Related Paper Set for 2022 ASTE International Conference

Lessons Learned: Successes and challenges of fostering cross-stakeholder collaborations to enhance the effectiveness and coherence of secondary science preservice preparation programs

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Strode, P., & Martin, A. (2022, Jan 7). *Using STeLLA as a framework for teaching and learning biology in a tier 1 research University setting* Paper presented at 2022 ASTE International Conference, Greenville, SC.

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Lessons Learned: Successes and challenges of fostering cross-stakeholder collaborations to enhance the effectiveness and coherence of secondary science preservice preparation programs

Preparing new secondary science teachers to navigate the multiple and sometimes conflicting images of what effective science teaching looks like, sounds like, and feels like in the age of the Next Generation Science Standards (NGSS) is a complex challenge for preservice teacher programs. Darling-Hammond (2014) identified common features of effective teacher preparation programs that made a difference in producing graduates who were “extraordinarily well prepared from the first days in the classroom” (p. 548). Among those features, Darling-Hammond noted that effective teacher preparation programs were characterized by strong relationships, common knowledge, and shared beliefs among all those who influence the preparation of new teachers, including university and school-based instructors, supervisors, and mentors. These programs were grounded in a common, clear vision of good teaching that “permeated all coursework and clinical experiences” to create a coherent image for new teachers. Korthagen et al. (2006) went further to state that learning about teaching is enhanced when “the teaching and learning approaches advocated in the program are modeled by the teacher educators in their own practice” (p. 1036). To reach these goals, Zeichner (2010) advocated creating third spaces in teacher education that allow for boundary-crossing with a sharing of knowledge and expertise among all aspects of university instruction and field experiences.

Theoretical Framing

While many programs strive for coherence between university-based teacher education and secondary school settings, these efforts are often stymied in the face of complex university and school district institutional contexts, the siloed knowledge bases of education and science faculty and mentor teachers, and the varied background knowledge and beliefs of stakeholders invested in the success of teacher candidates (Korthagen et al., 2006; Nordine et al., 2021; Zeichner, 2010) that hinder opportunities to collaborate and co-develop a shared vision for organizing secondary science teacher preparation. Given this backdrop, the STeLLA CO^2 project was developed to study how building community among university science faculty, university education faculty, and mentor teachers to develop a common knowledge base and a clear, well-articulated vision of secondary science teaching could enhance the effectiveness and coherence of secondary science teacher preparation programs at three universities in the Mountain West region: University of Colorado at Colorado Springs (UCCS), University of

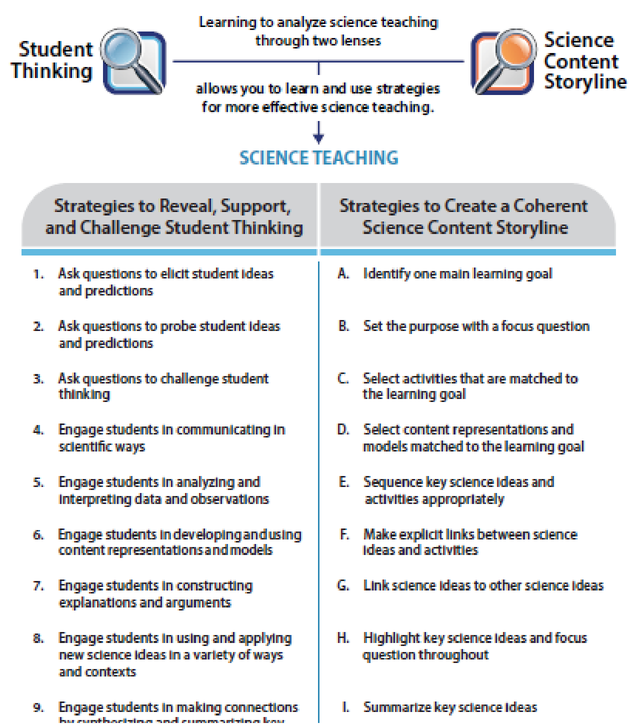

Figure 1: The STeLLA Conceptual Framework used to bring coherence to university-based science and education courses and practicum experiences at three university sites (BSCS Science Learning, 2018).

Northern Colorado (UNC), and the University of Colorado at Boulder (CU Boulder). This work is grounded in the reform vision found in the National Research Council (2012)'s Framework for K-12 Teaching and the STeLLA (**S**cience **Te**achers **L**earning from **L**esson **A**nalysis) Conceptual Framework (see Figure 1, BSCS Science Learning, 2018), which includes strategies that students and teachers can employ to realize this reform vision. The STeLLA Conceptual Framework has two lenses: 1) the Student Thinking Lens, which includes strategies to reveal and challenge student thinking, and 2) the Science Content Storyline Lens, which includes strategies to support students in developing strong, coherent connections to science concepts (Roth et al., 2017). 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) and preservice settings (Wilson et al., 2017).

The STeLLA CO^2 Approach: Facilitating cross-stakeholder collaborations to realize the reform vision

The STeLLA CO^2 approach towards tackling the lack of coherence in preservice science teacher (PST) preparation involves developing a community among all relevant stakeholders involved in preparation: university science faculty, who contribute to PSTs' science content knowledge and vision for how science is taught; university education faculty, who contribute to PSTs' content and pedagogical content knowledge (Shulman, 1986); and mentor teachers (MTs), who supervise PSTs' field experiences. Figure 2 illustrates our Theory of Change for how the STeLLA CO^2 approach can support PSTs and their students.

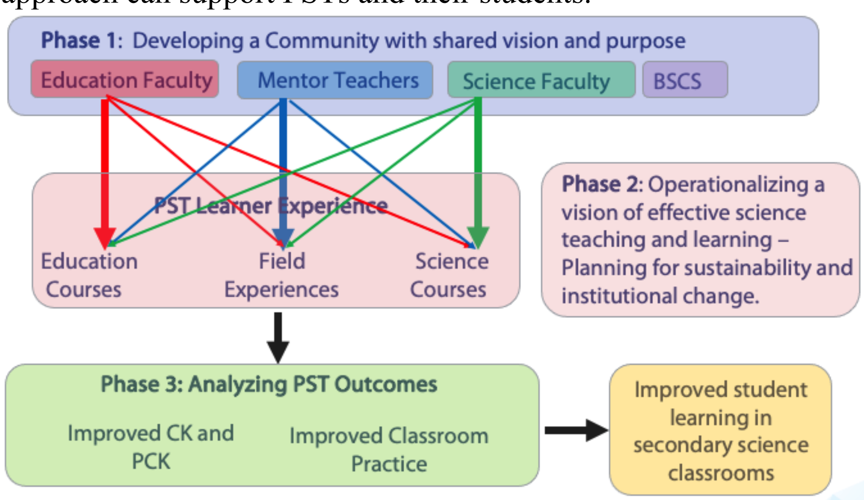

Figure 2. STeLLA CO^2 Project Theory of Change

In Phase 1, we invited stakeholders who work with PSTs at each university to work in cross-stakeholder teams using video analysis to learn about the STeLLA strategies and their use in supporting secondary science learning. Team members then applied what they had learned to enhance their own unique university or secondary classroom teaching. Through this work, the STeLLA strategies served as a common language through which relevant stakeholders could describe desired classroom practices and co-develop actionable ways to realize their vision for effective science teaching in their own contexts (Lo et al., 2021).

In Phase 2, we invited cross-stakeholder teams to apply what they've learned to enhance the effectiveness and coherence of their university preservice science teacher programs. 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. A core feature of our approach involves supporting equity in the role and participation of all stakeholders, allowing stakeholders to adopt different roles than they might traditionally adopt, such as involving MTs in the design and teaching of university courses with university faculty. It is a novel, yet challenging approach, as it requires developing and reinforcing norms to ensure all ideas and voices are heard and respected, regardless of their position or role in preparing PSTs. In our theory of change model, 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) and vary the thickness of the arrows to reflect the vision of each stakeholder contributing their perspectives and expertise to inform each aspect of the PST learner experience.

In Phase 3, we analyze the effects of the university teams' revisions to their university preservice science teacher programs on PSTs' content and pedagogical content knowledge related to the use of the STeLLA strategies and how PSTs' use of those strategies improved secondary science learning. We are currently in this phase.

