior to student teaching. When asked who influenced her the most in becoming the science teacher she wants to be, one PST identified her student teaching supervisor and science methods instructor.

> He was super into STeLLA. 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. So, he was super into it. So, we learned a lot about lesson planning from the STeLLA perspective. (PST Interview, 4/22/20)

While coherence across the educational and practicum experiences was a goal of the STeLLA CO^2 work, our preliminary findings indicate that the goal has not been fully achieved across the three universities. The findings suggest that PSTs are benefiting from University C's implementation of STeLLA throughout their PST program. It should be noted that University C began incorporating STeLLA during Phase 1 of the project. Thus, these findings suggest that University A and B's PSTs could have positive effects as changes are made and impact PSTs.

University Team Work

In other STeLLA projects, BSCS staff has taken the lead on developing innovations and providing support for new leaders to enact the developed innovations. In contrast, an important feature of our scaling work involved shifting the ownership of the work to the university team participants and giving teams the freedom to reinvent the program to meet their needs, with support from BSCS staff. In doing so, each university faced their own unique challenges as they implement and iterate upon their plans.

University A. As a team, University A team participants reported a common vision for the usefulness of the STeLLA strategies to support and enhance PSTs' classroom practices. The university plan had a positive impact on MTs' relationship with education faculty, as MTs reported having a clearer understanding of what the PSTs were working on in their university courses, allowing MTs to provide PSTs with the right opportunities to practice and develop their classroom practices and use consistent language when providing feedback.

At the same time, University A experienced some challenges. Due to the size and number of districts represented on the team, MTs desire more frequent meetings among the entire team to ensure a common vision as they continue to test and refine the designed tools. MTs reported that additional meetings would be helpful to allow the lesson planning template and observation protocol teams to share their ideas to ensure alignment between the tools. In addition, MTs wished to have additional conversations with education faculty about how the developed tools

would be used in the context of the university program to ensure that the tools were used to provide formative feedback rather than to formally evaluate PSTs. Furthermore, MTs desired opportunities to improve the tools and protocols and to design less scaffolded versions of the tools in later courses to correspond with PSTs' developing expertise and more closely resemble tools that practicing teachers may use on a regular basis.

Although University A team's work contributed to improving relationships between education faculty and MTs, the science faculty felt less engaged in the core aspects of the university team work. The science faculty members designed courses that used pedagogy that aligned with the STeLLA strategies, including one course that was cross-listed with the School of Education to learn strategies for teaching biology. However, this work was done in parallel and was not part of University A team's original plan. During interviews, science faculty shared ideas for working with PSTs, such as co-teaching the cross-listed course with a faculty member familiar with the STeLLA strategies or inviting mentor teachers to host small group discussions. However, science faculty resisted sharing their ideas with the broader team, as they felt that the PST program was a "well-run ship" and did not want to suggest ideas that may not be useful or without being explicitly invited to do so by education faculty. Thus, more intervention might be needed to welcome science faculty's contributions to the University A PST learner experience. At a recently hosted STeLLA CO^2 project meeting, this issue was brought up through a facilitated conversation, and the University A team decided to make this cross-listed education and science course a core part of University A's team plan. Thus, the stakeholder role arrows in Figure 2 represent the science faculty's increased role in the cross-listed teaching and learning biology course, while maintaining their primary role in the instruction of their own science courses.

University B. The University B team is beginning to overcome issues that affected their team's progress. Due to competing priorities and differences in participants' perceived usefulness of the STeLLA strategies and/or the STeLLA CO^2 program, the team struggled to develop common vision among education faculty and MTs for how the STeLLA strategies could support PSTs. The pilot project, described earlier, was a turning point for the team, as it prompted the education faculty members and MTs to be more receptive to hearing one another's perspectives to support PSTs. In addition, this experience was the impetus for the co-development of a shared vision for how the STeLLA strategies could be a central, rather than a tangential, part of efforts to support PSTs. MTs pushed for the STeLLA strategies to have a more central focus in education courses and offered to take on a more active role in supporting the practical aspects of teaching PSTs how to use the STeLLA strategies in their classrooms. In addition, it was decided that the university team would be co-led by an education faculty member and MT to ensure a shared vision and enhanced communication among the team.

