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Jessica Thompson
University of Washington

Sara Hagenah
Boise State University

Karin Lohwasser
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Kat Laxton
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Jessica Thompson
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Abstract

Support for new forms of teaching expertise with rigorous and equitable outcomes for student learning is a particular challenge when communities of actors working together do not share a similar language or vision of teaching practice. For this project we coordinated activities in and outside of secondary science classrooms for Cooperating Teachers (CTs) and their Pre-Service Teachers (PSTs) to inquire into a set of research-based teaching practices and tools. Using frame analysis we contrast three problems of practice addressed by 23 dyads: problems of developing novice teachers, problems of improving teaching, and problems of improving student learning. The last frame, improving student learning, required actors to share and co-create knowledge with members outside of their dyads. To do this, groups of dyads formed new or repurposed existing social networks to share tools and work on problems "without ceilings," meaning those that fueled on-going lines of inquiry. We describe ways in which knowledge became shared, actors assumed new roles, and new types of tools, activities, and forms of discourse emerged for contextualizing collective work. This study suggests a need for a systems-level approach to teacher education that focuses on institutional networks of shared tools, practices, and deliberate socio-professional routines for improving practice.

Studies in teacher education have demonstrated just how difficult it is to implement reform-based practices in classrooms (Elmore, 2004). There is growing consensus that these efforts require an investment in activities that build professional knowledge across a system of learners, not just support the development of individual clinicians (Bryk, Gomez, & Grunow, 2010; Hiebert & Morris, 2012). In order for knowledge of reform-based practices to accumulate and become shareable, teachers and teacher educators must focus on common teaching practices (Cuban, 2013). One potentially powerful learning node for instructional improvement in systems rests in the interactions between mentor and novice teachers. Historically these relationships have been characterized as traditional apprenticeships that function to disseminate teaching practices by investing in the improvement of individual novices. In knowledge-building systems, however, Cooperating Teacher (CT) and Pre-Service Teacher (PST) dyads could merge their best understanding of teaching and not just enact, but advance reform-based practices.

To this end, this study represents an important departure from most mentor-novice studies. We designed social routines and tools for CT-PST dyads that could foster productive conversations about teaching and learning, build a shared language of practice and support principled risk-taking together. We wanted to move away from the frequently described "two-worlds pitfall"; where CTs and PSTs approach teaching with different visions of best practices in university contexts and school contexts (Feiman-Nemser & Buchmann, 1985). In the most simple articulation of the two-worlds disjuncture it is assumed that the CTs may be unfamiliar with reform-based teaching practices advocated for in the university setting and that the culture of the public school classrooms may work against novice teachers using and mastering these practices (Angnostopoulos, Smith & Basmadjian, 2007; Kennedy,

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1999; Zeichner & Tabachnick, 1981). As such, PSTs have limited opportunities to "observe, try out and receive focused feedback about their teaching methods learned about in their campus courses" (Zeichner 2010, p. 4) and two-way sharing of ideas about practice is restricted. For this study we attempted to work against this notion both in terms of the intervention we designed and our analysis of teacher learning. Structurally we supported dyads in planning for, enacting and debriefing science lessons during practicum, and ran monthly meetings for dyads to participate as one community. Although this study was conducted in a science teacher education context it was designed to more broadly impact and inform structures at the programmatic level.

This study investigates small-scale negotiations CT-PST dyads made as they learned about reform-based practices and tried to name and solve problems and tensions related to these practices in their classrooms. We differentiate between problems with ceilings and those without. Problems *with ceilings* have little room for negotiation and a finite number of solutions. Conversely, problems *without ceilings* do not have easily defined endpoints and can drive innovation in defining and working on problems. Addressing issues of equitable opportunities to learn is a problem without a ceiling, as making progress on the problem requires consideration of all learners in a classroom as well as larger historical, social, cultural, and institutional inequities. Most educators, teacher educators, and educational researchers would agree that focusing on consequential problems of practice—and using teaching practice as a site for inquiry—is important for transforming teaching (Ball & Cohen, 1999; Cochran-Smith & Lytle, 2009; Feiman-Nemser, 2001). However, we have yet to fully understand what kinds of problems of practice best support teacher and student learning, and under what circumstances.

Designing for Improvement in Teaching and Learning

For this design-based study we made three conceptual and structural shifts in traditional opportunities for CT-PST dyads to interact with one another and a larger community of dyads. We had three design principles: 1) balancing stereotypical asymmetric power differences among actors, particularly CTs and PSTs, 2) orienting the work of the dyads toward a finite number of teaching practices supported with well-designed social resources, routines, and tools, and 3) building communities of actors whose shared work was aimed at the improvement of teaching and student learning and the development of distributed expertise across a community. Following is a description of the structures we put in place and a brief review of the literature supporting the design principles.

Design Principle #1: Balancing Asymmetric Power Dynamics Among Actors

Typically CTs are positioned as field experts of practical classroom knowledge and PSTs are positioned as acquirers of this knowledge (Carter, 1988). This means that conversations about teaching and learning flow in one direction from the CT to the PST. Historical and cultural norms of isolationism and individualism (Kennedy, 1999) perpetuate the notion that teaching is a craft best learned from an artful master teacher, and structural constraints make it difficult for CTs and PSTs to experiment with alternative forms of communication. Some CT-PST conversations orient toward the CT explaining particular teaching moves and instructional decisions or explicating logistics for enacting a lesson but few feature CTs and PSTs as co-teachers or co-inquirers.

In order to shift away from a rigid expert-novice dichotomy our teacher education program attempts to place PSTs with CTs who are familiar with teaching practices emphasized in the university science teaching methods course. The intentional pairing ideally helps PSTs "see" similar practices in the classroom and build a common language for CT-PST co-teaching and co-experimentation. The program has ample time for CTs and PSTs to interact during practicum (equal to 120 school days, half of which overlaps with university coursework). For this project university coaches helped co-plan, co-teach and co-debrief lessons with CT-PST dyads three times during practicum. Tobin and Roth (2005) described similar structural and conceptual shifts taken to implement co-teaching models with researchers as co-teachers alongside CTs and PSTs.

The literature on co-teaching is limited—particularly in secondary settings—but it may be that addressing asymmetric power dynamics between CTs and PSTs in co-teaching situations is made difficult due to limited opportunities to *co-inquire* into teaching (Eick, Ware, & Jones, 2004; Feiman-Nemser, 2001; Roth & Boyd, 1999). This study aims to understand affordances and challenges when attempts are made to support collaborative co-inquiry into teaching and learning, disrupt traditional asymmetric power dynamics and work toward the improvement of teaching, not just improvements of novice teachers (Hiebert & Morris, 2012).

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Design Principle #2: Orienting the Work of Communities Toward a Finite Number of Practices with Well-Designed Social Resources, Routines, and Tools

Without clarity about a core set of teaching practices and without structures in place for all actors in a system to learn about those practices, it is difficult to establish a shared vision of teaching and learning (Grossman, Hammerness & McDonald, 2009). In this study CTs and PSTs learned about a set of research-based ambitious teaching practices that support student and teacher learning (Thompson, Windschitl & Braaten, 2013; Windschitl, Thompson, Braaten & Stroupe, 2012). The four teaching practices are: Eliciting students' ideas; Supporting on-going changes in thinking; Pressing students for evidence-based explanations; and a planning practice we call Planning for engagement with important science ideas. We consider these practices and their associated tools and routines "ambitious" because they support a more intellectually demanding and equitable vision of science instruction than the current norm (Corcoran & Gerry, 2011; Kane & Staiger, 2012; Weiss, Pasley, Smith, Banilower, & Heck, 2003). Ambitious practices engage students in long-term investigations of authentic disciplinary problems through the development of evidence-based explanations, by treating students' ideas as legitimate intellectual resources and by providing tools for publicly representing and revising students' ideas over time (Windschitl et al., 2012).

Models for coordinating teacher learning around complex instructional practices, such as the four above, remain under-researched and underspecified (Levin, Hammer, & Coffey, 2009; McDonald, Kazemi, Kelley-Petersen, Mikolasy, Thompson, Valencia, & Windschitl, 2014). To support the appropriation and refinement of the practices, we created new types of social arrangements and routines for CTs and PSTs as well as a suite of tools consistent with the vision of quality instruction. We define a tool as a material object that enables (and constrains) actors to interpret and attend to a particular feature of an activity such as planning, teaching, debriefing (Goodwin, 1994). A tool is not simply a resource given from one teacher to another or from a teacher to a student; it is constructed as actors "make sense, name, stabilize, represent and enact foci for activities" (Engeström & Blackler, 2005, p. 310). In this way tools are objects of mediation that can support CT-PST dyads in jointly naming and solving problems.

