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How Does Practice-Based Teacher Preparation Influence Novices' First-Year Instruction?

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Title: How does practice-based teacher preparation influence novices' first-year instruction?

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Abstract

Background/Context: Teacher preparation suffers from a lack of evidence that guides the design of learning experiences to produce well-prepared beginners. An increasing number of teacher educators are experimenting with practice-embedded approaches to prepare novices for ambitious instruction. This study examines the role of core instructional practices introduced during preparatory experiences, in shaping novices' first-year teaching.

Research design: Employing a mixed-methods approach, we compare the first-year teaching of two groups of individuals with secondary science certification, one of which is comprised of graduates from a practice-embedded preparation program and the other of graduates from programs that did not feature practice-embedded preparation. A total of 116 science lessons taught by 41 first year teachers are analyzed, focusing on the quality of student opportunities to learn (OTL) observed during the lessons.

Research questions: This study sought answers to two research questions: 1) What are the characteristics of students' OTL from first year teachers, one group of whom learned a set of core instructional practices during their preparation program and the other group of whom were not exposed to core practices? 2) Who provides opportunities for students to engage in meaningful disciplinary practices as outlined in the Next Generation Science Standards, during the first year teaching, if any? How did they create such opportunities?

Findings: Independent-sample t-tests showed that there are significant mean differences between the two groups ($t=3.1\sim8.9$; $p < .001$), on four metrics associated with their students' opportunities to learn. In-depth qualitative case studies reveal two ways that core practices shape instruction in new teachers' classrooms: (a) they support novices in formulating an actionable curricular vision as advocated by the science education community, and (b) they appear to help novices notice, attend to, and build upon students' ideas in classrooms with the use of strategies and tools recommended by the program.

Conclusions/Recommendations: A focus on a set of strategic and intentional practices, designed to help teachers achieve rigorous and equitable learning goals, has potential as a curricular frame for teacher preparation. But the emphasis should be placed on the vision and pedagogical goals that underlie the core practices, rather than the ungrounded use of strategies or tools themselves.

The Executive Summary

Background

An increasing number of teacher educators are experimenting with practice-embedded approaches to prepare novices for ambitious instruction. These approaches use combinations of "core-practices" as the basis for pre-service teachers' apprenticeships into the kinds of instruction that support rigorous and equitable opportunities to learn for students; they also serve as a way to build and test knowledge about teacher education pedagogy across programs. This movement emerges in the context of intense scrutiny about the effectiveness of teacher education and about methods of preparation in particular. Recent national reports conclude that the empirical base from which to draw conclusions about the types of instruction and experiences that aspiring teachers need is inadequate. With a lack of common understanding across the field for what it means to get novices ready for the classroom, transforming learning experiences for K-12 students continues to be an unrealized ideal.

The focus of inquiry

This study intends to advance the knowledge bases on teacher preparation, by exploring the influence of preparatory experiences facilitated by methods course activities on first-year teachers' instructional practices. We focus on one pedagogical feature of preparation—helping preservice teachers take up practices that are rigorous, responsive to students' ideas, and equitable in fostering widespread classroom participation.

Research design

Employing a mixed-methods approach, we compare the first-year teaching of two groups of individuals with secondary science certification, one of which is comprised of graduates from a practice-embedded preparation program and the other of graduates from programs that did not feature practice-embedded preparation. A total of 116 science lessons taught by 41 first year teachers are analyzed, focusing on the quality of student opportunities to learn (OTL) observed during the lessons.

Research questions

The analyses were guided by two research questions: 1) What are the characteristics of students' OTL of first year teachers, one group of whom learned core instructional practices during their preparation program and the other group of whom were not exposed to core practices? 2) Who provides opportunities for students to engage in meaningful disciplinary practices as outlined in the Next Generation Science Standards, during the first-year teaching, if any? How did they create such opportunities?

Data analysis

In this study, the OTL observed in each science lesson is characterized using four metrics: (a) framing of learning goals, (b) practice demand of tasks, (c) conceptual demand of tasks, and (d) responsiveness of classroom discourses. Each of the 116 lessons was assigned four ratings, one for each dimension of OTL, such as HHMH or LLLL (H= "High," M= "Medium," L= "Low"). Based on the results of OTL rating and some distinctive and holistic patterns of teaching observed in lessons, we grouped 116 lessons into four conceptual categories: (a) Type I: =Engaging in disciplinary practices for sense-making (e.g., HHHH, HHHM), (b) Type II: Engaging in disciplinary practices for sense-making with less sophisticated practices (e.g., HMMM or HMML), (c) Type III: Engaging in disjointed practices focusing on topic or procedure (e.g., MMMM, MMLL), and (d) Type IV: A focus on doing without expanding thinking (code=LLLL). In addition to this coding, in-depth qualitative analyses were conducted to examine the processes by which first year teachers created high quality opportunities to learn, and the role that core practices played in the processes if any.