Introduction to Our Related Paper Set

Previously, Stennett et al. (2020) and Lo et al. (2021) described each university team's work. However, we felt it was important for each university team to share, from their perspective, the successes and challenges of fostering these types of cross-stakeholder collaborations to enhance the effectiveness and coherence of their specific university contexts. To that end, each paper will address a common research question, *What are the successes and challenges of fostering cross-stakeholder collaborations to enhance the effectiveness and coherence of secondary science preservice preparation programs?*

- The first paper, *Successes and challenges of developing cross-stakeholder collaborations to enhance preservice teacher preparation,* described the journey that a team of university education faculty and mentor teachers took towards developing a common vision for supporting PSTs' use of the STeLLA strategies and the successes and challenges for developing a mutually respectful and productive collaborative team to realize this common vision. You'll read about how this team collaborated to co-design revisions to and co-taught revised education classes that involved the use of the STeLLA strategies.
- The second paper, *Closing the Loop: University science educators and mentor teachers collaborating to support coherent teacher preparation*, describes a unique collaboration among university science faculty and mentor teachers to co-develop a shared vision for effective science teaching that impacted disciplinary science instruction, secondary science practicum seminars, and science teaching methods courses.
- The third paper, *Using STeLLA as a framework for teaching and learning biology in a tier 1 research University setting*, describes a collaboration between university science faculty member and a mentor teacher in applying what they have learned to propose a new approach to teaching and learning undergraduate science that addresses the

challenge of a misalignment between the pedagogy used in undergraduate science and education courses.

Each paper will discuss (1) the specific problems of practice that they sought to address through revisions to their PST preparation program and work with local school districts, (2) a window into specific aspects of the program improvements being initiated by each university community, and (3) lessons learned from the process of working together to develop plans and make progress towards realizing their vision. We will conclude with a discussion about how the STeLLA CO^2 approach towards developing coherent PST preparation could be used broadly in university settings to foster productive cross-stakeholder collaborations while enacting sustainable and productive changes within complex systems to better prepare effective secondary science teachers.

Successes and challenges of developing cross-stakeholder collaborations to enhance preservice teacher preparation

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The University of Colorado in Colorado Springs (UCCS) team embarked on a journey to enhance the coherence and effectiveness of the UCCSTeach secondary science preservice teachers (PST) program. A typical PST would engage in eight, sixteen-week long courses prior to student teaching (see Table 1 below for a typical course trajectory). Our team consisted of two university education faculty members, seven mentor teachers (MTs), and one university science faculty member. During our initial planning meetings, the MTs identified common issues when working with PSTs: the need for greater command of strategies to elicit and build on student thinking. Our team deliberated on how we could use what we learned about the STeLLA strategies to better support PSTs. In addition, the team identified the need to create additional fieldwork and mentoring opportunities for PSTs with MTs to allow PSTs the opportunity to practice using the strategies they had learned in their education courses and leverage the expertise of teachers who use them daily.

The Beginning

As a team, it was decided to target the course Science Research Methods first, as it did not originally have a field component and could be a fruitful starting point for developing ways to integrate the STeLLA strategies into the coursework and design opportunities for PSTs to work with MTs to learn how to use them effectively in an actual classroom. Furthermore, it was a valuable opportunity for both the university education faculty and MTs to work together to use the STeLLA strategies as a common language to discuss desired mechanisms for enhancing PST teaching and secondary science students' learning.

During the Fall 2019 semester, we implemented our first version of the revised Science Research Methods course that focused on learning the STeLLA strategies and designing a culminating lab activity, in which PSTs worked with a MT to design a series of inquiry-based lessons that involved using the STeLLA strategies to elicit, probe, and challenge student thinking and support students in analyzing and interpreting data collected from the planned investigations. In doing so, we desired to shift the PSTs' focus from the mechanics of doing the planned investigations to supporting student sensemaking during the investigations. PSTs were paired with a MT involved in the STeLLA CO^2 program to support their use of the STeLLA strategies.

Our initial findings were varied. During our debrief sessions, the team shared that PSTs had challenges using the STeLLA strategies when designing and carrying out their lessons. We realized that reading about the strategies was not sufficient for preparing teachers to use the strategies with students. Furthermore, the lack of consistency in the level of explicitness for using the STeLLA strategies by team members prevented the PSTs from developing a common language or vision for how the STeLLA strategies could support students' learning. Furthermore, our debrief revealed that our team did not always effectively collaborate with a common vision and leverage one another's strengths to support the PSTs. We felt the need for better communication so that we developed a common understanding of what was expected of PSTs and indicators of a successful lesson.

Learning and Growing: Making Better Change

As a team, we recognized the need to better understand one another's classrooms and develop a common understanding of our priorities. During our team study groups, we analyzed videos of one another using the STeLLA strategies and considering how the strategies could improve our own practices. Understanding what was emphasized in the education classroom could help MTs better support PSTs during their field experiences. As we continued to work together in service of our PSTs, rather than advocating for their viewpoints, we began to better support one another as a team and developed three goals that framed the design of future work to support PSTs:

Goal 1. The first goal was to better support PSTs' intentional use of the STeLLA strategies through explicit instruction in their education and opportunities to practice using the strategies in ways that aligned with the PSTs' experience in the planned trajectory of the program. To effectively do this, we planned to have MTs who had classroom experience using the STeLLA strategies design and facilitate classroom sessions related to the STeLLA strategies with PSTs in their university education courses. These same MTs would then support the use of the STeLLA strategies during field experiences in their classrooms. Education faculty would also model the use of the STeLLA strategies in their instruction and create periodic opportunities to take off their "teacher hat" to talk about which STeLLA strategies they were using and why. Through this complementary work, MTs and education faculty worked together to enhance the coherence of the PSTs' learner experiences by allowing PSTs to observe the STeLLA strategies in action and understand not only how they could use them with secondary students, but experience how the strategies impacted their own learning.

Goal 2. The second goal involved MTs designing and hosting workshops for PSTs to complement the revised university courses and provide PSTs with lesson planning support and more opportunities to learn about the use of STeLLA strategies while deepening relationships with MTs. This goal married the ideas of strategic incorporation of these STeLLA strategies within the UCCSTeach program and deeper collaboration between university education faculty, MTs, and PSTs.

Goal 3. The third goal involved disseminating the successes and outcomes of our collaborative work to incorporate STeLLA. Part of this work involved sharing and encouraging other UCCSTeach faculty to consider the relevance of the STeLLA strategies for their courses. This goal is synergistic with our desire to build sustainable changes to our program so that relevant stakeholders understood the significance of the work and would be willing to invest in it in the future.

Articulating these three goals provided a shared vision for how our team was going to work together going forward to develop a shared understanding for the intentional use of the STeLLA strategies to support student learning Since the UCCSTeach program involves both math and science students, courses were chosen based on their ability to impact science students and involvement by STeLLA CO^2-associated faculty in their teaching (see Table 1 for the current and planned revisions to courses).

Table 1.
Current and planned course revisions to UCCSTeach program

Typical PST Path	**Modifications with STeLLA Currently Implementing**	**Future Planned Implementations**
Step 1 and Step 2	Intro Class (Hybrid Step 1-2 course with STeLLA strategies embedded in course)	Continue implementation and refinement to meet needs of PST.
Knowing and Learning	-	-
Classroom Interactions	-	Redesign to add elements of STeLLA strategies to course
Science Research Methods (Science only)	Field Experience with STeLLA strategies embedded in the course and work with MT to develop further understanding of strategies	Continue implementation and refinement to meet needs of PST.
Perspectives on Science and Mathematics	-	-
Reading in the Content Area	-	-
Project Based Learning	-	Redesign to add elements of STeLLA strategies to course
Student Teaching	Work with MT to continue practicing strategies	

The team developed revisions to the courses that accounted for their position and role in the planned trajectory for a typical PST and created synergistic opportunities for PSTs to practice what they've learned with MTs. For example, PSTs in introductory courses would receive support in designing inquiry-based lessons that make explicit use of a limited number of STeLLA strategies learned in class. By the time the PSTs got to Science Research Methods, the hope was that PSTs would have developed sufficient capacity to plan and enact their own lessons. Cycles of reflection and feedback from stakeholders were incorporated at the end of each semester, which then informed the design of revisions.

In what follows, we describe steps that we've taken to achieve Goals 1 and 3. In particular, we outline revisions that were made to the Science Research Methods and the first two courses of the UCCSTeach sequence (Step 1 and 2) that foregrounded the collaborative work between education faculty and MTs to enhance the coherence of the PST learner experience and better support PSTs' use of the STeLLA strategies to support secondary science students' learning.

Science Research Methods: Use of STeLLA strategies to support structured inquiry. From our discussions, Science Research Methods went through two further rounds of revisions to better support students in using the STeLLA strategies. We redesigned the first five weeks of the course to introduce "structured inquiry," to help students learn strategies and approaches that align with the new Colorado Academic Standards for Science (2020) and the NRC (2012)'s Framework for K-12 Science. Central to these revisions involved supporting students in using evidence to iteratively develop models to explain phenomena. To complement this work, MTs designed a learner experience allowing PSTs to experience using a phenomenon-based approach. The MTs modeled and engaged in explicit discussions about how the STeLLA strategies of *Identifying a main learning goal* and *Setting a purpose with a focus question* could support coherent learning from the students' perspective. In addition, MTs designed lessons to support PSTs in using the Claim, Evidence, Reasoning (CER) framework (McNeill, 2009) to support the development of evidence-based explanations. Through these revisions, PSTs had the opportunity to ask questions and learn how to use these strategies in intentional ways with their lessons before using the learned strategies to develop inquiry lessons that they would enact with secondary science students in the MTs' classrooms. Education faculty complemented these lessons with additional learner experiences using different phenomena and learner experiences. Initial feedback from PSTs and MTs was promising. PSTs ended the fall semester with a stronger conceptual understanding of what the inquiry process looked like and how to use the STeLLA questioning strategies to elicit, probe, and challenge student thinking. MT also reported a much more solid experience for their secondary students, which included how the PSTs supported inquiry and designed activities that were focused on the explanation of phenomena. The team also identified the need to provide additional support for PSTs in planning lessons and activities that were linked to one main learning goal.