For this study three types of tools were created and modified to support co-engagement in planning and co-inquiry into student learning: planning tools, face-to-face tools and reflection tools. The tools have built-in assumptions about the ambitious science teaching practices and rigorous and equitable student learning important to making pedagogical decisions. The planning tool most used in this study was an 11x17 piece of paper called the "Big Idea Tool." It was designed to help teachers co-plan units of instruction by identifying a conceptually rich scientific phenomenon and creating scientific models to represent these ideas. *Face-to-face tools* are named as such because they face teachers as they develop and refine the tools during planning and reflection, and then face students during a lesson. An example of a face-to-face tool aligned with the ambitious practices is a scaffold, such as sentence stems given to students to help their writing of a scientific explanation. These tools represented teachers' attempts to a) uncover student thinking and b) engage in the practice of scientific modeling and constructing explanations. Lastly, teachers used a reflection tool to co-debrief lessons. The most common tool used was the Rapid Survey of Student Thinking (RSST), which was designed to support teachers in reflecting on students' partial understandings, everyday language and everyday experiences that surfaced in classroom conversations and in student work. The tool also included possible pedagogical strategies to follow-up on students' ideas. For this project researchers supplied prototypical versions of the tools—with embodied knowledge about the ambitious practices and an intentional focus on noticing and attending to students' ideas—but we also engaged CTs and PSTs in further development of the tools.

In theory these tools had the potential to act as boundary objects that support cross-institutional communication and collaboration and function as a focal point for making connections across the university and clinical settings (Anagnostopoulos, Smith, & Basmadjian, 2007). These tools also had the potential to be reshaped as actors continued to engage in practices and make adaptations based on localized knowledge. The ways in which teachers took up and modified tools was considered an artifact of learning, and was a focus of this study.

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Design Principle #3: Building Communities of Actors Whose Collective Work is Aimed at the Improvement of Teaching for All Students

Ball & Cohen (1999) describe how professional learning communities that orient collective work toward teaching and learning "create capacity for professionals to learn from one another, capitalize on existing capability, and break down the traditional isolation of teachers' work and broaden their opportunities to learn" (p. 17). The idea holds tremendous promise that has not been realized in teacher education models. This study draws on knowledge-building research that aims to develop Networked Improvement Communities (Engelbart, 1992). Such communities arrange human and technical resources so that the group—as well as individuals—is capable of "getting better at getting better." We provided structured time for PSTs, CTs, coaches and university faculty to work on problems of student learning both in practice (when teaching) and outside of practice (when planning and debriefing). Bryk, Gomez, and Grunow (2010) argue, "complex problems of 'practice improvement' demand that a diverse mix of skills be brought to bear and require reconsideration of when and how in the arc of problem solving this diversity of expertise is best exploited" (p. 37). We chose to draw on the expertise of multiple actors involved in science teacher education—in our case, cooperating teachers, pre-service teachers, and university teacher educators.

This study examined small-scale negotiations about the improvement of teaching among CT-PST dyads and the larger community. We leveraged framing theory to understand teachers' discursive engagement in describing and addressing problems-of-practice (Coburn, 2006; Coburn & Stein, 2006). Research on teachers' framing of enactment problems has painted a picture of teaching decisions as collaborative sense-making situated in contexts of particular schools and districts, not purely cognitive acts individual educators deploy. For example, educational framing theorists describe 'trickle-down effects' of mandated curriculum by considering how institutional messages among groups of teachers and leaders get produced, interpreted and ultimately shape actions around important questions around what to teach and what students are/are not capable of (Coburn, 2006; Rigby, 2014). In the foreground is an attention to meaning-making and how these groups align and resonate with narratives about teaching and learning. This study adds to these efforts by examining how mentors and novices negotiate the improvement of teaching around a set of instructional practices.

In this study we investigated *co-learning* between PSTs and CTs; operationalized as: 1) building a shared language and purpose for ambitious practices, 2) sharing a repertoire of ways of reasoning with tools and routines specific to the PST-CT dyad, 3) taking principled risks together when experimenting with ambitious practices, and 4) co-developing and adopting innovative instantiations of the ambitious practices. From these conceptual and practical approaches, the following research questions emerged:

1. How do Cooperating Teachers (CTs) and Pre-service Teachers (PSTs) orient toward the improvement of teaching? What are their shared aims and goals? Where do tensions arise?
2. What tools and social routines do CT-PST dyads develop to work toward these goals? How do these resources reflect and shape the framing of shared problems of practice?
3. Do certain frames afford PSTs different opportunities to appropriate the ambitious teaching practices?

Methods

Context and Participants

PSTs were placed with CTs in 14 different school contexts; four were suburban schools and 10 were urban and under-resourced. Populations ranged from 38.5% to 86% of the students on free-and-reduced lunch and English Language Learners ranged from 6.5% to 22%. The CT's teaching experience ranged from three to 22 years. Of the 23 CTs, six graduated from the same Teacher Education Program as the PSTs.

Three university coaches (the three co-authors) and one teacher educator (the first author) worked with CT-PST dyads, collaborating, mentoring and inquiring into ambitious science teaching practices. Coaches had foundational knowledge and expertise around working with the practices due to their role as teaching assistants in the university-based methods courses.

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Design Study and Data Collection

In order to study how CT-PST dyads orient toward the improvement of teaching we conducted a design study using principles described above (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Penuel & Roschelle, 1999). Design-based studies apply theories of learning, systematically study the processes that unfold, and develop theories of learning within the designed context. This research approach prioritizes understanding learning within a bounded setting (in our case science education) but intentionally aims to inform a "broader class of phenomena" (Cobb et al., p. 10) (in our case teacher education programs and interactions between and among CT-PST dyads). Design studies have an engineering bent and aim to understand the process and the means of supports for learning within complex systems. Here we detail the activities we put into place to create new learning opportunities for CTs and CT-PST dyads. We did not collect data on all dimensions of this design project; in this section we specify the types of data collected.

Initial support through a summer institute. Sixteen CTs attended a weeklong summer institute where CTs, district-level instructional leaders, together with university coaches and researchers learned about the evidence basis for the core-practices and related tools and routines the PSTs learned in their methods course (Windschitl et al., 2012). CTs created and revised mentoring resources, such as routines for co-inquiring into practices, and tools for co-planning around important scientific ideas. They also imagined how tools might be used with PSTs during practicum and revised the tools during the institute. The concept of iterative design is central to design-based research (Cobb et al., 2003; Penuel & Roschelle, 1999) as well as theories about tool evolution (Engeström, 2004).

On-going supports through monthly meetings and social media. To support co-inquiry into and the advancement of ambitious and equitable practices, the authors held monthly meetings for CTs and PSTs. Eighteen of the 23 PSTs attended monthly meetings (16 together with their CTs). Activities included sharing new tools to track students' ideas, devising strategies for instructional transitions in the classroom (i.e. between small group and whole class conversations, as well as transitions between the CT and the PST taking turns leading instructional activities), and watching video from classrooms to identify instances of productive student-student conversations.

In between these meetings, discussions continued on a closed Facebook group page (nine CTs and four TCs participated regularly). Members of the community posed questions, provided resources, and held discussions that provided daily/just in time support. Conversations typically focused on development of big ideas (related to the first core-practice) and tools and activities for tracking students' ideas (an important principle for all core-practices). Members also shared artifacts of student work, such as posters of students' revisions to scientific models (demonstrating use of the tools associated with the practices).

Data collection. For this manuscript we downloaded threads of interactions on Facebook. This provided an opportunity to understand interactions across the larger community.

Targeted coaching. As a part of the Teacher Education Program, university coaches typically visit classrooms to conduct observations with PSTs. For this study coaches (the second, third and fourth authors) were more involved; they supported CTs' and PSTs' co-planning, co-teaching, and debriefing lessons—referred to as *enactment cycles* in this manuscript. For co-planning the coaches acted as sounding boards and let the CT take the lead on designing lessons and activities. Planning sessions varied in length; some were 30 minutes long and others an hour long. Some CTs opted to use planning tools such as the Big Idea Tool they developed during the summer institute. During the lesson coaches often participated as guides-on-the-side; they circulated around the room noting productive student ideas, bringing these to the attention of the teachers, and making suggestions for elevating productive and innovative student ideas to whole-class conversations. Following the lesson the coaches asked a series of questions that prompted PSTs and CTs to reflect on links between student learning and instructional practices. The debriefing sessions typically took 30-45 minutes. The PSTs and CTs often completed a tool called the Rapid Survey of Student Thinking (RSST). Coaches identified a few items for targeted feedback using a performance progression for the four practices (See Thompson, Windschitl, & Braaten, 2013) then showed segments of video from the lesson to playback to dyads for discussion of practices and enactment.

Data collection. The four authors collected data on the enactment cycles for the 23 dyads over two years. In total we observed 115 cycles in detail (with video and/or audio recordings). Two of these multi-day enactment cycles occurred during the fall quarter when PSTs only assumed part of the teaching responsibilities. The other three

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observations took place in the winter quarter during full-time student teaching with the PST assuming primary responsibility for teaching. We completed protocols and field notes for co-planning, co-teaching and co-debriefing sessions. Lessons were scripted; we paid particular attention to how teachers framed discussion tasks for students and how teachers drew attention to models, explanations, evidence, and observable and unobservable data (typically 10 pages of typed, single-spaced dialogue per observation). We recorded whole class conversations, sampled small group conversations, recorded notes teachers wrote on the board, collected copies of handouts, and took photographs of student posters. We also audio recorded the planning and debriefing sessions, took detailed field notes of the types of interactions occurring between the CT-PST dyad (and the role of the coach) and took pictures of the tools and resources dyads used.