Initial feedback from University B's team's work has been positive, which provided evidence for continuing the collaborations between education faculty and mentor teachers. Team members felt that there was more coherence within the courses and a greater sense of community among the team. In addition, university faculty members reported that the co-constructed work was more effective at achieving the desired learning goals compared to previous efforts.

> [Mentor Teachers are] designing some lesson plans with my input and then I'm going to teach them. We started with research methods like Friday, and I taught [Mentor

> Teacher]'s lesson and it went very well, very well. It's just kind of taking what I've already done and tweaking it to fit the needs of what they think the students [need], and I have to say I think the lesson that she designed was much better than what I was doing previously. (University Faculty Interview, August 30, 2020)

The team is now developing plans to revise additional courses within University B's PST program to ensure the incremental and coherent development of PSTs' understanding of the STeLLA strategies through their time in University B's PST program. In addition, University B's PST program approved the development of a new course centered around the use of the STeLLA strategies for PSTs early in their program. This program will be co-taught with a new university education faculty member, who recently joined the STeLLA CO^2 project.

Despite the progress in the University B team's work, there are some persistent challenges. Due to time constraints, not all members of University B's team were able to actively participate in the plan development and implementation. However, we hope that participation will increase post-COVID-19. Although we have had some participation from science faculty, their involvement, including attendance at meetings and collaborative contributions, has been limited. As a result, the impact of what they learned about STeLLA has been limited to their own instruction and courses. Thus, the stakeholder role arrows in Figure 3 represent the collaborative work of the University B education faculty and mentor teachers, and the parallel work of the science faculty in teaching their science courses. Despite these challenges, the team has made tremendous progress towards achieving their goals for building a more coherent and effective PST program.

University C. Three big challenges face University C. The first is that multiple, rotating faculty from across the sciences lead practicum seminars – only a few of whom were introduced to STeLLA through our Phase 1 STeLLA workshops. The team has creatively met this challenge by having mentor teachers introduce STeLLA strategies and video analysis as guest instructors throughout the seminar sequence. This has multiple positive impacts. More science faculty are introduced to STeLLA as they take their turns as instructors in practicum courses and may begin implementing the strategies in their own science instruction. In addition, PSTs are introduced to experienced teachers who use these strategies themselves and begin to develop relationships that can support them throughout their PST learning (and beyond). The second challenge was that there were more PSTs needing practicum placements than trained STeLLA teachers. The team met this challenge by developing a program for teachers in the local district who wanted to host PSTs to introduce them to the STeLLA approach. The third challenge is the lack of involvement of education faculty, leading to a lack of coherence between what PSTs learn about effective education in their foundational coursework and the practicum courses taught in the College of Natural Sciences. In interviews, many PSTs mentioned the lack of continuity between their theory-based education courses and the science department-led practicum seminars and methods courses. Additionally, the University C's School of Education arranges all practicum placements, which presents a problem when trying to prioritize placement with STeLLA CO^2 MTs. Thus, additional coordination may be needed between science and education faculty and school districts to ensure coherence for PSTs and take advantage of the PD planned by the MTs in the district to have teachers well-versed in STeLLA. Although the roles on University C's team were met by recruiting science faculty who taught science-specific methods courses and science

courses, these findings suggest the need to reach out to education faculty to support coherence in PSTs' learner experience. We have had some initial meetings with education faculty involved in teacher placements and will continue to introduce the STeLLA-focused work being done in the science department with PSTs and MTs, and then, hopefully, begin to enter collaborative exchanges to bring greater coherence to the PST learning experiences in the field.