Combining of Step 1 and 2 Courses: Beginning program coherence.

Throughout the project, the STeLLA CO^2 education faculty had been continually updating and sharing the products of our collaboration with the rest of the UCCSTeach faculty, with the desire to incorporate the STeLLA strategies in additional courses to support the coherence of PSTs' learner experience in the program and design additional field experiences for PSTs to work with MTs. In parallel to these discussions, the UCCSTeach program had discussed streamlining the program by combining the first two field-based courses, which supported students in designing and implementing lessons with elementary and middle school students. The UCCSTeach program faculty was encouraged by the initial findings from the STeLLA CO^2 team's work and the collaborative and authentic experiences that the cross-stakeholder team was designing for PSTs that leveraged a synthesized understanding of best practices from education faculty and MTs.

The team developed a proposal, which was accepted, to revise and develop the proposed combined course. Through this work, the team could begin thinking about the intentional, incremental development of a common language and understanding among all PSTs using the STeLLA strategies that could be built upon by all stakeholders through the PSTs' experience in the UCCSTeach program. The STeLLA strategy booklet (BSCS Science Learning, 2018) became required reading for the course. There are 18 STeLLA strategies, so our team decided to introduce a fewer number of high leverage strategies in this course, leaving space to add additional strategies in later courses with the goal of exposing PSTs to most of the strategies before student teaching. The STeLLA questioning strategies, Communicating in Scientific Ways, and identification of the main learning goal were the strategies chosen for this course. As a team, we chose these strategies because we felt they were easy to understand and could be put into practice quickly to support student learning. In addition, PST could utilize those specific strategies in all their remaining courses to help them grow and aid in their journey toward a successful student teaching.

The Step 1 and 2 courses used the 5E instructional model as a framework for planning lessons. During our initial planning, we restructured the course in two key ways. First, we separated each of the Es and identified STeLLA strategies that would support the knowledge-building work occurring in each E. Second, we incorporated additional field experiences in elementary and middle schools to allow them time to observe and practice using the learned STeLLA strategies. In total, we designed twelve different field experiences (three at the elementary level and nine at the middle school level) during the course, which included classroom observations, opportunities for mentorship, feedback on designed lessons, co-teaching experiences with MTs, and solo teaching experiences. Thus, experiences in the university classroom were reinforced through field experiences and a debrief with education faculty.

The first part of the class focused on the Engage and Explore phases of a 5E lesson plan and the STeLLA questioning strategies. When PSTs went into elementary classrooms to observe, they would think about how the STeLLA strategies were evident in the Engage and Explore phases in teacher's lessons and document what questions were asked during those phases. In their education classes, faculty and MTs worked collaboratively to teach PSTs about the STeLLA strategies through reading about the strategies in the STeLLA strategy booklet and analyzing video excerpts from a STeLLA-trained, elementary MT's classroom to identify examples of the three types of questioning strategies. The video clips shown during the class helped start a discussion about the purpose for using the various question types. PSTs then revisited the questions they documented from their classroom observation to see whether they could then categorize those question using the STeLLA framework. To supplement the discussion, the MT facilitating the discussion shared personal experiences using the questioning strategies in her eighth-grade classroom. She shared how the different question types could be used and what their purpose was in a specific lesson she taught which helped PST deepen their understanding of the questioning strategies. Learning about the strategies in this way allowed PSTs to see the theory of questioning put into practice from different points of view: readings about strategies with examples, observations in elementary MT classrooms, classroom video, and anecdotes from the MTs' classroom experiences. In each experience, PSTs could unpack their understanding of the strategies and how they impacted student learning. Education faculty continued to explicitly model the questioning strategies, which elevated the importance of using the questioning strategies and provided additional time for PSTs to practice and reflect on the use of the STeLLA strategies

The second part of the course involved using the STeLLA strategies to design lessons that were aligned with the standards. We focused on the *Communicating in Scientific (and Mathematic) Ways* and *Identifying one main learning goal* strategies. During this part, students worked with both science and math MTs to design lessons using the STeLLA strategies. PSTs designed lessons using the questioning strategies learned during the first part of the course and the Communicating in Scientific and Mathematic Ways strategies to support classroom discussions to address the main learning goal of the lesson. After the lesson, PSTs and their MTs debriefed about their use of the STeLLA strategies to make visible students' learning. The revisions to the first part of the course paid dividends for PSTs when they taught their lessons at the middle school level. MTs shared that PSTs remembered their experiences with the questioning strategies and were able to employ them with greater confidence and intentionality compared to previous PST cohorts. Because the PST had more opportunities to work with their

MT compared to previous groups, the MTs had already established a relationship in which to better support PSTs' lesson planning and use of the questioning strategies.

Moving Forward and Lessons Learned

Our goal is to use our model for collaboration to continue to revise additional courses in the UCCSTeach program to include more intentional use of the STeLLA strategies to enhance the coherence for PSTs. Our model of collaboration involved 1) stakeholders identifying areas of growth, 2) identifying common goals and expectations, 3) identify examples to illustrate aspects of desired practices, 4) modeling the use of the strategies with PSTs, and 5) providing structured support for PSTs in enacting this work with secondary science students. We have now built two courses that we can use as a model for revising future courses and consider ways to leverage ways of using the STeLLA strategies as a common language that can be used not only by members of the STeLLA CO^2 team, but also other UCCSTeach faculty who co-teach these courses with our team. Through observation and reinforcing what is learned during parts of the class that explicitly support the use of the STeLLA strategies, these faculty members are becoming familiar themselves with the STeLLA strategies. Within a community of practice framework, these faculty may initially be seen at the periphery, but through time and their legitimate peripheral participation in co-teaching the lessons alongside STeLLA CO^2 faculty and MTs, the goal is for them to understand the usefulness of the strategies and the course revisions in the work (Lave & Wenger, 1991). Thus, the goal is for all members of the faculty to be familiar with the common language that is being explicitly developed in these courses. Continuing to include MTs in the review, re-design, and implementation of revised lessons will be important as we move forward. From our initial investment in Science Research Methods, we have seen a huge difference from previous years. The PST have been better at questioning students to reveal, support, and challenge student thinking as well as utilizing evidence-based explanations to explain a scientific phenomenon.

Our team has gone through a lot of growing pains, but this journey has resulted in the development of a cohesive team, who has learned to trust one another as professionals and develop a common vision for preparing effective PST. With a growth mindset, we have prioritized communication and community building. As a team, we are constantly reflecting and re-evaluating our goals to ensure we stay on track with the needs of our PST and attend to all the voices and concerns on the team. We recognize limitations on our own personal capacity, amidst competing demands on our time, and programmatic constraints. At the same time, our focus on a common goal allows us to be creative in how we can meet the desired outcomes. Certainly, our work has shown that this is possible, and we look forward to creating the best teacher preparation program possible, the trust and mutual respect has grown because we have all been working towards a common goal.

We hope that others in the science education community can learn from our experience of partnering together as university faculty and MTs to develop more effective and coherent teacher preparation programs. Promoting institutional shifts at this scale can be a complex challenge. It was important for us to identify opportunities for making small change that were within our sphere of control and learning from those efforts. Through many iterations, we identified important ways in which these small changes led to important shifts in classroom teaching for the PSTs. These small efforts served as important steppingstones for promoting broader, programmatic shifts. Involving MTs and their perspectives from the classroom was critical to these efforts. As such, thinking about ways to increase capacity to sustain these changes over time will be important.

Closing the Loop: University science educators and mentor teachers collaborating to support coherent teacher preparation

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The University of Northern Colorado (UNC) has a robust secondary science teacher education program with a unique context. Whereas foundation courses are taught in the School of Teacher Education, all practicum and science teaching methods courses are taught by university science faculty and housed in the College of Natural and Health Sciences. While UNC prides itself on its strong teaching faculty in every discipline, university science faculty do not have formal training in educational theory or pedagogy. The belief is that content area faculty will bolster PSTs' confidence in their content area while allowing them to apply concepts learned from the School of Teacher Education. Faculty from Chemistry and Biochemistry, Physics and Astronomy, Earth and Atmospheric Sciences, and Biology rotate each semester to teach three practicum seminars and one methods course. In the past, each faculty instructor has drawn on their own experience and expertise in crafting the content of the courses with a central emphasis on using inquiry practices and developing students' scientific thinking through careful use of questioning. The faculty in each area either has specific preparation in K-12 education or has an education-focused research agenda. The STeLLA CO^2 project provided a common professional development experience in which to ground the program.