We also conducted individual interviews before and after the study. Initial interviews focused on teachers' views of teaching science, how students make sense of science, and experiences and beliefs about co-teaching. Final interviews asked teachers to reflect on the co-teaching experience—opportunities to teach and inquire into the teaching practices, mentor-mentee relationship, and tools routinely used for planning, teaching, and debriefing. Prior to this interview we did an analysis of teachers' repertoires of practice (practices aligned with the ambitious practices, or not, that were used routinely and those attempted two or more times)—we had CTs and PSTs comment on the accuracy of the list and the development of the practices over time.

Analysis

Analyzing Problems of Practice

A major objective for this study was to characterize how dyads developed collective frames through social interactions and interpretive devises (Coburn, 2006; Coburn & Stein, 2006; Gee, 2011). In particular, we were interested in small-scale negotiations that framed problems of improving teaching practice. To answer the first and second research questions about interactions, tensions and tools, we first analyzed PSTs and CTs "routine" practices (see Appendix A for an example). We noted which were prototypical practices (observed at least 4/5 times we observed the teachers) and which were practices that teachers seemed to be "trying on" (observed 1-2 times). With one column for the PST and one for the CT we had a visual representation of the practices CTs or PSTs were beginning to share (or not). We noticed differences in the ways dyads framed and solved problems around these practices. We identified types of conversations CT-PST dyads tended to have and created spreadsheets with these conversations for the 23 CT-PST dyads. Temporally there were differences in when problems of practice were identified and discussed: before a lesson, during a lesson, or after a lesson. Across practicum there were also differences in how problems were framed: early in practicum when PSTs were still taking a methods course at the university, the middle of practicum when PSTs took on more responsibility, and late practicum when CTs transitioned back into a lead teacher position. Dyads also solved problems differently; we noted how they used and developed tools to work on problems and when they sought additional social and material resources from the larger CT-PST community. To understand how dyads interacted with the larger community we also performed a systematic analysis of the Facebook posts by CTs and PSTs.

As a research team we met weekly and weighed evidence and counterevidence for each dyad. Across these data sources we identified three problems-of-practice dyads worked on together. The findings are organized around the framing and working on these problems.

Coding Classroom Observations of Ambitious Practice

To answer the third research question about the appropriation of practices we coded 115 classroom observations (five for each PST) for instances of the four ambitious teaching practices using the performance progression (See Figure 1). We coded PSTs and CTs practices but only report on PST data in this paper, as we did not have sufficient data on the CTs to assess shifts in their teaching over time. Each lesson received a rating for each of the four practices; ratings were based on the most frequent practice observed—if 50% or more of talk in a lesson was at a higher level, then we coded the lesson at the higher level. We evaluated lessons based on observed classroom discourse, not teacher self-reports of their intentions for the lesson. To calibrate scores across the four researchers we coded the first 10 videos independently and discussed similarities and discrepancies. On a weekly basis we continued to discuss coding.

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Findings

Three frames characterized the persistent problems-of-practice CT-PST dyads worked on as they sought to improve science teaching: 1) developing the novice teacher, 2) improving teaching, 3) improving student learning. CT-PST dyads often worked within all three frames concurrently, but they differed in how they allocated their time to each and how they viewed the frames as interconnected. We describe the frames not as contingencies of individuals' or dyads' attributes or contexts but rather as a set of social and material resources and activities (Horn & Little, 2010) dyads engaged to negotiate meaning about teaching. Contextual features, such as the amount of time teachers participated in CT-PST activities, the demographics of the schools, and curricular materials, were suggestive but not predictive of CT-PST participation in one frame versus another. The first part of the findings section addresses the first two research questions and describes discursive patterns in the data around activities, interactions, distribution of roles, and tensions associated with each frame. In interactions we consider patterns of CT authority, the negotiation of ambitious practice and tools, and the role of the larger CT-PST community.

Frame 1: Developing the Novice Teacher

The first frame of improving teaching by developing the novice teacher is well documented in the literature. It is a manifestation of the "two-worlds problem" where visions of learning and practices for teaching differ significantly between preparatory settings and school classroom settings (Anagnostopoulos, Smith, & Basmadjian, 2007; Feiman-Nemser & Buchmann, 1985; Zeichner & Tabachnick, 1981). We add to the literature by describing patterns in the small-scale negotiations between CT-PSTs that effectively reproduced status-quo teaching, and inhibited collaborative investigations into ambitious and equitable forms of teaching and learning.

Classic two-worlds model for the improvement of teachers. Five of the 23 dyads tended to frame problems as developing the novice teacher. Contextually, the CT and PST participated in divergent discourse communities, or communities with views of science teaching and collegial interactions that appeared to the dyad to be diametrically opposed. Mentors were either unfamiliar with ambitious teaching practices as they had not attended professional development opportunities, or they were knowledgeable about the practices but not enacting them. The focus of CT-PST conversations was on strategies the novice teacher could improve by better emulating the practices of the mentor teacher. PSTs were charged with working on underspecified practices often not specific to teaching science.

Unproductive tensions. Similar to findings from other studies, PSTs struggled to manage their relationships in both discourse communities while developing their own vision of teaching. CTs struggled to support PSTs develop their (the CTs') vision of teaching. And the university coaches struggled to help these PSTs create spaces to enact the ambitious science teaching practices in CTs' classrooms. As a consequence of disjointed and absent conversations about underlying beliefs of how to improve students' learning, tensions in the dyads mounted. Overall, PSTs had one of two responses to tensions: either they conformed to the CT's way of teaching or they resisted and sought alternative forms of support from other PSTs or their university coaches.

Discourse and tool use to reproduce current practice. The dyads that worked on the problem of improving the novice teacher tended to concentrate on providing resources, skills acquisition, checkpoints, and a linear progression of mastery. This led to a clear division of roles and positioning of the CTs as experts. It also meant that most opportunities for verbal exchanges about instruction occurred in *debriefing conversations* (not planning or during teaching). Interactions around planning were often not exchanges of ideas, but rather a handing over of resources such as pacing guides and worksheets for classroom activities.

Typically, the first six weeks of the school year were already planned out. So rather than engaging the PSTs in planning discourse, CTs assigned managerial tasks as the PSTs' first roles. Not being a part of planning conversations was problematic for PSTs emulating CT instruction but also for developing planning practices. There were resources available (such as state standards, text books and worksheets CTs had used in previous years) but no social routines or tools for conveying how to transform these documents into lesson plans.

Discussing teaching practices was not a simple task for these dyads. They had difficulty naming teaching practices and decomposing them into manageable teaching chunks (Grossman et al., 2009) with clear outcomes for students. For example, Paul (CT) asked Brian (PST) to work on building relationships with students, but Brian was not able to "copy" what Paul demonstrated during a lesson. After class, the dyad attempted to engage in a sense-making

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conversation about building relationships and the PST's progress towards this strategy. However, the flow of the conversation remained from the CT as the expert to the PST as the novice. In general, Paul attempted to redirect Brian's teaching, but the essential steps in Paul's teaching remained hidden and Brian often fell short of Paul's expectations.

When working on the problem of improving the novice, the *CT's curricular enactment established the standard.* When certain checkpoints were met to the CTs' satisfaction, PSTs were asked to individually plan certain instructional tasks or "model and follow" entire lessons. Some level of proficiency (determined by the CT) signaled that feedback on how well the PST's practice matched that of the CT's was no longer necessary and PSTs were able to teach on their own. CTs left the classroom and assumed the role of a content and activity consultant for the remainder of the placement. PSTs would seek knowledge from the CT on what or how to teach, but they *would not engage in co-problematizing and co-developing content* for learning or teaching strategies.

Frame 2: Improving Teaching

Aligning ideas about ambitious teaching for improvement of teaching. Ten of the 23 dyads tended to frame problems as improving teaching. When working on these problems CTs interacted as co-learners and in some cases brokers for tools accompanying the core set of teaching practices. Unlike the Frame 1, CTs negotiated some of the aspects that typically create two-world pitfalls between teacher preparation and schools. Moreover, unlike Frame 1 where CTs expected PSTs to work on abstract and underspecified practices, these dyads focused on the first core practice: planning for engagement with important science ideas. Importantly, CTs working on these problems were familiar with the teaching practices, as they had attended the summer institute. CTs created social routines for *co*-planning units of instruction prior to lessons (not after, as was the case in the first frame). In some cases dyads partnered up with other dyads from in the same school discuss what was to be taught and the overlap with existing curriculum and standards.

Lack of tension. Curiously, when the 10 dyads focused on problems of improving teaching in planning conversations, there were relatively few tensions or disagreements. Dyads often appreciated each other's roles and contributions to these conversations. Similar to Tobin and Roth's study (2005), teachers entered the conversations with complementary sets of skills and knowledge; CTs shared case knowledge based on teaching experience—both in terms of knowledge of their students' learning needs and the arc of the curriculum. PSTs typically brought content knowledge and ideas about how to frame a unit around a puzzling phenomenon.

Discourse and tool use to improve planning. CT-PST dyads used tools they developed over the summer—both planning and face-to-face tools—to solve problems of *what* and *how* to teach. For long-term unit planning, the dyads generally used the "Big Idea Tool" to rearrange the curricular unit around a puzzling scientific phenomenon. Each dyad developed a social routine that was used throughout the practicum. In almost all cases CTs in these dyads stayed involved with the planning throughout the practicum. One CT rationalized that this would support PSTs in having the best chance to be successful while teaching.