Discussion

Through the STeLLA CO^2 project, three university teams used and applied what they learned about the STeLLA framework to develop a common vision for effective science teaching and develop plans that enhanced the coherence of their PSTs' learner experiences. Through this work, the STeLLA program was not adopted whole-cloth; rather, it was reinvented to meet the specific institutional needs of each university program. Underpinning this work was the use of the STeLLA Conceptual Framework that provided a common vision and language for stakeholders to use when referencing effective science teaching and learning. While BSCS staff released control of the program to university team participants, BSCS still supported each team with the resources to help them realize their goals. However, each team's plan included sustainable components that would allow the inclusion of the STeLLA conceptual framework to persist in each university team program beyond the grant period. For example, each university has developed tools or revised aspects of their education courses that will institutionalize aspects of the STeLLA program. At Universities B and C, relationships have been built with local schools to develop a network of co-instructors who can facilitate lessons within the university context, thus enabling STeLLA to be at the center of instruction despite changes in faculty. At University C, they have gone further to enhance the pool of mentor teachers within local districts through district-based professional learning who could host PSTs and potentially serve as instructors in the university courses.

We are currently mid-way through Phase 2 of this research and will continue collecting data from PSTs experiencing the STeLLA-modified programs at their universities through the Spring of 2022. Thus, we hope that the analysis of data from the remainder of Phase 2 will present additional findings to ascertain the effects on PSTs' classroom practices from the implementation of each university's plan. Although PSTs reported alignment of pedagogy and feedback in education courses and student teaching, almost all PSTs reported lack of coherence in the pedagogical approach used in their traditional science courses. These findings suggest additional work is needed to enhance coherence with science courses. As suggested by PSTs' statements about the alignment of pedagogy in science courses taught by faculty affiliated with university education programs with their vision of effective science teaching and learning, efforts by science faculty to learn from and with education faculty colleagues may support the use of strategies and approaches that can support coherence for future PSTs and enhance PST learning. In addition, the development of education and science courses that incorporate the use of the STeLLA strategies may support the use of those strategies with departments, particularly as new or different faculty are exposed to the strategies through the co-teaching of courses. Thus, plans for sustaining the use of the STeLLA strategies in these courses require on-going support.

Our research also highlights that there is still work to be done in using the STeLLA strategies in more explicit ways in university courses in order to leverage the opportunities for PSTs to use the same language with science faculty (and in the case of University B, Learning Assistants), education faculty, and their mentor teachers to describe approaches to teaching and providing meaningful feedback. The university teams certainly saw the affordances of using the

STeLLA strategies as a common language; however, in order to leverage it, university faculty need to make a concerted effort to incorporate the strategies in their coursework.

Our research also highlights the challenges of developing and implementing a common vision that accounts for the ideas and roles of all relevant stakeholders. Figures 2-4 reflect the differences in the roles adopted by each stakeholder group at each university. All stakeholders need a clear role and invitation to meaningfully contribute to their community's plan. Each university team distributed leadership in different ways that influenced the focus of their plans. At University A, the team was led by education faculty, which influenced their focus on developing tools needed for their PST program. Since education faculty and MTs were the primary stakeholders responsible for using those tools, the science faculty adopted more of a consulting role in the work. In contrast, there was more distributed leadership between MTs and faculty at Universities B and C, which may have been due to only having two, rather than three, stakeholder groups actively engaged in the STeLLA CO^2 project work. In addition, this research highlights the importance of communication and intentionality when inviting stakeholder groups to the table to ensure that all stakeholders are productively engaged in realizing the vision.

In conclusion, our findings suggest the promise of using the STeLLA approach to support coherence in PST programs. The STeLLA CO^2 program offered the opportunity for relevant stakeholders to use STeLLA framework and approach to video-based analysis to support the co-development of a common vision for effective science instruction and use a common language to describe targeted aspects of science teaching and learning. As part of our ongoing research, STeLLA leaders have used these initial findings to support university teams in modifying their plans and resolving identified community issues. Ongoing work includes the analysis of data to investigate the impact of the university plans on PSTs' content knowledge, pedagogical content knowledge, teaching practices, and the science learning of students taught by STeLLA CO^2 participants.

Appendix

End of Year University Plan Implementation Survey (All Participating university faculty & mentor teachers)

Progress on University Plan

1. What progress has your university team made on your plan this year?
2. How do you think these changes better prepared or will better prepare PSTs?
3. As a member of your University Team, what suggestions do you have for improving your University Team's plan? Why?