Findings

Independent-sample t-tests showed that there are significant mean differences between the two groups (t=3.1~8.9; $p < .001$), on four metrics associated with their students' opportunities to learn. Overall, four patterns emerged within and between the two groups of first year science teachers' classrooms. First, there was wider variation in the quality of student learning opportunities in classrooms of the core practice group (CPG) than in the comparison group (CG). Second, the teachers in CPG were more likely to frame learning goals in ways aligned with the vision of NGSS. Third, high quality tasks that were coded as both high practice- and high conceptual-demand were rarely observed in both groups of first year teachers. This result suggests that, in general, new science teachers have difficulties in designing and enacting high quality tasks with students. Finally, the classroom discourses that facilitate students to build upon ideas toward expanding their thinking is known to be difficult, especially for novice teachers. In our dataset, overall less than two in every 10 observed lessons were coded as highly responsive (n=21 out of 116, 18.1%). Notably, highly responsive classroom discourses were five times more frequently observed in CPG teachers' classrooms (n=20 out of 77, 26.0%) than CG (n=2 out of 39, 5.1%).

In-depth qualitative case studies reveal two ways that core practices shape instruction in new teachers' classrooms: (a) they support novices in formulating an actionable curricular vision as advocated by the science education community, and (b) they appear to help novices notice, attend to, and build upon students' ideas in classrooms with the use of strategies and tools that are consistent with this curricular vision.

Conclusion and implications

The analyses suggest three implications for research and policy in teacher preparation. First, core practices, as a set of strategies to achieve valued learning goals, have a potential as a useful curricular frame for teacher preparation, in particular with respect to achieving two important goals: supporting new visions of teaching and developing a beginning repertoire of effective teaching. Importantly, our analyses suggest that in order to improve the teaching quality in K-12 classrooms with use of core practices, the emphasis should be placed on the curricular vision and pedagogical goals that underlie the core practices, rather than the ungrounded use of strategies or tools themselves.

Second, this study calls for a new integrated approach to study the curriculum and pedagogy of teacher preparation, moving beyond the search for *what* should be taught (i.e., curriculum) and *how* it should be taught (i.e., pedagogy) as separate pursuits. In our study, the teaching quality of the CPG teachers' 77 lessons varied widely. Given that the vast majority of observed lessons from the comparison teachers were characterized as Type III or IV, the overall shift of the teaching quality observed in the CPG teachers' lessons toward Type I or II OTL is significant. At the same time, the wide distribution of teaching quality within CPG teachers' lessons implies that, as noted by numerous prior studies, the exposure to core practices and the concept of sense-making facilitated by the methods courses activities interacts with novices' personal backgrounds, such as their conception of the disciplines, of teaching, learning, and their own evolving identities as educators. In addition, the ways in which novices work with core practices in local school contexts matter. It may be important to attend *how* novice teachers experience the core practices, either individually or collectively both in the program and in schools, during their preparation. We argue that more attention needs to be paid to the questions of what experiences need be provided for whom, when, and how to achieve particular learning goals for preservice teachers.

This study also contributes to research on teacher preparation by providing conceptual tools that guide a systematic examination of the impact of preparation experiences on the quality of teaching in novices' classrooms. We proposed a framework and strategies for linking preparation experiences to students' opportunities to learn in K-12 classrooms, in order to address the methodological complexities of studying graduates from different programs and avoiding the substantial assumptions with using students' standardized test scores as proxies for teacher quality.

Introduction

An increasing number of teacher educators are experimenting with practice-embedded approaches to prepare novices for ambitious instruction (McDonald, Kazemi, & Kavanagh, 2013). These approaches use combinations of "core-practices" as the basis for pre-service teachers' apprenticeships into the kinds of instruction that support rigorous and equitable opportunities to learn for students; they also serve as a way to build and test knowledge about teacher education pedagogy across programs (Core Practice Consortium, 2016). This movement emerges in the context of intense scrutiny about the effectiveness of teacher education and about methods of preparation in particular (Levin, 2006; Zeichner, 2012). Recent national reports conclude that the empirical base from which to draw conclusions about the types of instruction and experiences that aspiring teachers need is inadequate (National Academy of Education, 2013; NRC, 2010). In one case, a National Research Council committee concluded that we don't have basic knowledge of how methods courses are structured or about the influence of coursework on novice teachers' work in schools (NRC, 2010). Each of the approximately 1500 teacher preparation programs in the United States continues to experiment with preparing educators, largely in isolation from one another and from any reliable research base about instruction itself (Clift & Brady, 2005; Wilson, 2011). With a lack of common understanding across the field for what it means to get novices ready for the classroom, transforming learning experiences for K-12 students continues to be an unrealized ideal.