We hypothesize that the Big Idea Tool supported collaborative work between the CT and PST. Lisa (CT) and Kathleen (PST), for example, used the Big Idea Tool to adapt a unit on earthquakes (See Figure 2). Together they decided to orient a unit on earthquakes around a comparison of an earthquake in San Francisco and Kobe, Japan. Both earthquakes had the same magnitude but different levels of destruction. The CT and PST wrote out ideas for the puzzling phenomenon on post-it notes and added them to the same document. In general, we found that PSTs reasoned first with the puzzling phenomenon and the underlying explanation and CTs reasoned with the puzzling phenomenon and alignment with activities and investigations. Both partners had areas of expertise and starting places for recording these ideas on the Big Idea Tool in a way that did not privilege one type of knowledge over the other. Typically in planning routines CT-PST dyads would also develop face-to-face tools for students to use during class. For example, for the earthquake unit Lisa and Kathleen designed a worksheet for students to compare earthquakes at three points in time (before, during and after each of the earthquakes). CTs who attended the summer meeting learned about these tools and how to design one as a complement to the practice of eliciting students' ideas.

In terms of the discursive routines surrounding the tools, the 10 dyads who engaged most in this frame tended to have planning conversations focused on three sub-topics: entertaining and researching possible puzzling phenomena to conceptually anchor a unit of instruction, coordinating parts of a scientific explanation with curriculum

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(standards, textbooks), and selecting which activities would best support the development of students' scientific explanations. Note that we did not use the term "negotiation" to describe these conversations; in some cases ideas were challenged and elaborated, but in most conversations teachers cordially added to one another's ideas.

Frame 3: Improving Student Learning

Building a networked activity system for improvement of student learning. Eight of the CT-PST dyads that worked on problems of improving teaching also worked on problems of improving student learning. These sense-making conversations focused on identifying how and why students composed scientific explanations over the course of a unit of instruction. Importantly, the conversations surfaced questions about equitable learning opportunities for all students. CTs and PSTs not only collaboratively unpacked scientific phenomena in planning conversations but also calibrated the pace and sequence of activities with individual students' evolving ideas following lessons. When inquiring into learning, teachers developed tools and routines for tracking and investigating students' divergent ways of composing explanations.

Power relations between the PST and CT were not always balanced as dyads attempted to work in this frame, particularly at the beginning of practicum. CTs tended to press PSTs to frame and work on problems of student learning, but PSTs were not prepared for such a press and often tried to shift conversations back into Frame 2 and focus more on their enactment of practices. Four of the CTs in this frame were intimately familiar with the science teaching practices, as they had graduated from the university teacher education program themselves and had partnered with the university on several projects. The other four CTs were new to the core practices but had a strong repertoire of teaching practices oriented toward student discourse.

In terms of shifting toward a core set of practices, we found that when teachers focused on genuine questions about how students learned (not if they learned), dyads began to specify smaller grain-size practices and tools for planning, teaching and reflecting throughout practicum. We also found that access to a larger community of actors working on similar problems of student learning was important for the specification of tools and practices.

Productive tensions. The third frame, like the first, required teachers to take a close look at the purpose behind the practices being enacted; this was often fraught with tension. Eventually dyads engaged in productive experimentation that supported the revision of tools and teaching practice, and perhaps even lead to a better articulation of the purposes behind the practices. At the beginning of practicum, PSTs split time between the university and schools. This meant that PSTs had difficulty tracking how students' ideas were evolving day-to-day. CTs expressed frustration with PSTs not having the skills to elicit and work on students' ideas. For example, early in practicum Lori (PST) was caught off-guard by Sharon's (CT) unwavering focus on students' ideas. Lori was frustrated because she expected feedback on her own teaching skills. Instead, she received feedback "just on students' thinking" (post-practicum interview). Tensions were never fully resolved, but eventually the CT and PST found a way to work on problems of student learning (Frame 3). When university coursework began in October, they had an additional tension: time. They had less time to co-plan and co-debrief lessons, thus less time for conversations about students' thinking. Consequently, Sharon asked that Lori answer four questions by e-mail each night: "(1) What did you hear students thinking about? (2) What worked/didn't work from today? (3) For whom? (4) How will this change what you do tomorrow?" In the following quote from a debriefing session near the end of practicum, the PST and CT reflected upon developing this routine.

> Lori (PST): We didn't really have a lot of time to talk after class so the four questions–the big thing was, what are you hearing? It just became kind of a routine. I was responding to those four questions every night and I knew that I would be responding to those questions so that was something that I was thinking about during the day. I was able to differentiate a little better. I feel like she [Sharon] was pushing me to do something that was really helpful.
>
> Sharon (CT): I think our discussions about what kinds of things students were thinking about and what we might want to support them in, were maybe the best parts of co-teaching.

Debriefing how students learned and how this impacted future instruction helped orient instruction toward making students ideas public and fueled CT-PST inquiry into students' ideas. This routine enabled the dyad to debrief student ideas and implications for upcoming lessons. Other dyads came up with similar routines for attending and responding to students' partial understandings and their everyday language and experiences.

Discourse and tool use for improving students' ideas. CT-PST dyads took improvement stances toward understanding students' ideas and engaged in small-tests of small changes (Hiebert & Morris, 2012) in tools and routines that supported student learning. Specifically they inquired into two problems: how to increase the rigor of students' scientific explanations and how to track all students' explanations.

Discourse and tool use for improving students' explanations. Dyads working in Frame 3 developed routines for specific types of classroom interactions. For example, Emily (CT) and Rachel (PST) prepared "back pocket questions" that would support students in gradually moving from an explanation of what happened to why a particular phenomenon occurred. Emily recalled, "Every night she (PST) came up with questions and wrote them on a binder and she would go up to a group and just start hammering them with questions that she'd come up with." This planning routine not only cultivated classroom discourse that revolved around why a puzzling phenomenon occurred, but it also pushed the CT and PST to constantly revisit their content knowledge. In a post-practicum interview, Emily reflected on how she and Rachel worked on classroom discourse and new ways of giving students feedback on their final assessments.

> Emily (CT): I think going through it (the practicum) we both realized the importance of asking the students the "why" part. And I had had teaching experience and had been in the classroom but that wasn't how I was taught to teach. I was more on the "what" and the "how" and *I think that as it evolved we both really liked the "why" part.* And really pushing the kids and I think the one thing that was very hard for her- well it was very hard for both of us when we would get these final explanations. She would spend probably five or six hours giving them feedback. Her feedback said—"Why? Why? Explain. Why?"

Unsatisfied with student responses Emily and Rachel developed an additional face-to-face tool, the "How it All Connects" tool (See Figure 3 for an example). Their goal was to have students connect emergent science ideas over the course of a unit to the puzzling phenomenon. Rachel described, "Our tool helped sense-making lessons get more complex and closer to the final explanation." These tools provided a window into student thinking and allowed dyads to ask more questions about student learning and the supports they need to improve their scientific explanations.

Classrooms that planned for deeper engagement with student ideas, heard more from students, and gave teachers more resources to reason with "in the moment." This meant that CTs in Frame 3 had the opportunity to model both rigorous and responsive teaching moves. In the following example Mary and Robert quickly realized the puzzling phenomenon they selected (about a log burning inside a box) was not providing a conceptual anchor for students to reason with chemical versus physical changes. The students put forward the idea of cooking an egg.

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Classroom Discourse	**Framing**
S1: Would ash be considered a physical change? Like an egg? PST: So what did we just have in the back of the class? S3: We thought also that it was physical changes even though it comes after melting and boiling. S4: I don't agree with that, because even though there was a color change, CO2 was emitted so the identity of the log would have had to have changed CT: Does anyone have something to add to this? … PST: Raise your hand if you have seen a fire burning…so is it possible that a physical change is happening? CT: So this is chemistry. Let's think about this at an atomic level…What makes up an egg? S5: Elements S6: Potassium PST: Be specific! S7: Proteins, and when we cook proteins the proteins change PST: What does it look like? What happens when it cooks? [PST draws on board and shows a tightly bound protein and an unwound protein.] S7: So it is breaking and forming bonds S8: It expanded because of heat. When it heated they [bonds] move apart rather than together.	Practices and tools: CT and PST planned to have students use the phenomenon of a log burning in a closed box to help students reason with chemical and physical changes (practice 1), however they quickly have to adapt to their students' ideas as they elicit (practice 2) ideas. Their urban students did not have a lot of experience with a log burning. Authority: CT and PST are both eliciting students ideas. The CT models how to press for deeper levels of explanations with student-initiated idea (egg). The PST then switches his line of questioning to also be about pressing for a deeper level of explanation using the egg example.

Such co-teaching opportunities pressed students to try on new ways of expressing ideas publically and gave PSTs and CTs models for adapting questioning strategies. Other dyads devised less public ways to "co-press" and learn from one another (and from students). For example, Sharon and Lori did quick check-ins with one another during class as a way to share effective questions for pushing student thinking. Ashley and Kim developed power point presentations ahead of time with three to five targeted "turn-and-talks." Between classes they would evaluate the structured conversations and make revisions for the following periods.