Participants' Role in Community of Practice

4. What was your role in enacting this plan this year?

5. Likert style questions from University Team Monthly Check-in: Reflecting on your experience **this year**, please indicate the extent to which you agree with the following statements.
    - I am satisfied with my university team's progress in implementing our STeLLA plan.
    - The STeLLA work my team has been doing is aligned with **my vision** of what should be occurring.
    - I am satisfied with **my role** on the University team.
    - **My ideas and expertise** were valued by my University team.
    - Through my STeLLA work, I feel like **I am part of a community** that is committed to improving preservice teacher education.

6. Likert Style Question with Conditional Follow-up: Based on your experience working with your University team as a whole, please indicate the extent to which you agree with the following statement:

    I believe that **my team members share a common vision** for implementing STeLLA.

    - For those who *agree/strongly agree*:
        1. What are some examples of ways in which your team has demonstrated and/or utilized this shared vision?
    - For those who *disagree/strongly disagree*
        1. What challenges do you think prevented the development of a shared vision?
7. In what ways did your participation in the STeLLA community of practice impact your own classroom practices?

8. In light of your successes and challenges working with PSTs this year, what changes will you make to your work with PSTs moving forward? Why?

University Team Participant Interview Protocol

1. What do you think are the most important features of a program for preparing effective PSTs?
    - Are there ways in which your STeLLA experience has enabled to you better support (or not) PSTs in these areas? If so, in what ways.
    - In what ways did your University Team Plan reflect these features?

2. To what extent do you think features of your University Team's plan have the potential to effectively prepare PSTs?
    - As a member of your University Team, what suggestions do you have for improving your University Team's plan? Why?

3. Did you feel like *everyone on your team* shared a common vision for implementing STeLLA or improving PST education?
    - If yes:
        - What are some examples of ways in which your team demonstrated and/or utilized this shared vision?
    - If no:
        - What are some examples/experiences that indicate, to you, that not everyone shared a common vision?
        - What challenges do you think prevented the development of a shared vision?

4. <u>University Team Lead</u>
    - What successes or challenges has your team faced as a result of implementing STeLLA?
    - What success or challenges do you anticipate in the coming year as we look forward to the coming year?

5. What suggestions do you have to help your community work better together to support your team's goals?

6. Show General Theory of Change Model with participants
    - To what extent do you think this diagram identifies the relevant features of our collective work together to influence PST classroom practices and Ss learning?
    - Are there particular things that you would change to reflect your experience?

End of Student Teaching PST Interview Protocol

Thank you so much for agreeing to talk with me today about your pre-service teaching experience. I'd like to talk with you today about your student teaching experience and how the program you participated in helped to prepare you to be a successful science teacher.

- Do you have any questions before we get started? YES NO
- Is it OK that I record our interview? YES NO

Name:
Content Area for Certification:

First, we'd like you to reflect on the student teaching that you have either completed or will soon complete.

1. **What has your student teaching experience been like this semester?**
    - To what extent did you plan and teach your own lessons?
        - What type of support did you receive to do this work?
    - To what extent did you have to adjust your classroom practice to engage in remote teaching?
        - How did this affect your ability to elicit, probe, and challenge your students' thinking?
    - [If PST had limited student teaching experiences this semester, ask them to reflect on other teaching experiences they may have had in previous classes or semesters.]

2. **Have you heard about STeLLA or the STeLLA strategies in your university coursework?**
    - If so, what strategies have you heard/learned about? In what ways did faculty help you learn about these strategies (Watch classroom video? Read about the strategies?)
    - If not, do a high-level explanation about STeLLA. As part of our work with your universities, we've been talking about strategies that can help teachers reveal and support student thinking and support coherent science instruction from students' perspective (e.g., having a focus question or making explicit links during a lesson.