As our team began our participation in the STeLLA CO^2 project, we faced a two-pronged challenge in our secondary science teacher education program. The first was that PSTs were not provided with a clearly articulated vision of effective science instruction across the seminar and method course sequence. Every instructor had their own vision and goal for their class, which was not consistent across the secondary science teacher education program. In addition, each instructor described and modeled inquiry instruction and effective questioning strategies differently, using their own experiences as a guide, and did not use the same language to convey ideas about effective teaching and learning. This created issues with creating consistent pedagogy, instruction, and flow through the secondary science education programming.

The second challenge occurred when PSTs observed a considerable amount of direct instruction with limited use of carefully crafted questioning strategies or inquiry-based teaching in their field experiences. While the PSTs were being instructed to use inquiry-based teaching methods prior to the STeLLA CO^2 project, all too often they were observing didactic science instruction in their field placements. This made it difficult for them to see the science teaching practices they were being taught in action and created a disconnect between the instruction at the university and the message students would receive during their practicum and internship experiences.

Through the STeLLA CO^2 project we brought together a team of mentor teachers (MTs) from local districts and university science faculty to develop a common vision of high-quality science instruction and then bring this vision to life through the design of a coherent program of teacher preparation courses and field experiences. Through a series of workshops over the course of a full year, which included extensive work in analyzing video of science teaching, the MTs and university science faculty came to a common understanding of how to develop student thinking using multiple strategies that reveal and support student scientific discourse and reasoning and how to improve science instructional planning using a coherent science content storyline. Creating a common vision and curriculum for the classes created consistency with instruction and vision regardless of which instructor was teaching. This also allowed science professors to become more familiar with instructional strategies and better be able to model and use those strategies both in their science content classes and the science education classes. The PSTs were then placed in classrooms with STeLLA CO^2 MTs to ensure they were observing classroom teaching that was consistent with what they were learning through their university courses.

Both MTs and university science faculty were encouraged to enact and model these strategies in their own teaching by developing strong storylines and using NGSS-aligned instructional practices to encourage student thinking and reasoning. The university science faculty were to both enact these strategies in their own science courses and teach the strategies to PSTs through the seminars and methods course. Through doing this, university science faculty would model the strategies and help PSTs identify and enact those strategies.

To support these changes in practice, MTs and university science faculty analyzed their use of the strategies by filming their own classrooms and sharing their clips with the team. In doing so, all team members could reflect on their practice and discuss the nuances of their own disciplinary content and classroom contexts, share their challenges and success, reflect on their own growth, and deepen their connection as a community of teacher-learners. The videos also created more knowledge and connection between the university instructors and MTs creating a continuity and common vision.

We realized that we had a great opportunity to revise our three-semester practicum seminars to slowly introduce the STeLLA strategies in a clear and intentional way – despite the rotating faculty involvement. The STeLLA strategies were part of a framework that could be used to create a flow of content that could be used and taught, regardless of the instructor. Working together, MTs and university science faculty developed a syllabus for each course, designating a sequence for introducing strategies that aligned with the course goals to be sure that the strategies were meaningfully included throughout practicum observations, teaching experiences, and course assignments. In our program, most of this instruction takes place in courses tied to the practicum experience and culminates in the science methods course. By building and incorporating strategies throughout the course and field experiences, students were able to build on and add to their instructional toolbox as they progressed throughout the program.

To best embed the STeLLA strategies in the real world, we invited MTs who were part of our STeLLA CO^2 team to serve as guest instructors to introduce new strategies and engage PSTs and course instructors in analysis of classroom video. In this way we were able to deepen our collaborative partnership with MTs in the community. Since these courses were being taught by university science faculty, these presentations also served to broaden the number of university science faculty with an understanding of the STeLLA-based teaching strategies. Our capacity has grown through this process, so that more university science faculty can model the STeLLA strategies in their own instruction and teach them explicitly in their secondary science seminars and courses. STeLLA strategies provided university science faculty with effective strategies that provided a common language, vision, and direction for the science teacher education program that was coherent with strategies that PSTs were observing with STeLLA-trained MTs. This has helped to create a true 'team' approach to the development of PSTs and allowed the PSTs to feel part of a single coherent system.

We still had a big challenge. With students needing placements in secondary classrooms during three different courses and student teaching, there were not enough MTs with STeLLA experience for all students to see the strategies modeled effectively throughout their university-based course of study and student teaching. It was important for strategies taught at the university to be modeled within their practicum experiences. This allowed a common language between the university science faculty, MTs, and PSTs, as well as coherence with what was being taught at the university and within their classroom observations. This also increased the buy-in of PSTs in the STeLLA strategies as they saw them in practice after learning about them in the classroom.

One outcome of the collaboration between our MTs and university science faculty was the development of a sense of teacher-leader in the MTs. They believed so strongly in these strategies and coherent storyline planning frameworks they wanted to teach them to their colleagues. Our MTs worked with one local district to begin leading STeLLA-based professional learning during district-sponsored release time. While this effort was cut short by the pandemic, we hope to continue the effort and extend the PD workshops to teachers in other local districts. Our goal is to have enough teachers in the community who teach in ways consistent with what is taught at the university so all teacher candidates and their MTs can plan together, have a common language, provide and receive feedback, and reflect on teaching practice and student learning in ways that are coherent and consistent with our vision of high-quality instruction. Finally, we worked with our university placement office to ensure the science PSTs would be placed with STeLLA CO^2 MTs. This closed the loop for the PSTs so they could see in action the same strategies and coherent storyline planning practices they learned about on campus in practice in the field. For the PSTs, this eliminated the discord they often experienced prior to this STeLLA CO^2 project and enabled them to feel more confident the practices they were learning would be effective in their own future classrooms.

Our efforts continue as we work together to make the science-based practicum aspects of the teacher education program more coherent and improve the experiences of teacher candidates. In addition, we are initiating efforts to ensure that the program is sustainable beyond the grant period and reaches throughout the science and education faculty, our university supervisors of student teachers, by continuing to cycle university faculty through these positions and recruiting more teachers who mentor our future teachers through professional development in our local school districts.

Using STeLLA as a framework for teaching and learning biology in a tier 1 research University setting

Paul Strode, Fairview High School
Andrew Martin, University of Colorado Boulder

Context and history of the course

The University of Colorado in Boulder (CU Boulder) offers and supports a training program for students to become certified in Science, Technology, Engineering, and Mathematics education. One of the courses offered through the program is "Teaching and Learning Biology" (TLB), an upper-level course. TLB was originally developed in 2008 and most recently taught in 2017. The class was designed to support students who were interested in, or were on their way to, becoming teachers, as well as students who had an interest in becoming more effective at communicating what they know in ways that educate others but who were not considering becoming a teacher. The original main learning goals for the course include "1) to have students critically reflect on the process of learning biology, focusing on what you know, how you know it, and to extend and deepen understanding of biology; and 2) to examine the nature of biology and how it is—and should be—taught in K-12 and higher education settings." In addition, the course focused on

> examining the nature of biology as compared to models based on the physical sciences; digging into studies about common conceptual challenges in student understanding of biology, such as molecular level stochastic processes (mutation), Lamarckian ideas about evolution, micro-macro relationships, social and sexual selection, and non-adaptive processes (drift, founder effects); and examining how scientific 'facts' are constructed in biology through in-depth analysis of the Grants' research on the Galapagos Islands and the impact of technology on the ability to study stochastic processes.

These content areas do not explicitly map onto the Next Generation Science Standards (NGSS) that has become an increasingly well-established curricular framework for STEM education. Instead, the course foci reflected the research interests of the professor who originally developed the course.

In 2020, the authors teamed up with the original course developer to offer TLB during the fall semester. Paul Strode is a high school biology teacher on the STeLLA CO^2 project and contributed perspectives of a mentor teacher and the College of Education. Andrew Martin, is a university science faculty member from the Department of Ecology and Evolutionary Biology on the STeLLA CO^2 project and brings to the collaboration years of experience teaching at the undergraduate level and professional development experience, including being a participant in the HHMI Summer Institute program (Pfund et al., 2009), the CREATE training program (Hoskins et al., 2011), and most recently, the STeLLA CO^2 program.

Another important group of stakeholders was biology professors in the MCDB and EBIO training programs, and more generally, all faculty who engage in education in the College of Arts and Sciences. The reason we identified this broad group is that the course was offered within the natural science departments—in this case MCDB and EBIO—rather than only in the School of Education. By offering a course focused on education in university science departments and taught by university science professors—as opposed to education professors—it set a precedent of emphasizing the scholarship of teaching and learning as a core part of the science department. We viewed this as important because the University community within which we work has a history of discounting or undervaluing teaching excellence. (As a tier 1 research University, our record of valuing and promoting excellence in teaching has been poor.