Dyads in schools with other CT-PST pairs were at an advantage. In particular CTs attempting to frame problems of student learning (Frame 3) were able to model to other CTs and PSTs how they planned to be responsive to students' knowledge—of culture and of science. In the following example, two CT-PST dyads used a planning tool they adapted from the Big Idea Tool to plan a unit on climate change. They puzzled over the science and how to best engage more of their Samoan students; one CT was particularly concerned about why her Pacific Islander students were typically quiet during class. The excerpt starts with a reflection from a CT on one of her students from a previous year, who express a personal interest in climate change. This student's personal interest and the fact that many of their students identified as Samoan drove the group's decision to focus a unit of instruction on the phenomenon of why the Pacific Islands are "disappearing."

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Planning Discourse	**Framing**
CT1: …I asked my students what evidence is there for climate change and should we be concerned? This one girl had a really personal interest in it and she said "Well I am from Samoa and the islands of Samoa are being…because the sea levels are rising we are actually losing our island, and that is concerning to me." PST1: Wow. UC: I was thinking about how you have a lot of kids who are Pacific Islanders. CT2: Or from an island. CT1: It was neat because she was, you know, because everyone is concerned about the polar bears, for good reason, and she was like, "polar bears are distant, but this is my family's home, culture and land and may be becoming gone and in hundreds of years." PST1: That sounds like a good phenomenon. It sounds like something the kids could connect with and be like why is this land disappearing on islands like Samoa. CT2: Is it the sea level rising and/or the plates shifting? [After 30-minutes of unpacking phenomena] CT1: It is interesting because I didn't know, literally I just thought loss of land, but it is actually like the soil is more depleted for farmers, their burial sites are being washed away, it is more complicated…Hmmm. What I like about this idea is that it targets a population of our students who struggle a lot in science. PST1: I agree. CT2: It will be interesting to see if we get a higher engagement level.	Authority: CT1 presses others to try-on students' perspectives, while describing how she presses for evidence-based explanations (one of the ambitious teaching practices) Practices and tools: planning with and for students' engagement in important ideas (one of the ambitious teaching practices) was given adequate time; teachers used an adapted (school-specific) Big Idea Tool to record ideas from this conversation Community: Planning practices were not kept local to one CT-PST dyad

There are three important features of this conversation. First, the teachers raised questions about equitable participation and attempted to intervene at the level of a unit of instruction, not just a lesson. Second, this conversation was routine. The dyads had a set time for co-planning with their specialized tool, which allowed them to engage in a similar type of thinking their students would undergo when unpacking a puzzling phenomenon. Third, CTs' "backstage labors" (Anderson & Stillman, 2013) for making curricular decisions was on display; specifically a CT who typically framed and worked on problems of student thinking (Frame 3) could model this frame for PSTs and another CT who typically focused more on Frame 1 and Frame 2 activities.

Discourse and tool use for tracking student learning. Working on improving students' scientific explanations also sparked another line of inquiry: How can teachers best track students' explanations? Two of the eight dyads working on this frame consistently used a university-developed tool, the Rapid Survey of Student Thinking (RSST), to co-debrief lessons. The tool asks teachers to consider four dimensions of students' discourse: partial understandings, alternative understandings, everyday language and everyday experiences students used. Lorena (CT) and Mike (PST) used the tool almost every day to collect data during class, then debrief after class. The other dyad modified the RSST to track individual students' ideas and consensus ideas from an entire class period.

Improving tools for tracking student learning became a problem for which individual CTs sought support from the larger community. On the Facebook group page Sharon prompted a discussion thread about methods for tracking individual students' science ideas. This problem resonated with other CTs and they collaboratively described their own routines for co-teaching and co-debriefing lessons with novice teachers.

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Facebook Conversation	Framing
Sharon (CT1): How are we tracking our *students' explanations* throughout a unit? How can we explicitly *support students* in connecting activities to the big idea? We will explore the use of summary tables and various public representations to *help us help kids* make connections between activities and the big idea. I am also interested in how *students think about their changing ideas* throughout the unit.	Authority: Only CTs and university coaches were involved in this conversation. Note that CTs referring to their actions in terms of "we," implying collaboration with PSTs.
Emily (CT2): I am also interested in *how students think* about their changing ideas throughout the unit. We are asking students to go back to their original ideas tomorrow. We decided to have students date their original ideas after first hearing of the puzzling phenomenon in their own journal. At the end of the second activity tomorrow students add the new date and *changes in their thinking* to help us track better. I am excited to see how it all works out. Someone gave the suggestion of writing what students say/taking notes as I am pressing them. Great idea! It has been a great way *to help show them [students] how their ideas* can be put into words. It is also helps jog a memory of the conversation when we [CT-PST] are looking at their responses later.	Practices and tools: Discourses about *improving learning* (italics) are tightly linked with tools (underlined). CTs articulate small-grain size practices, which elaborate and extend the original 4 ambitious teaching practices
Sharon (CT1): Emily, what is your system for keeping track of what your students say? **Lorena (CT3):** My PST and I are both not very good at documenting conversations *between students*. We both have difficulty writing and listening. I like the idea of dating and going back to *students' ideas* in their notes. Perhaps when they go back to their originals have them reflect on *how their ideas changed* is definitely something I would like to do when we wrap up our EMS explanation.	More than just emphasizing practices that work best for students, they discuss how to support particular groups of students (ELL) and how to empower students to learn from tracking their own ideas over the course of a unit.
Sharon (CT1): I had some success with putting checklists of questions on the student tables and asking them to assign a *role to one person in the group to ask those questions*. These could be some of the "back pocket" questions. **Lorena (CT3):** I like that idea. With the back pocket questioning, I would like to figure out *how to make the kids ask themselves these questions*. **Michelle (CT4):** I like that idea too...I'm definitely going to use it. I have *an ELL student who can articulate his ideas but is a VERY reluctant writer* – this would be perfect for him (and some others).	Community: CTs seek and share co-planning and co-debriefing routines and name how the routines of other dyads might solve specific problems they face.

It is striking that in this exchange students' ideas and students' ways of reasoning with their own ideas were just as important as, and intertwined with, teaching practices and the use of tools. For example, the thread of how to track students' current and evolving ideas went beyond using a summary table (a university-developed tool) to the question of how to capture students' ideas in the moment. The idea to build a checklist of student ideas "in the moment" centered on students and how to help *them* track their own evolving ideas. Importantly, their discourse about improving learning was tightly linked with using, adapting, and inventing tools and practices. This forum for communication provided CTs with opportunities to expand their discourse community, work with others on similar student-centered problems and seek out multiple ways of addressing these challenges. Through this press teachers took on larger issues of rigor and equity in teaching and learning.

Frames and PST Enactment of Practices

Our third research question was about the frames for improving teaching and opportunities to appropriate the ambitious teaching practices. Depending on the frame, PSTs had different opportunities to "try on" the ambitious teaching practices during practicum, and different ways in which they were successful. We retrospectively examined our observational data in light of our coding for frames (See Figure 5). The ratings are composites of the four teaching practices averaged across the number of PSTs in each frame (N = 5, 10, and 8 PSTs respectively for Frames 1, 2, and 3). We do not use this representation to imply causality between frames and novice teacher practice, nor do we suggest that some novices were more capable than others. We interpret the trends as an indication of what is possible for the well-supported novice teacher. One of the striking patterns was the variation in the first observation; in just one month of working with CTs, the novice teachers had a range of opportunities to try and receive feedback on the ambitious teaching practices.

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The third observation was particularly telling for describing the PSTs' experience in Frame 3. This observation was in January when PSTs were no longer consecutively taking their science methods teaching course at the university and PSTs were asked to take more responsibility for teaching. All eight of the PSTs experienced a period in which their attempts at ambitious practices were less successful. CT-PST dyads were doing less co-teaching at this time and PSTs struggled to enact the practices in the same way their mentors did. Meanwhile, CTs expressed frustration with not knowing how to participate in conversations with students. Rather than interpreting the problem as one of the PST's capabilities (Frame 1), the CTs framed the problem in terms of their own proximity to students' ideas. CTs in these dyads tried to resolve tensions with a mid-course correction in which they re-engaged in planning lessons to help PSTs structure opportunities for students' to participate in rigorous ways. In one extreme case the CT made her PST re-teach a unit, which meant that the PST had to extend her practicum experience.

Discussion

Problems without Ceilings and Cascading Lines of Inquiry

This study suggests that some conversations between cooperating teachers and pre-service teachers are more productive than others. We assert that framing and working on problems of improving the novice teacher (Frame 1)—also known as "fixing novices" (Feiman-Nemser, 2001, p. 1032)—are not productive in supporting teacher learning or systems learning. These were problems *with ceilings* because they had little room for negotiation of teaching practices. In Frame 1, CTs and PSTs discussed teaching and learning with the novice teacher as the object of inquiry. Foregrounded in these conversations were underspecified instructional moves and measurements of the degree to which the novice teacher matched the more veteran teacher's practice. Problems *without ceilings* did not have easily defined endpoints, and drove innovations in planning, teaching, and debriefing. These negotiations occurred when dyads inquired into problems of improving teaching (Frame 2) and improving student learning (Frame 3). Most teachers would characterize their conversations under these general categories, but there were specific ways in which teachers framed and worked on these problems that made them sites for co-inquiry. For example, in Frame 2 CT-PST dyads worked on aligning ideas about one of the ambitious teaching practices, 'planning for engagement with important ideas'. They developed routine times to plan instructional units; discursively CT-PST dyads questioned the content they wanted to teach and interrogated their own content knowledge.