Well-constructed methods courses are assumed to be foundational to the development of novice practice (Ronfeldt, Schwartz, & Jacob, 2014), indeed many preparation programs are built on the premise that methods experiences can help novices disrupt traditional instruction in schools. Our study contributes to the knowledge bases on the curriculum and pedagogy of teacher preparation, by exploring the influence of such experiences on first-year teachers' instructional practices. We focus on one pedagogical feature of preparation—helping preservice teachers take up practices that are rigorous, responsive to students' ideas, and equitable in fostering widespread classroom participation. In this study, we compare the first-year teaching of two groups of individuals with secondary science certification, one of which is comprised of graduates from a practice-embedded preparation program and the other of graduates from programs that did not feature practice-embedded preparation.

Theoretical Framework

We first review the literatures that describe the impact of preservice teacher education on classroom instruction. Next, we unpack the theoretical underpinnings of practice-embedded teacher preparation and core practices—the focal features of pre-service experience examined in this study. We then outline a conceptual framework that articulates the relationships between preparation experiences and first-year science teaching; these hypotheses guide our research activities and analyses.

Challenges in studying the impact of teacher preparation

Studies that examine the impact of teacher preparation on classroom teaching are frequently conducted in response to policy debates about effective pathways for producing "high quality teachers." These investigations are predominantly large-scale and quantitative. Researchers, for example, compare different routes of becoming a teacher, such as traditional vs. alternative (e.g., Boyd, Grossman, Lankford, Loeb, & Wyckoff, 2009; Goldhaber, Liddle, & Theobald, 2013), or assess the influence of coursework on measureable outcomes (e.g., Harris & Sass, 2011). In this research tradition, researchers generally assume that effective teaching depends largely on practitioner knowledge—knowledge of subject matter, general pedagogy, and subject specific pedagogy (Gitomer & Zisk, 2015; Shulman, 1987). Accordingly, researchers may ask: "Does coursework in general or subject-specific pedagogy matter to student outcomes that we value?", or "Does mastery of subject matter outweigh other effects of teacher preparation in terms of student achievement?" Typically, researchers employ a process and product model to test these questions. For example, the number of courses or credits taken by the teachers during preparation period is used as "process measure," representing teachers' knowledge on subject, general pedagogy, subject-specific pedagogy. Researchers use these variables as the predictors of discrete outcomes, such as teachers' self-reported preparedness, retention in the profession, and their students' achievement measured by standardized tests. In one case Harris and Sass (2011) examined the effect of preservice teacher education on student achievement using a state-wide data set of students (math and reading in each of grades 3-10 for years). They linked teachers to their university coursework, creating variables that described each course in these programs according to its focus on teacher content knowledge, pedagogical knowledge, and classroom observation/practice in teaching, then aggregated these measures for each participant to characterize their undergraduate preparation for teaching. They used this measure to test if preservice teacher education had any impact on teacher productivity, as measured by student achievement gains.

Thus far, the effects of program variations reported by these studies remain inconclusive. Some studies provide evidence suggesting the significant effect of certified teachers from traditional teacher preparation programs on student achievement in comparison to the non-traditional routes (e.g., Boyd et al., 2009; Darling-Hammond, Holtzman, Gatlin, & Heilig, 2015). Other studies show mixed or no significant effect of traditional preservice teacher education (e.g., Goldhaber et al., 2013; Harris & Sass, 2011; Koedel, Parsons, Podgursky, & Ehlert, 2015).

These large-scale, quantitative studies contribute to our knowledge of the effect of teacher preparation by identifying several important elements that influence student learning outcomes in K-12 classrooms. At the same time, these studies reveal the complexity of studying how preparation experiences impact teaching and learning in K-12 classrooms. Measuring constructs such as teacher knowledge or instructional quality is incredibly complex both conceptually and methodologically. The debate on whether we can estimate the quality of teaching with value-added scores derived from standardized assessments has produced many questions, but little in the way of consensus (see Darling-Hammond, 2015; Rothstein, 2010 for example). Furthermore, virtually all large-scale, quantitative studies that examine outcomes of teacher preparation are susceptible to confounding variables, which makes it difficult to tease out the influences of preservice experiences. For example, Kennedy (2008) points out that teachers self-select into educational programs; consequently, their existing values and predispositions are not independent of their preparation experiences or their credentials. Once certified, they engage in nonrandom job-seeking practices and districts engage in nonrandom hiring practices, so the resulting pattern of job placements interacts with teachers' educational backgrounds, certificates, and attitudes (see Boyd, Lankford, Loeb, & Wyckoff, 2003; Lankford, Loeb, & Wyckoff, 2002). Notably, such large-scale, quantitative studies are limited in improving preservice teacher education by leaving the processes of influence (i.e., *how* preservice teacher education influences teaching practices in classrooms) as a black box.