For instance, between 2011 and 2017, only 1.3% of the 230 individuals who received tenure did so on the basis of being recognized as excellent in teaching.) We hoped that by offering a course focused on the scholarship of teaching within STEM departments—instead of only the College of Education—we would send a signal of a greater commitment to excellence in teaching by providing examples of what the scholarship of teaching within a discipline looks like, creating training opportunities for constructing pathways towards teaching excellence, and ideally establish an interdisciplinary collaboration. We believed our combination of using NGSS and STeLLA strategies for enacting best practices, and our inclusion of an emphasis on equity and inclusion, might expand the scope of stakeholders committed to sustaining offering education courses within science disciplines.

While the three course instructors brought a shared interest in the scholarship of teaching science to the collaboration, we discovered that our goals, approaches, and the perceptions of the purpose of TLB were different. It was clear, for instance, that each professor's framework for teaching differed. By framework, we mean why and how a course is structured in a particular way. Both authors were trained in the use of the Next Generation Science Standards and the STeLLA strategies (Figure 1) whereas our collaborator employed what he defined as a Socratic method of teaching, although there was not an explicit, referenced, and objective framework useful for collaborative teaching.

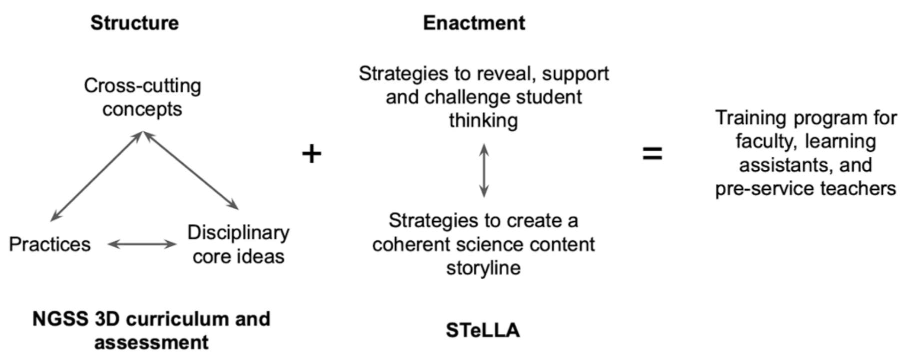


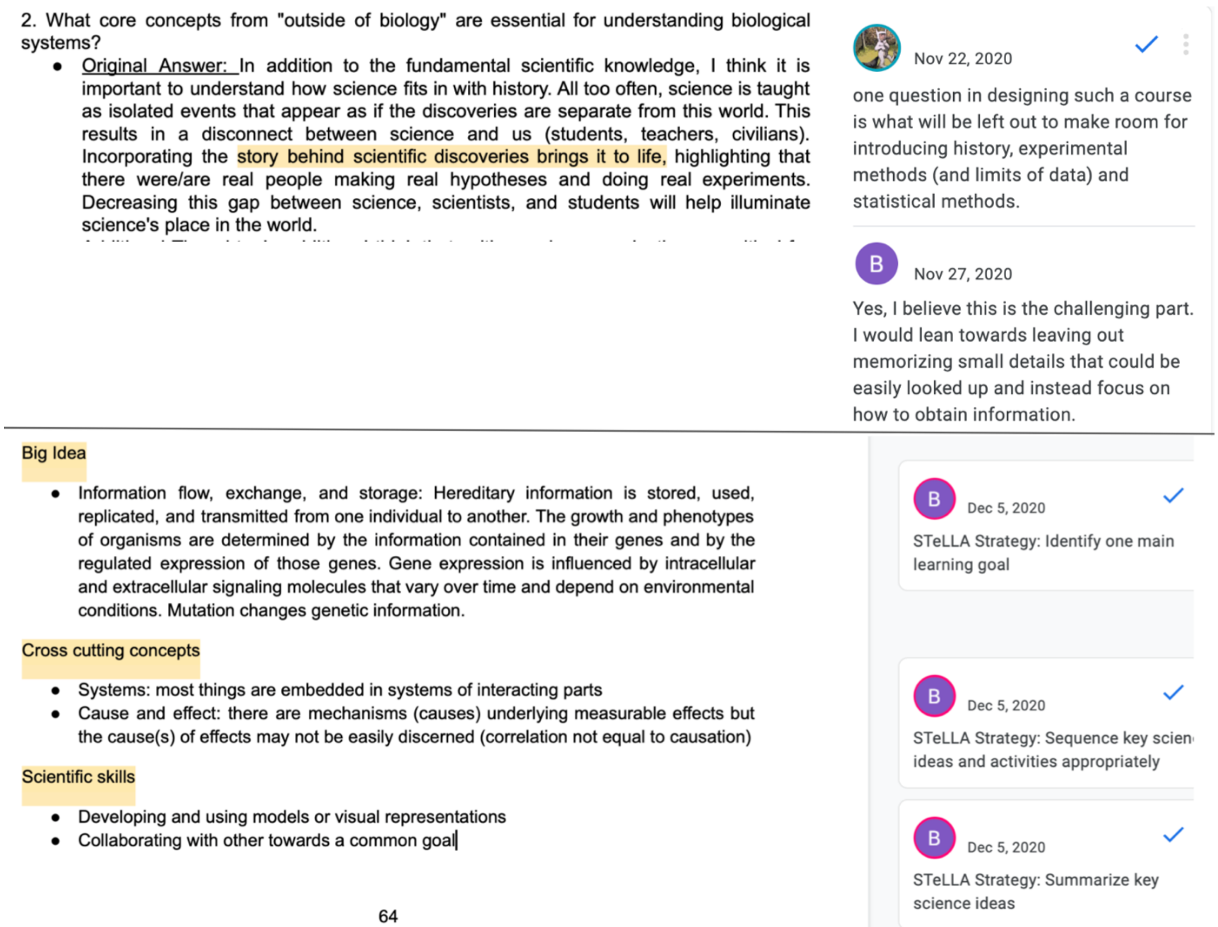
Figure 1. Model of the structure of curriculum based on NGSS and the 3D framework and enactment of curriculum using STeLLA framework.

As a means of trying to create a common framework, we decided to focus on four main topics: the value and purpose of assessment, the important big ideas in biology, key science process skills (especially the analysis and interpretation of data), and the nature of science. Each of us agreed to focus on these four main topics as we planned to be the lead instructor for four consecutive weeks across the 15 weeks of the course. We reasoned that overlap in emphasis on a particular aspect of each main topic among us would provide opportunities for making connections across our different perspectives and approaches. Furthermore, we similarly reasoned that any differences in approach, perspectives, or emphasis among us within a main topic area would serve to create an opportunity for revealing the instructor dependence of curriculum and teaching strategies. The experience was a case study in some of the successes and challenges of collaborative teaching.

Successes

One success was the use of a shared spreadsheet for collaborative lesson planning among the three professors. The lesson plans provided a way for multiple instructors to know the purpose of the proposed curricula, provide feedback and suggest revision, and document similarities and differences in approach between instructors. Furthermore, because we were operating remotely, the shared spreadsheet provided a means of interacting and sharing pedagogy, specific teaching strategies, and past experiences in the classroom: it was the vehicle for social interactions among the three of us. More specifically, the shared spreadsheet allowed us to make teaching strategies stemming from the NGSS and STeLLA frameworks explicit. For example, the spreadsheet included columns defined by the STeLLA strategies to create a coherent science content storyline. Lesson plans outlined in the spreadsheet were supported by folders containing the curricular materials. The value of making all curriculum available and shareable meant the collaboration could extend from conception of learning goals through their implementation and then serve as an archive for future courses and for evaluating and revising curricula. For example, included in the curriculum materials for the nature of science lesson developed and implemented by the first author was an exercise designed to make student thinking visible. The activity was implemented prior to class, providing information useful for exploring student thinking about the properties of hypotheses. Knowing, in advance, that there was variation among students generated discussion between the instructors about purpose and approach prior to class in ways that enabled greater participation by the instructors. Importantly, by making student thinking visible, and revealing differences in student perceptions of the hypothesis as a central pillar of science, the data enabled a more inclusive discussion focused on misconceptions and correct conceptions about the meaning of hypothesis.

Another success stemmed from how we implemented assessment of student work during the course. We adopted a pointless grading scheme (Zerwin, 2020). Our approach emphasized students creating, maintaining, and revising portfolios (we referred to them as dossiers) as a means of documenting work and provided a place for productive interaction with the instructors. Each of us interacted with students through their dossier (see Figure 2).