Frame 2 conversations, however, often stopped short of considering how students processed the content and how tools—such as templates for students to draw models—could be improved to better support student learning. In Frame 3, dyads took on such questions as they inquired into how students constructed explanations, and the productive variation among students' ideas. Working in this frame required teachers to find new ways to not just plan for instruction but to co-teach and co-debrief. They generated new tools for tracking all students' ideas, propelling further inquires into student learning and their interpretive devises. Cohen, Raudenbush, and Ball (2003) describe the cascading effect of focusing on students' ideas in terms of generating more intellectual resources for student and teacher reasoning.

> Students that have learned to reflect on their ideas, listen carefully, and express themselves clearly are likely to be better users of materials, teachers' and others' contributions. They are also likely to make it easier for other students and teachers to use their ideas. How students and teachers organize their interactions also shapes resource use. Students and teachers whose classroom cultures support the respectful expression, explanation, and scrutiny of ideas are likely to generate more usable material for instruction, and thus to have more resources to use than classrooms in which conventional lecture and recitation are the rule (Cohen, Raudenbush, and Ball, 2003, p. 92).

This current study suggests that focusing on student learning also has a cascading effect on the nature of teacher learning (for novices, mentors, and the two together). CTs and PSTs created lines of inquiry around strategies for helping students improve the depth of their scientific explanations and for tracking how students were changing their ideas over time. And they allocated portions of their time together to *debriefing* student ideas. In fact, data from this study suggest that the heightened need for communication between partner teachers about students' ideas fueled the development of the practices and tools.

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The Role of CT's Knowledge of Practice and Student Ideas

One of the questions this study raises is: What is the role of the CT's knowledge in influencing which frames take precedence? While there are many contextual factors, the data suggest that CT's knowledge of the practices and attentiveness to students' ideas makes a difference for which frames get negotiated with PSTs. Without any knowledge of the practices the default frame for CTs (and most of their PSTs) was *improving novices* (Frame 1). This frame was fraught with tensions but CTs often used a position of authority to maintain a focus on the novice as an object of inquiry. With minimum introduction to the research-based teaching practices (attending the summer institute) CTs tended to frame and work on problems of *improving teaching* (Frame 2) with their PSTs. CTs were brokers for the ambitious teaching practices (particularly when planning), which minimized potential tensions between university and school contexts. Rather than experiencing frame conflict (Coburn, 2006) dyads quickly settled into planning routines that questioned the worth of the content students would learn and how best to have students represent their ideas during lessons. These routines, along with the use of a structured planning tool, provided an opportunity to CTs to share their "backstage labors," meaning their knowledge about curricular and instructional decision-making (Anderson & Stillman, 2013) but also afforded an opportunity PSTs to contribute complementary sets of skills and knowledge (Tobin & Roth, 2005).

CTs most knowledgeable about practices, and who had repertoires of practice that supported students in making their ideas public, were able to support TCs in working on problems improving student learning (Frame 3). Of the eight CTs who supported this frame, four graduated from the same teacher education and four were veteran teachers with multiple, established routines for eliciting and responding to students' ideas. All eight uncompromisingly positioned students' ideas as the touchstone of pedagogical inquiry with PSTs. In Feiman-Nemser's (2001) framework these mentors were "advocates for change." More than providing images of what was possible in planning and teaching (Anderson & Stillman, 2013) these CTs' pressed PSTs to adopt a student-learning frame throughout practicum. They asked PSTs to focus on students' ideas from a position of authority (Fligstein, 2001). Not only did they require PSTs to participate in routines for debriefing student learning and accounting for how all students learned, but they also held PSTs to a high bar as they gradually turned over teaching responsibilities to the PST during practicum. Midway through practicum PSTs in Frame 3 struggled to enact the ambitious practices on their own; CTs pressed PSTs to better specify lesson plans and in some cases, re-teach lessons. CTs in these pairs kept close tabs on students' ideas, at times at the risk of maintaining cordial relationships with PSTs. They also literally 'stayed by' PSTs throughout the practicum so that they could remain close to their students' reasoning. PSTs working with these CTs had fundamentally different experiences during practicum—in terms of interactions with students in classrooms and professional collaborations. The CTs also had different experiences as they found they needed to seek additional resources beyond their dyads and school colleagues to work on problems of improving students' explanations and methods for tracking students' evolving understandings.

Conceptually these CTs worked on aligning others to their frame (Coburn, 2006; Snow, Rochford, Worden, & Benford, 1986). They provided conceptual hooks for particular ways of seeing, believing, and valuing. They mobilized individuals (their PSTs) and groups (other PST-CT dyads) to similarly take up a focus on students' ideas. From a knowledge building perspective, *knowledge of practice and tools became distributed and advanced across individuals and across settings* (classrooms, departmental planning spaces, on-line social medium) as teachers framed and worked on problems of improving student learning.

The Role of Tools

Across the frames, the explosion of tools and inquiries into tools in Frame 3 was striking. We hypothesize part of the reason for this trend was teachers' understanding of the complex and diverse learning needs for each student. In discursively rich classrooms, they felt compelled to develop more scaffolds to guide student thinking and to do so in a way that fit with their local contexts. Teachers were able to use existing tools at face value but also develop productive instantiations—thus simultaneously reasoning with the concepts behind the tool as well as the pedagogical value (Grossman et al., 2009). Through the development of new tools and routines Frame 3 not only supported the improvement of human capital (as indicated in the performance of PSTs), but also social capital among a wider group of actors as teachers shared examples of how they embedded knowledge of student learning into tools (Engeström, 2004; Hiebert & Morris, 2012).

We also hypothesize that Frame 2 activities could be enhanced with access to more prototypical tools. It is possible that the lack of teacher enactment-focused tools might have contributed to finding that PSTs in this frame were less likely to try on and appropriate the ambitious teaching practices. For example, we might imagine a tool that would remind teachers to track different discourse moves during a lesson. Teachers could watch video of the lessons to identify instances of these moves being made. Both the face-to-face prototype tools (such as a template for students to model scientific phenomena) and reflective tools (i.e. the Rapid Survey of Student Thinking tool) created by the university were designed for the expressed purpose of eliciting and understanding students' ideas, not for tracking which teaching strategies were used. These tools supported Frame 3 but did little to support small-scale negotiations of teaching in Frame 2. While this was intentional, it may be that there were missed opportunities for teachers to engage in conversations about smaller grain-size teaching practices. Furthermore there may be a way to design tools that allow for dual participation in Frames 2 and 3 such that more teachers could engage with the frames and differentiate the added value of each (Achinstein & Barrett, 2004).

Implications for Teacher Education

This study suggests that simply being in the company of accomplished mentors is not enough to support the improvement of teachers and teaching. While this study was conducted in science teacher education context it has applicability to the broader field. Shifting foci from problems with ceilings toward problems without ceilings is difficult and requires time but this study suggests a starting place—the conversations between mentor and novice teachers. Teacher education programs can specifically design for work on problems of improving teaching and student learning (Frames 2 and 3). Coaches, mentors and teacher educators can focus first and foremost on teaching practices known to support intellectual engagement and equity and limit conversations about competencies of novices. In teacher education models, the goal of practicum then is not to develop individual artisans but to support conversations that specify and improve common practices and their associated routines and tools.

The effectiveness of teacher education programs cannot be viewed simply through the lens of novice proficiency nor be tracked with check-off boxes suggestive of some level of novice competency. Based on this study we propose three process measures: the quality of student discourse CTs and PSTs support, the quality of discussion among dyads (and larger groups of dyads) about students' ideas, as well as the quality of newly created or evolving social routines and tools. These measures index systems improvement.

This study does not diminish the importance of prior research chiefly focused on individual teachers, but rather it defines components necessary for a systems perspective that supports and improves learning over time. Moving forward this study suggests that university-school partnerships engage multiple role actors—teacher educators (especially methods course instructors), university supervisors, CTs, PSTs and K-12 students—in articulating a common vision of quality disciplinary-specific student learning and a complementary set of teaching and mentoring practices. Importantly, partnerships need to create systems that co-investigate productive variations of the practices and their associated tools. Once a potential tool or practice that supports K-12 student or PST learning is identified, it can be tested across the network to understand whom it best serves and under what conditions. Investing in social and technological infrastructures that position multiple role actors to work on meaningful lines of inquiry needs to be a part of the design as well as an object of study—specifically interrogating structures intended to address multi-layered tensions (such as those identified in Frame 3). Addressing tensions and identifying tradeoffs in decision-making need to be a network, not an individual or dyad problem. When knowledge building is a part of a network, productive adaptations as well as productive failures can travel quickly and inform improvements throughout a unified community.

Note

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Figure 1. Performance Progression of Ambitious Science Teaching Practices.