3. **When observing or student teaching with mentor teachers, to what extent were they familiar with using the STeLLA strategies (or similar strategies) in their classrooms?**

4. **To what extent do you feel that you used the STeLLA strategies or similar strategies when planning and carrying out your lessons?**
    - How were the strategies useful for moving your students' thinking forward/advancing your students' learning? Can you give us some examples?
    - What type of support did you receive for using these strategies in your classroom?
        - Probe whether exposure was during PST/CT workshop at BSCS or in university courses

In light of the experiences you've had thus far, let's now think about your ideal vision what effective science teaching and learning would look like in your own classroom.

5. **Classroom Vision:** Without considering the limitations or constraints for what you can do, how would YOU *ideally* like to see teaching and learning taking place in your classroom?
   - What do you envision the learning process to be like?
     - How do you envision yourself supporting that learning process?
   - What are the students doing?
   - What is **your role** in this classroom? Why is this role important?

The next few questions ask you to reflect on your pre-service teacher experiences and the people that feel were important for preparing you to be a successful teacher.

6. **What were the two most important aspects of your PST experience that you think will prepare you to be a successful teacher? Why?**
   - Probe role of Education Courses, Observations, Student Teaching, and Science Courses.

7. **Who along your path [PST experience or before] were influential for preparing you to be a successful science teacher? In what ways were these individuals helpful?**
   - Probe role of Education Faculty, Mentor Teachers, and Science Faculty.

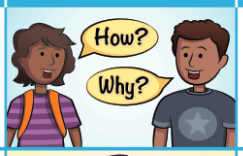
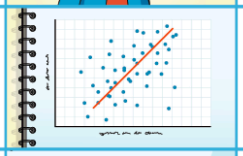
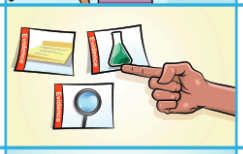
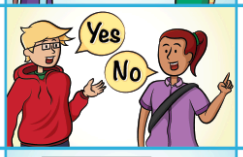
8. **As you start your career, what type of support do you feel you will need to become the teacher you desire to be?**
   - Is there anything you do not feel prepared to do?
   - [Identify what was missing from their PST experience or how they would build upon what they experienced]

Coherence of PST Experience

9. **INSTRUCTION**: As a learner in your *education* and *science classes*, to what extent was the way in which you were taught consistent with your views about effective science teaching and learning?
   - Probe the methods or approaches used to support the PST's learning.
   - Probe any differences between courses.

10. **FEEDBACK:** As a developing teacher, to what extent was the *advice* and *feedback* you received from faculty, mentor teachers, and/or science supervisors coherent?
    - Probe any differences between stakeholder groups.

Communicating in Scientific Ways

What a scientist does	Symbol	What a scientist says
1. Ask why and how questions.		How come … ? I wonder how … ? I wonder why … ? How do they know that … ?
2. Observe.		I see … . I noticed … . I measured … .
3. Organize data and observations; look for patterns.		I see a pattern … . I think we could make a graph … . I see a relationship between … . Our data tell us … because … .
4. Think of an idea that explains your data and observations.		My idea is … . I predict _____ will happen because … . I think what causes this is … . I could draw a picture/diagram to show … .
5. Give evidence for your idea or claim.		My evidence is … . The reason I think that is … . I think it's true because … .
6. Listen to others' ideas and ask clarifying questions.		Are you saying that … ? What do you mean when you say … ? What is your evidence? Can you say more about … ?
7. Agree or disagree with others' ideas; add onto someone else's ideas.		I agree/disagree with _____ because … . I want to piggyback on _____'s idea. I want to add to what _____ said.
8. Search for new ideas from other sources.		We could get some new ideas from … . Is that a reliable source? How do we know? This information is like (or not like) other ideas we've found because … .
9. Consider if new ideas make sense.		That idea makes sense to me because … . That idea doesn't make sense because … . That idea matches what we saw because … .
10. Design an investigation to get more evidence.		What if we … ? We could get better evidence if we … . We could test our ideas by … .
11. Let your ideas change and grow.		I'm changing my idea, now I think … . I want to add to my idea … . I am going to write down _____ in my notebook.

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