2. What core concepts from "outside of biology" are essential for understanding biological systems?

- Original Answer: In addition to the fundamental scientific knowledge, I think it is important to understand how science fits in with history. All too often, science is taught as isolated events that appear as if the discoveries are separate from this world. This results in a disconnect between science and us (students, teachers, civilians). Incorporating the story behind scientific discoveries brings it to life, highlighting that there were/are real people making real hypotheses and doing real experiments. Decreasing this gap between science, scientists, and students will help illuminate science's place in the world.

Nov 22, 2020

one question in designing such a course is what will be left out to make room for introducing history, experimental methods (and limits of data) and statistical methods.

B Nov 27, 2020

Yes, I believe this is the challenging part. I would lean towards leaving out memorizing small details that could be easily looked up and instead focus on how to obtain information.

Big Idea

- Information flow, exchange, and storage: Hereditary information is stored, used, replicated, and transmitted from one individual to another. The growth and phenotypes of organisms are determined by the information contained in their genes and by the regulated expression of those genes. Gene expression is influenced by intracellular and extracellular signaling molecules that vary over time and depend on environmental conditions. Mutation changes genetic information.

Cross cutting concepts

- Systems: most things are embedded in systems of interacting parts
- Cause and effect: there are mechanisms (causes) underlying measurable effects but the cause(s) of effects may not be easily discerned (correlation not equal to causation)

Scientific skills

- Developing and using models or visual representations
- Collaborating with other towards a common goal

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B Dec 5, 2020

STeLLA Strategy: Identify one main learning goal

B Dec 5, 2020

STeLLA Strategy: Sequence key scien ideas and activities appropriately

B Dec 5, 2020

STeLLA Strategy: Summarize key science ideas

Figure 2. Example of two types of engagement enabled by student dossiers of their work. In the top example, the professor and student interact stemming from student work. In the bottom example, the student revises and annotates their dossier. Students were asked to develop a lesson using the NGSS 3D learning goals. After they had identified their goals, they were asked to revise their plan by adding STeLLA strategies that would help enact curriculum for achieving their stated goals.

The origin of the dossier stemmed from what the first author calls the course journal in their high school courses. The dossier in both the high school courses and the TLB course is a live Google document that students have shared with the instructors. Successful students filled their dossier pages with reflections on their learning from the week, wrote down details of their preparations for each class meeting, and documented work that they created during class meetings. The dossier was less of an assignment and more of a strategy for facilitating self-edification and self-actualization as a way of learning through the process of making the student experience visible (in words and pictures), building on their experience by engaging in frequent revision, and finding information that connects with the topics on their own. At the end of the course, the dossier was used as the primary source of evidence of student progress and success and formed the basis for assigning a grade. Moreover, the pointless dossiers in the TLB course aligned with the NGSS and STeLLA frameworks by raising the level of cognitive thinking in the students while eliciting student ideas about the nature and learning of science and providing a student and teacher device to track changes in student thinking.

Innovations and discovery

During the session devoted to the nature of science, the second author focused on a big idea: evolution results in the change in the characteristics of a population over generations. The lesson was set up as an example of scientific teaching, an approach to teaching in which the instructor collects data for the purpose of evaluating the effectiveness of teaching. The lesson was organized as an experiment. Students began the experiment by completing a pre-assessment designed to estimate their understanding of evolution by choosing statements about evolution that were either true or false (see Appendix). Students were divided into groups with group size varying from one to six. The purpose of dividing students into groups was to estimate the effect of group size on student experience and learning gains. Additionally, the experiment also had two different tasks that further defined the student learning experience. One set of groups was asked to construct a visualization using data followed by making sense of the visualization once the visualization was completed. For the other task, students were provided with the completed data visualization and asked to make sense of the information using annotation. The former task was more difficult, required a greater amount of time on task, and involved greater cognitive load. Both tasks enabled active, student-centered learning and both tasks provided information predicted to result in a positive learning gains.

Although class size was small and therefore the replication across the two different predictive variables was too limited for confident inference, the data did yield predictable results. One prediction was that there would be differences in gains depending on group size, and that the group size of three would yield greater gains than happen for individuals who worked alone or individuals who worked in groups of six (Figure 3). These results provided the basis for reflection on the value of students working in groups and the importance of group size for achieving inclusion, equity, and productive group work. In our experience, group sizes of three were better—estimated based on learning gains—than group sizes of six. The second prediction is that more cognitive load will result in lower learning gains than activities with less cognitive load. The task that involved students constructing data and making sense of the visualization involved significantly more load than simply making sense of the visualization. Although the difference in gains was small, there was some evidence for less learning gain with increased cognitive load (Figure 3). These two activities related to the STeLLA strategy of selecting activities that are matched to the learning goal. The activity of annotating the visualization (i.e., making sense of the information) was directly aligned with the learning goal. The activity of constructing the visualization was more aligned with a learning goal focused on data visualization rather than one focused on analysis and interpretation. The different outcomes depending on the two predictive variables (group size and cognitive load) served as a reminder to students that teaching is a complex, multidimensional endeavor with intersections and interactions between content, disciplinary expertise, and identities.

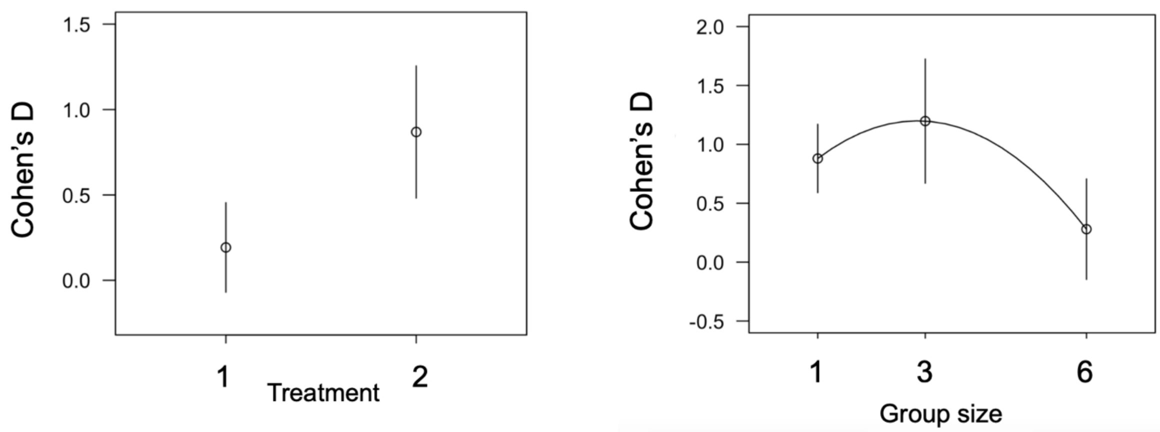

Figure 3. The results from an experiment in class designed to enact scientific teaching: the process of using science to inform teachers about the effectiveness and success of teaching using data. For these data, students engaged in a learning activity about evolution and there were two predictive variables that defined different groups: groups size (1, 3 and 6) and cognitive load (treatment 1 and 2). Treatment 1 was high load and involved students constructing a visualization from data followed by interpreting the visualization of the data. Treatment 2 was low load and involved only interpreting the visualization of the data. Learning gains were measured using a pre- and post-survey and calculating Cohen's D. There were too few individuals for statistical analysis to be informative.

Another innovation involved collecting and visualizing student thinking as a strategy for selecting activities matched to the learning goal. In this case, the learning goal was to distinguish between hypothesis and prediction as part of the nature of science topic. This activity stemmed from a study conducted by the first author of student projects at eight International Science and Engineering Fair (ISEF) competitions in recent years for a total of almost 2000 student projects. ISEF Students included a hypothesis in 78% of these projects but only wrote predictions 81.2% of the time. True hypotheses – potential generalizations of patterns or explanations of causative mechanisms – appeared in only 272 (18.8%) of the projects (Strode, 2015). Thus, even though generating hypotheses is a fundamental component of most scientific investigations, students at the ISEF seem to misunderstand the difference between hypotheses and predictions. In the TLB activity, the first author asked students to indicate whether a statement was a hypothesis or a prediction. The survey included many statements. For example: *If I add salt to freshwater, then the water will freeze at a lower temperature* (this is a prediction, not a hypothesis) and *Reaction time is faster for senses located closer to the brain* (this is a hypothesis).The purpose of the exercise was to simultaneously elicit, probe, and challenge student thinking, and then use the data and STeLLA strategies for making gains on student understanding of the difference between hypothesis and prediction (see Figure 4).