1) Planning for engagement with important science ideas (Note: this is a planning practice but the progression indicates planning decisions reflected in enactment)	**Focus on topic or "things"** • Teacher selects concrete or abstract entities (things) to learn about in varying degrees of detail. • Students asked to describe, name, label, identify, using correct vocabulary.	**Focus on observable processes** • Teacher selects as focus "what is changing" in a system or how conditions affect a naturally occurring event.	**Explanatory model focus** • Teacher focuses on *unobservable* processes, events, or entities, or the relationships among science concepts. • Teacher links these to important *observable* natural phenomena in order to develop an explanatory model that students will make sense of over time.	
2) Eliciting students' ideas to adapt instruction	**Monitoring and re-teaching ideas** • Teacher starts by presenting information, then monitors language students use to see if students are developing "correct" conceptions (whether students "get it" or not). • Teacher engages in 1-on-1 tutoring or uses IRE in whole class conversations to present more correct conceptions to students (perhaps using a different modality).	**Eliciting students' initial & unfolding understandings** • Teacher elicits students' initial and on-going hypotheses, questions, or conceptual frameworks about a scientific idea.	**Referencing students' ideas & adapts instruction** • Teacher elicits students' initial conceptions of a scientific idea by posing a rich open-ended task or puzzling event related to the big idea of the unit. • Teacher listens for partial understandings as well as alternative conceptions (without presuming students need to precisely replicate the teacher's line of thinking). • Teacher uses students' language and partial understandings as building blocks to shape the direction of classroom conversations. Teachers engineer productive classroom conversations or pursue students' lines of thinking by weaving students' lines of reasoning together with scientifically coherent ideas across multiple lessons.	
3) Supporting on-going changes in thinking	**Primarily focusing on procedure** • Teacher asks students to describe procedures for activities or experimental set-ups. • Science concepts are played down to allow time to talk about designing experiments. • Talk with students is about how to do an activity or about error, validity, reliability, recording data.	**Discovering or Confirming Science Ideas** • Teacher has students "discover" science concepts for themselves OR has students use an activity as a "proof of concept." • Science is about acquiring accepted facts, principles, or laws. Students collect information to recognize or prove patterns.	**Linking concepts within and across investigations** • Teacher first seeds students' thinking with new science concepts (not explanations) and asks students to use these ideas to makes sense of an investigation. • Science ideas are up for discussion. Students derive explanatory language from activity and use it to solve new problems. Public representations of students' ideas change in response to findings from each day.	**Model-Based Inquiry focus** • Teacher highlights tentative or partial explanatory models as the basis for multiple investigations. • Teacher asks students to use evolving model as a reference before, during and after each inquiry. Teacher builds in background knowledge of underlying (unobservable) science ideas and models before, during, and following an inquiry, but without doing the reasoning for the students. • Science is about revising and testing models to synthesize ideas and explain problems.
4) Pressing for evidence-based explanations	**No press for a scientific explanation** • Teacher does not ask students to provide any form of explanation; or teacher uses "explain" to mean "justify" as in justify the existence of an entity or accepted fact. • There is no event or process that is subject to explanation.	**"What happened" explanation** • Teacher asks students to describe relationships between variables, differences between experimental groups, trends over time, or qualitative observations. "Explain what you see in the data."	**"How/ partial why" something happened explanation** • Teacher asks students to hypothesize about reasons for relationships among variables or observations, and how these predict the ways some natural system will behave.	**Causal explanation** • Teacher has students use unobservable events, processes, and entities to construct a causal story of why something happened. (may mean first supporting students through "what" and "how explanations" with goal of working toward "why explanations") • Teacher unpacks learning about the nature of scientific explanations with students, and about "what counts" as evidence.

Figure 2. Big Idea Tool CT-PST dyads used to co-plan units of instruction.

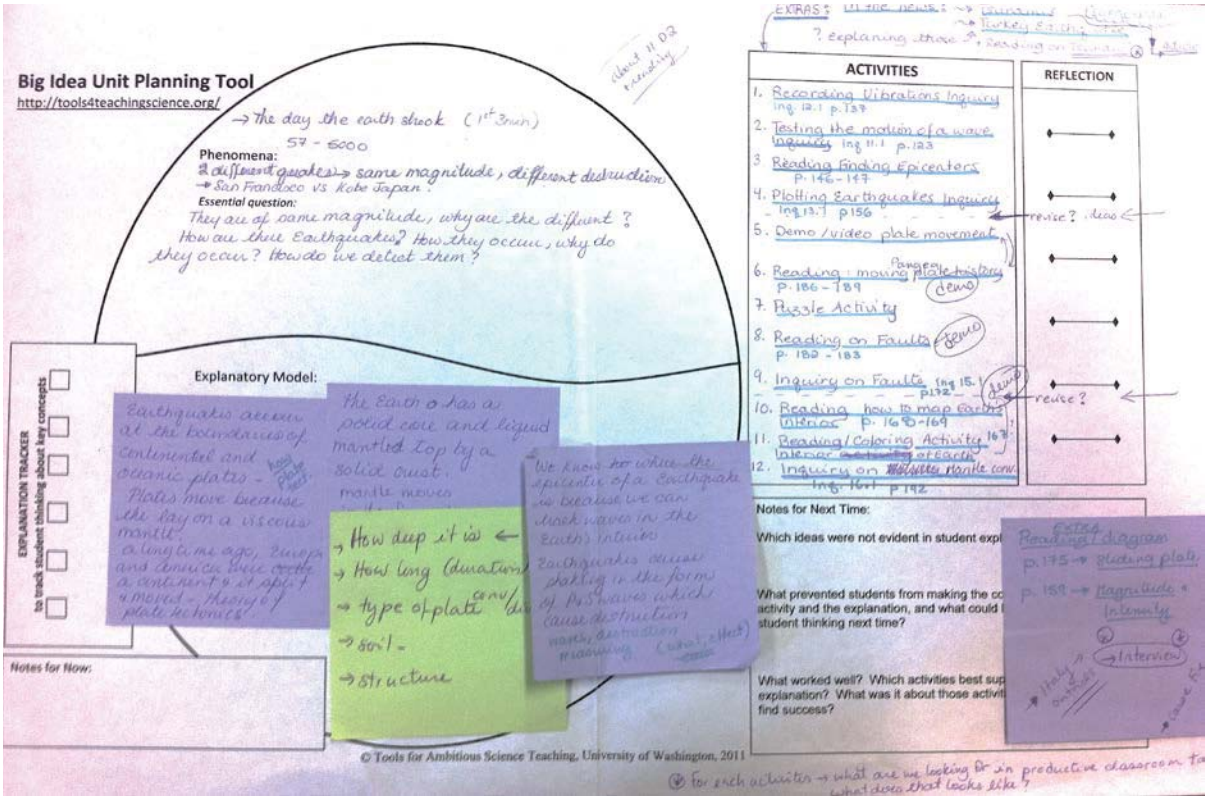
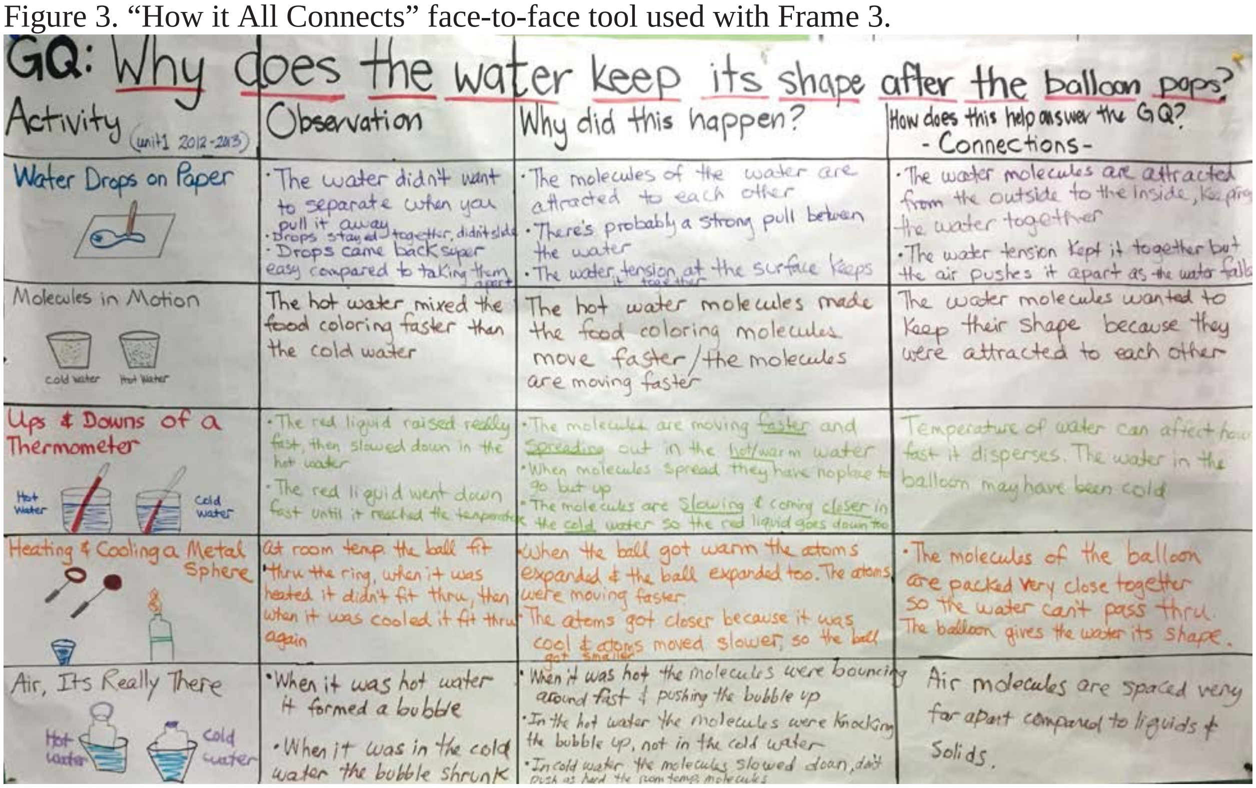


Figure 3. "How it All Connects" face-to-face tool used with Frame 3.