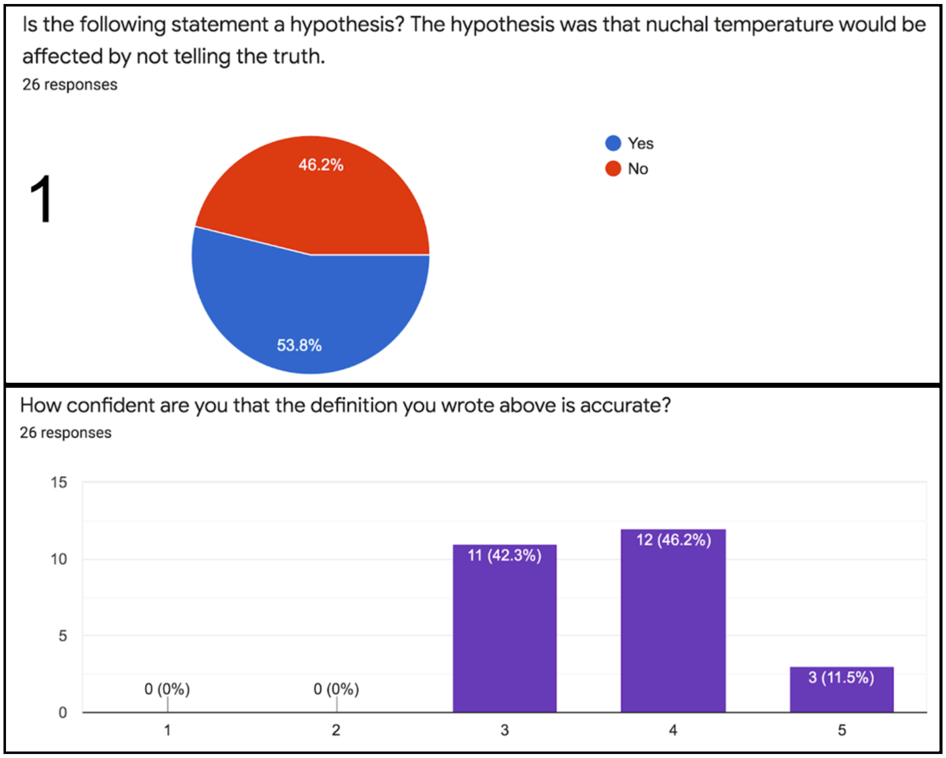

Figure 4. Summary of student data collected from a survey of student perspectives about the meaning of hypotheses and predictions and their confidence in their answers. These data were collected prior to class and used in ways that revealed, supported, and challenged student thinking.

Challenges

One notable challenge stemmed from differences in perspective about the role of the professor in the classroom. Is the instructor the epistemic center delivering key insights or is the purpose of an instructor to create opportunities for students to explore information and knowledge, make mistakes, and discover meaning with the aid of instructor coaching? Is learning passive and absorptive or active and constructed? Collaborative teaching works best if the participating instructors' models of effective teaching and learning overlap. Moreover, collaboration should recognize the existence of micropolitics in ways that limit the deleterious effects of exerting the informal power of participating individuals in ways that run orthogonal to collective purposes.

> Micropolitical theory thus offers a new lens for understanding collaborative reforms in schools by uncovering power, influence, conflict, and negotiating processes between individuals and groups within school organizations. It is particularly relevant in a study of teacher community-building initiatives because teachers activate micropolitical processes as they increase their interactions and expectations for coordination…Conflict can be understood as both a situation and an ongoing process in which views and behaviors diverge (or apparently diverge) or are perceived to be to some degree incompatible. That is, conflict can be an event whereby individuals or groups clash, in which divergent beliefs and actions are exposed. It is also a process whereby individuals or groups come to sense that there is a difference, problem, or dilemma and thus begin to identify the nature of their differences of belief or action.

In this way, conflict is a social interaction process, whereby individuals or groups come to perceive of themselves at odds. (Achinstein, 2002)

We believe the instructors were at different points along the continuum of teaching in ways that supported passive to active learning (Chi & Wylie, 2014). One example of this comes from analysis of transcripts for portions of the class when students were not in break-out rooms. If the instructor was using authentic questioning—including elicit, probe, and challenge questioning strategies central to the STeLLA framework—the epistemic center should shift between the instructor and students, and moreover, it should move among different students. Figure 5 shows data for two instructors who were focused on the same topic (Nature of Science). Overall, there was a more than two-fold difference in number of participating students and the amount of time the epistemic source resided with the students. Additionally, there was evidence of a difference in disciplinary inclusion: one instructor elicited responses from only students that matched the discipline of the instructor whereas the other instructor (elicited engagement from students enrolled in the course through all three disciplines. The difference in student engagement reflected a clear difference in pedagogy and purpose.

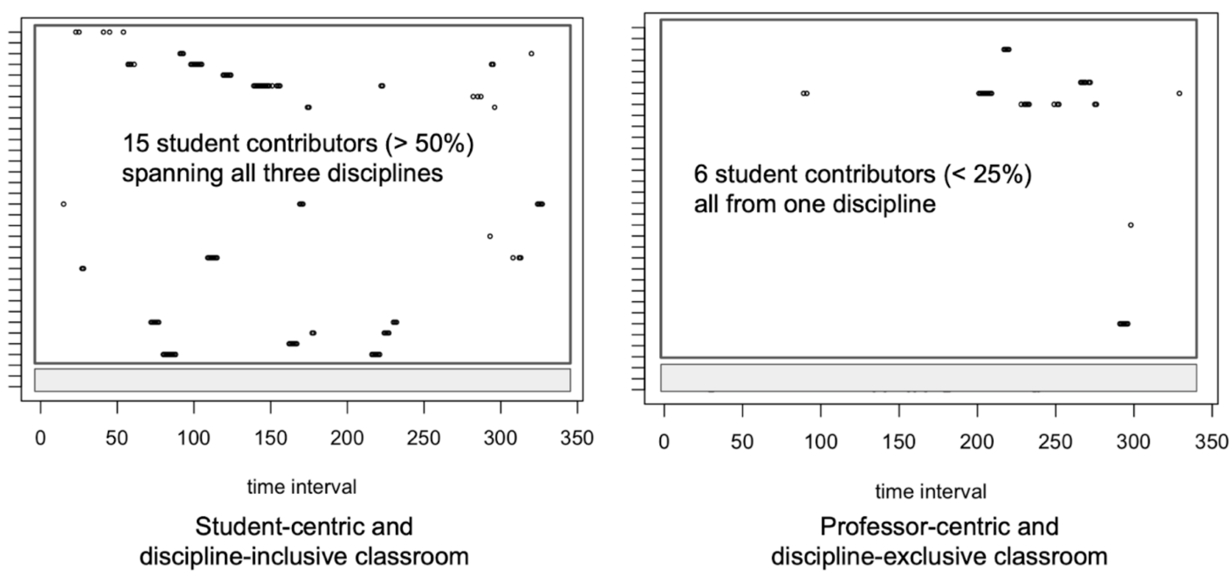

Figure 5. Picture of student engagement in two sessions of T&LB directed by different instructors: one that uses STeLLA questioning strategies (left graph) and one that does not use STeLLA strategies (right graph). The time analyzed was the same for the two sessions. Each black dot is a period of time based on a transcript from Zoom. The bottom three rows are the three instructors. The bottom row is Paul Strode, the second row from the bottom is Andrew Martin, and the third row from the bottom is the other instructor.

Importantly, there were explicitly articulated differences in the perception of the purpose of the course. One instructor emphasized that the course was a "referendum" on the success of one of a discipline's training program whereas another instructor viewed the course as an opportunity to improve students' abilities to effectively communicate their knowledge and understanding of biology and science by emphasizing the ability to teach others. Furthermore, the difference among instructors in valuing student voices resulted in a scenario in which one of us imposed a restriction on the amount of time one of the other professors could talk. This micropolitical action created interpersonal tension among the instructors but resulted in more participation by students. Seeing the positive effect of an explicit limit on an instructor's monopoly on "air time" served as a reminder that one important goal of teaching is about making space for other voices regardless of how much instructors know and want to say and regardless of our sense of entitlement and privilege that enables instructors to own the time allotted for discourse.

Another challenge stemmed from how collaboration happened. The original architect of the course had already developed a curriculum, a mode for delivering content using a proprietary website, and a structure for enacting curriculum based on previous iterations of the course. This particular structure was efficient and made sense, but limited the ability to collaborate. The other two instructors advocated for the use of shared Google documents as a vehicle for fostering collaboration, generating multi-authored curricula and lesson plans, exchanging ideas about teaching strategies, and archiving our collective actions. Because the two modes of planning were incompatible, collaboration involving all three instructors was limited. Furthermore, depending on the instructor running the course at a particular time, the other two instructors were either reactive or proactive. Being proactive and productively collaborative depends on purposeful interaction such that the purpose, flow, and potential involvement of all participants is known prior to enacting lessons. The division between the instructors stemming from lack of commitment by all members to a collaborative model of teaching was a missed opportunity.

Another challenge with respect to how the structure of teaching influenced the function and implementation resulted from differences in the emphasis on strategies to reveal, support, and challenge students (i.e., the STeLLA strategies). For example, while all three instructors used questions to guide discussion, only two instructors explicitly structured their lessons based on the important STeLLA strategy, "Set the purpose with a focus question". Furthermore, while all three professors asked questions, only two made explicit use of elicit, probe, and challenge questions for purposefully revealing student thinking.

It is worth noting that there was fallout because of micropolitical conflict during the course. The original architect of the course maintained precedence for a purpose of the course and made it clear that differences in perspectives among instructors were incompatible with the original goals that motivated creating TLB. Consequently, the course will no longer be interdisciplinary or collaborative.

Summary

The STeLLA framework was effective for promoting productive collaboration between two of the instructors and authors when developing and teaching TLB. Importantly, the opportunity to enact STeLLA strategies solidified their value for guiding curriculum development, teaching strategies, enactment of scientific teaching for data-driven revision, and assessment development. Although micropolitical conflict contributed to the lack of sustainability of our TLB project, the authors will continue to interact and hopefully we will develop a more sustainable way to offer a course designed with students as the primary stakeholder that helps provide a pathway for students enthusiastic and interested in biology to become effective primary or secondary school teacher. It is clear to both of us that the NGSS + STeLLA framework can become a flexible and sustainable means of both enabling individuality, promoting collaboration, and maintaining curriculum alignment across the many instructors and courses that make up the education program of young adults seeking a career in education.

Discussion

Participating in the STeLLA CO^2 project fostered the development of a common vision for effective science teaching and learning and a community among stakeholder groups to work together to enact meaningful programmatic changes. Having a common conceptual framework for describing effective science teaching and supporting team members in reflecting on their own instructional practices was critical; thus, allowing images of what was valued and the strategies for realizing PSTs visions for effective science teaching and learning to be aligned. Although many of our team members recognized the alignment between the STeLLA strategies and known strategies for effective science teaching and learning, each of the teams recognized the benefit of having a common language for university faculty and MTs to use when describing desired practices and a model for how PSTs can learn about and practice using those strategies across different aspects of their PST learner experience. In doing so, PSTs can see how each stakeholder was trying to reinforce the use of the same strategies to meet a common goal. In each initiative, university teams considered the PSTs' planned trajectory for learning and identified key STeLLA strategies that would be appropriate to explicitly support at each juncture. For many of our groups, the questioning strategies to elicit, probe, and challenge student thinking were fundamental to this work.

In addition, each initiative recognized the benefit of working with other stakeholders who shared this common vision and language and involving them in more aspects of the PST learner experience. A common approach involved MTs taking on a more active role in designing and supporting the PSTs' learning in their university classes and creating more opportunities for PSTs to observe and practice what they've learned in their field experiences in ways that were consistent with what they had been learning in their university courses. The UCCS team involved collaborations between university education faculty and MTs to co-design revisions to their courses and valued the expertise and experiences of MTs to help teachers deepen their understanding for how the STeLLA strategies could support student learning. The UNC team involved collaborations between university science faculty and MTs to enact similar initiatives between university science faculty and MTs to revise seminars and methods courses that foregrounded the use of the STeLLA strategies. This team attended to the need to develop the capacity among university faculty and MTs who were familiar with the STeLLA strategies and could model them in their teaching. The CU Boulder team discussed a collaboration that was grounded in the desire to make improvements at the intersection between undergraduate science and preservice teacher education by considering how the STeLLA strategies could be used to not only mediate undergraduates learning about biology, but also considering their use in classroom teaching. In this collaboration, university science faculty recognized the need to involve the perspectives of practicing teachers in co-developing and co-teaching this course. Parallel work, which was not discussed in this paper set, involve MTs collaborating with university education faculty to design tools to support PSTs' use of the STeLLA strategies when designing and carrying out lessons. Through this collaboration, MTs and university education faculty could provide synergistic and coherent feedback to PSTs for how to improve their classroom teaching.

While each initiative involved successful cross-stakeholder collaborations, they were challenging to implement and involve some lingering issues. Two teams shared issues that prevented them from establishing a common vision among the team and the progress they took to try to rectify those issues – with more success in some cases than others. One critical element of the STeLLA CO^2 approach involved fostering a safe space where members of the community are willing to take risks and try new strategies in service of improving student learning and having tools to assess their effectiveness. In this approach, participants first observed how the strategies could be used in the context of other teachers' classrooms before trying them in their own classrooms. For some team members, trying to incorporate the STeLLA strategies explicitly into their programs and seeing how their explicit use impacted PSTs' learning was vital for convincing them of the value of the strategies and the worthiness of the investment for incorporating them explicitly in their university courses. For UCCS, which struggled at the beginning of this project, their valiant efforts to persevere allowed others at the university to recognize the benefits of their efforts and endorse more program-wide changes. Two teams discussed challenges involving external partners who would be critical team members for planned initiatives during Phase 2 of the program but had different levels of success. We argue that this difference is due to external partners' willingness to try new things and observe its potential impacts on student learning. New university science faculty at UNC could observe MTs using the STeLLA strategies with PSTs in the context of their co-taught classes, which created the opportunity for them to consider the value of the strategies. However, the external CU Boulder university science faculty member's unwillingness to try new things or see the potential value of the work was a stumbling block. Thus, a lesson learned would be to identify early the key stakeholders who may need to be involved and design an experience for everyone to develop that common vision together, like what the BSCS team developed in Phase 1 (see figure 2). In doing so, it may help external partners see the value of the work that our team members sought to accomplish. Once buy-in related to the STeLLA strategies is established, incorporating them into the courses and planning for opportunities for new individuals to develop this common vision would be a critical part for sustaining change over time.

In each initiative, we described the product of collaborations involving two stakeholder groups: university education faculty and MTs at UCCS and university science faculty and MTs at UNC and CU Boulder. The work with the broader CU Boulder team shows promise with what can happen when all stakeholder groups are involved, but this work was largely done in parallel and not involving all three stakeholder groups. Furthermore, university education faculty were not part of the university team at UNC, so one could imagine the benefits of synergies between the disciplinary specific seminars designed by university science faculty and the education classes taught by university education faculty. However, what is encouraging about this initial work is the promise of what can happen when stakeholders choose to make small changes that are within their spheres of influence rather than trying to tackle bigger challenges that may encounter more challenging institutional challenges. As described in the UCCS paper, the team started with small changes in the one class taught by a single university education faculty member. Once others saw the benefits of what happened in that class, the team was invited to make bigger programmatic changes that will better enhance the coherence of the UCCSTeach program.

As program designers, the STeLLA CO^2 project staff used a proven program of teacher learning as a foundation for developing these communities. However, we recognize that innovations cannot be lifted whole-cloth from one context to another -- what works well in one setting does not always translate for a different context and set of individuals. We did not direct the way in which each university used the STeLLA resources, conceptual framework, and resources; rather, each university decided how to use what they have learned in a situated context – one that honored each university's unique strengths, its history, and the unique challenges that stakeholders encountered in their specific university settings. On each team, STeLLA CO^2 staff served as "critical friends" to help teams consider ways in which the STeLLA strategies or involving stakeholders could help address identified issues and improve the coherence of the program. In doing so, each university team was able to develop a sense of "ownership" and "authorship" that would enable teams to design innovations that will be sustainable beyond this research and our grant funding. We hope that the cases presented from the voices of each stakeholder encourages other universities to consider the power of developing cross-stakeholder collaborations. Although it can be challenging and time-consuming, each of these cases notes the catalytic power of leveraging these relationships for transforming PST education and that it is worth it. In future work, we hope to share the findings from Phase 3 of the project, in which we are measuring how the initiatives these teams have developed will impact PST and secondary science student outcomes.

Appendix

Survey used to assess changes in student thinking as a consequence of an activity designed to improve student understanding about evolution.

1. Choose the statements about evolution that are generally true
2. The average trait value of offspring is not statistically different from their parents: true
3. In scenarios where, on average, individuals with larger body size have higher fitness, individuals that are less than a threshold body size do not survive: false
4. Not all offspring survive to reach maturity: true
5. All offspring that survive to become parents reproduce: false
6. Some parents produce more offspring than others: true
7. In scenarios where, on average, individuals with larger body size have higher fitness, the average body size of offspring is larger than their parents: false
8. Offspring resemble their parents because of the effects of genes: true
9. The intensity of selection (i.e. the proportion of offspring that do not survive to maturity) is about the same every generation: false
10. When the number of individuals exceeds the resources necessary for growth and reproduction of the individuals, there is competition: true
11. In nature, at least one offspring of a parent will fail to survive to maturity: false
12. In general, more offspring are produced than can be supported by available resources: true
13. Parents produce the number of offspring that survive: false
14. If natural selection favors large body size, offspring that are smaller than their parents do not survive: false
15. In some cases, all offspring produced by a parent will fail to survive to maturity: true
16. Evolution happens between generations: true
17. Natural selection happens within generations: true
18. In general, the number of individuals that survive to maturity is directly proportional to resource abundance: true

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