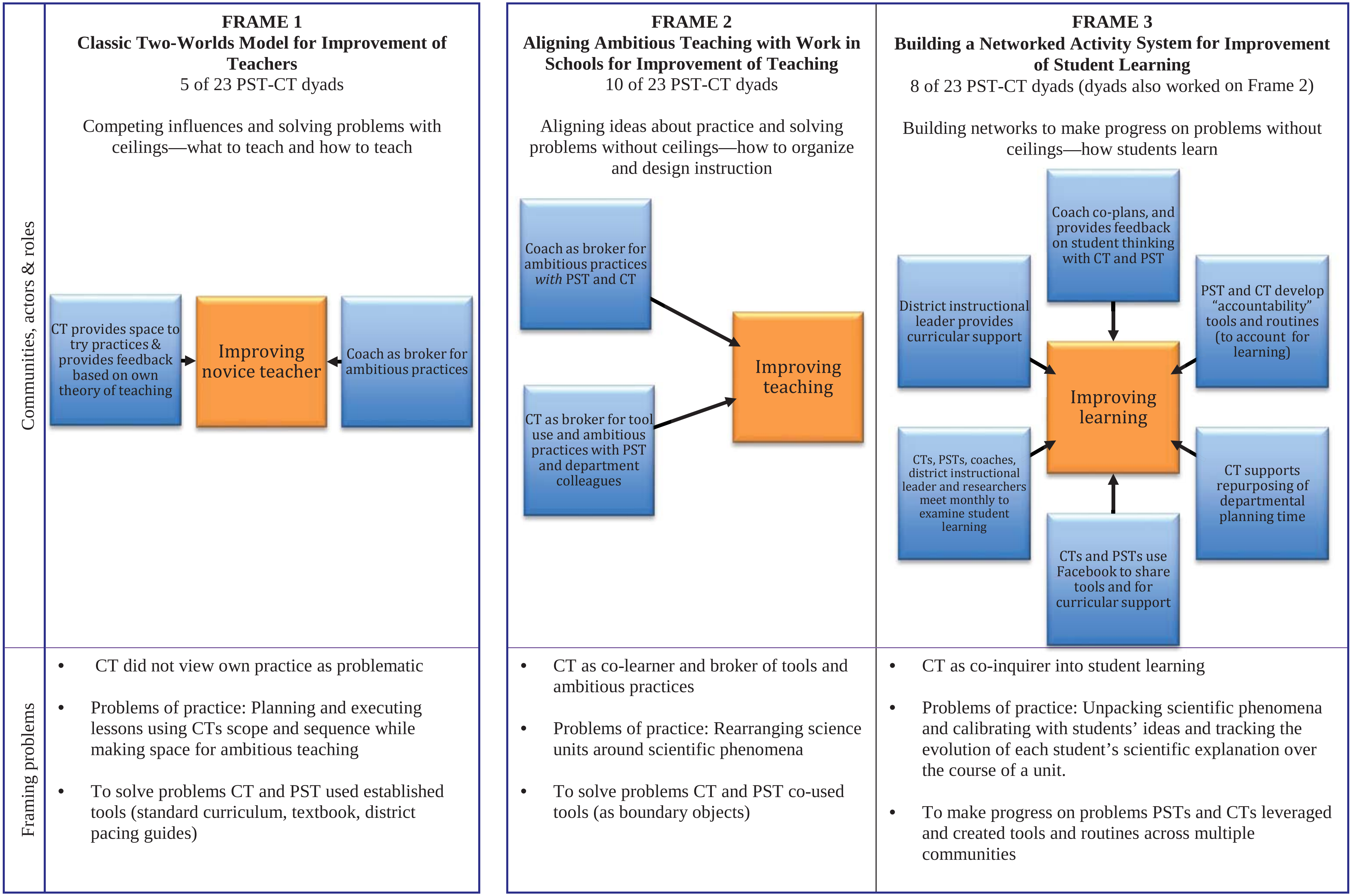


Figure 4. Frame activities CT-PST dyads participated in and negotiated during practicum.

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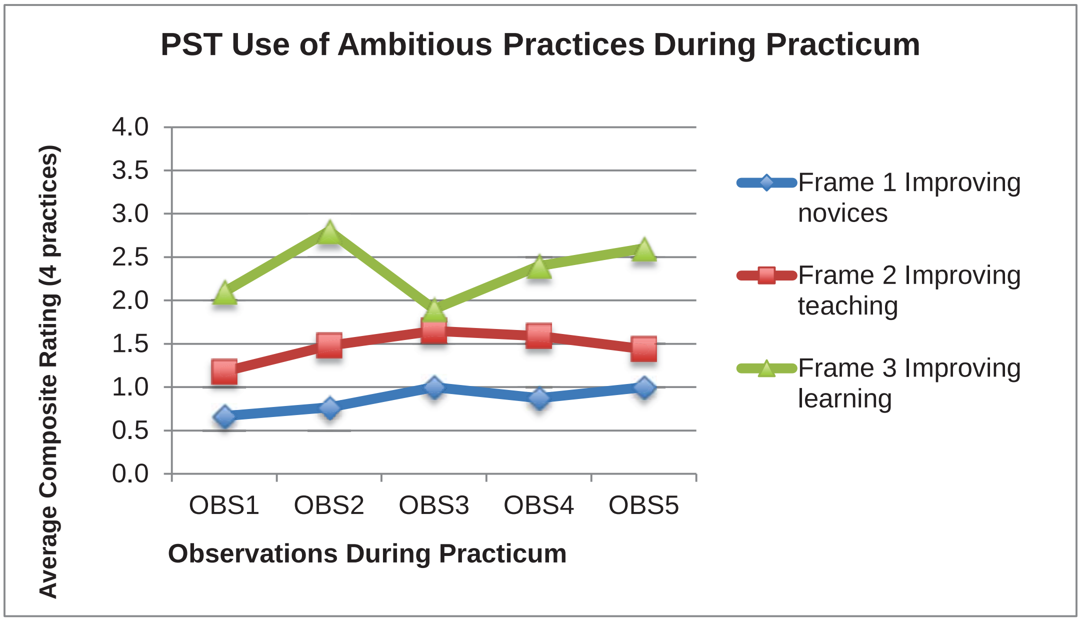
Figure 5. Observational data of Pre-Service Teachers' use of the ambitious teaching practices.



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Appendix A. Example of an intermediate document characterizing PSTs and CTs repertoires of practices and sense-making between the dyad.

Frame 3: Improving Student Learning			
Problems of Practice	**CT- Sharon**	**PST- Lori**	**Productive Tensions: Points of Negotiation**
Planning	Tool use: • Plans with big idea tool throughout unit Practices: • Organizes around big idea, explanations, and puzzles students are interested in solving • Plans for instruction based on students' incoming scientific ideas • Plans for connections across big ideas	Tool use: • Plans with big idea tool Practices: • Plans to make science interesting, practical, and relevant to students' lives • Plans for student to see the whole story within a phenomenon	CT and PST collaboratively unpacked scientific phenomena until end of practicum Big idea tool routinely used and repurposed as co-planning tool Revision of big idea in alignment with evolving student ideas CT pressed PST to frame and work on students' ideas and partial understandings
Instruction	• Teacher responds or re-voices students' science ideas, recognizing the students' contributions and providing feedback on students' ideas • Tracks how students are formulating scientific ideas • Teacher encourages student participation (teacher asks to hear multiple students' ideas, and asks students to listen to one another) • Asks students to clarify their idea before responding • Acknowledges that students' examples are from a lived experience • Makes statements about being a good participant • Invites more students to share ideas • Asked PST to answer four questions every night focused on students thinking and ideas • Gradual release of responsibility to PST • CT reengaged with lesson planning mid-practicum	• Initial request for feedback on her teaching skills • Teacher responds or re-voices students' science ideas, recognizing the students' contributions and providing feedback on students' ideas • Teacher encourages student participation (teacher asks to hear multiple students' ideas, and asks students to listen to one another) • Asks students to clarify their idea before responding • Acknowledges that students' examples are from a lived experience • Makes statements about being a good participant • Invites more students to share ideas	CT's unwavering press for framing and working on problems of student learning throughout practicum Communication about planning and students' ideas remained the same or increased as PST took on more instructional responsibilities Discourse and tools repurposed to improve student explanations Dyads co-pressed students for ideas CT framed tension in practicum in terms of own proximity to students' ideas
Debriefing	• Tracks students evolving ideas in connection to science explanation • Haves students track their ideas with each other • Repurposes and revises big idea throughout unit in response to students' ideas • Poses questions to networked community on how to track students' evolving ideas	• Tracks students' ideas as they construct evidence-based explanation • Repurposes and revises big idea throughout unit in response to students' ideas	Debrief about implications of student ideas, partial understandings, and everyday language and for upcoming lessons throughout practicum Repurposed tool use to track students' evolving ideas and explanations Sought out multiple ways of addressing student-centered problems with members of networked community