There is, however, a small body of qualitative studies that explores the influences of preservice education on new teachers' instructional practices. In these studies, researchers follow a few graduates of a program through the first one or two years of teaching to examine whether practices taught during preparation, such as inquiry teaching, are observed in the new teachers' classrooms (e.g., Grossman et al., 2000; Nolen, Horn, Ward, & Childers, 2011). Overall these studies demonstrate the power of classroom and school contexts over the instructional practices promoted by preservice programs. Researchers report that novice teachers are strongly influenced by the specific circumstances in which they find themselves—the students they serve, the curriculum and other materials at their disposal, organizational constraints, and professional norms in their buildings. In many of these studies, novice teachers' prior beliefs about what is proper and possible in the classroom can act as a filter on program ideas during preparation (Horn, Nolen, Ward, & Campbell, 2008; Nolen et al., 2011) or over-ride them entirely in shaping novices' eventual instruction. Researchers also note that teacher education courses (including methods) tended to provide only general ideas or theories about instruction, without the kind of principled guidance teachers need to translate these concepts into specific strategies (Liston, Whitcomb, & Borko, 2006). Several researchers found that teachers claimed to embrace program ideas but many of them could not understand how to put these into practice (e.g., Artiles, Barreto, Pena, & McClafferty, 1988; Ensor, 2001). Taken together, these studies do little to refute the claim that teacher preparation is a "weak intervention" in terms of shaping instructional habits and practices.

A new hypothesis for improving K-12 teaching through teacher preparation: Practice-embedded teacher education (PETE)

This study attends to one pedagogical feature of teacher preparation—a programmatic focus on core practices—and its impact on first-year teachers' instruction. Core practices refer to "specific, routine aspects of teaching that demand the exercise of professional judgment and the creation of meaningful intellectual and social community for teachers, teacher educators, and students" (McDonald et al., 2013, p. 378). A key characteristic of practice-embedded teacher education (PETE) is the program's systematic focus on developing teacher candidates' abilities to successfully enact these "core" or "high-leverage" practices (Ball & Cohen, 1999). The PETE movement is rooted in two persistent challenges of professional preparation. The first is the failure of teacher education to help novice teachers implement ideas advocated by preparation programs in K-12 classrooms—what Kennedy (1999) calls, "the problem of enactment." Advocates of PETE problematize preservice education regimes that focus on either traditional teaching or theoretical topics that may have only marginal relevance to the realities of the classroom. Traditional preparation tends to focus on observing and analyzing classrooms and teaching, leaving the work of putting theory into practice up to novices (Grossman & McDonald, 2008).

The other challenge that PETE addresses is the extreme variability in the curriculum and pedagogy of teacher preparation. A national report on preparing teachers could not find answers to basic questions about how methods courses are structured, the role they play within the preparation curriculum, or the effects of these courses have on novice teachers' work in schools (NRC, 2010). Other studies have concluded that there is no common curriculum for the preparation of teachers nor best practices around the design of courses, such as those focusing on instructional methods (Clift & Brady, 2005; Wilson, 2011). Wilson and colleagues (2002) found that preparation in pedagogy (e.g., courses in instructional methods, learning theories, and classroom management) could improve both teachers' practice and outcomes for students, however the research had not yet made clear what specific elements of these experiences yielded results.

The advocates of PETE argue for developing a more sharable curriculum for teacher education, centering on the work of teaching by first identifying core practices that have been shown in the literature to support learning and participation by students (Ball, Sleep, Boerst, & Bass, 2009; Windschitl, Thompson, Braaten, & Stroup, 2012). These core practices are used frequently in teaching and are learnable during the initial preparation period. They can become the basis for the instructional strands of the teacher education curriculum. Proponents hypothesize that the movement toward PETE will advance the scholarship of teacher preparation by facilitating connections between research on teaching and research about how novices learn the new forms of teaching. The PETE approach seeks to develop and refine shared language to refine the core practices themselves, and to help teacher educators innovate on their own pedagogy, collectively moving the field of teacher preparation forward.

Description of the practice-embedded approach used in this study

In this section we describe the design principles for one science methods class, its associated courses, and field work that were used in this experiment. Instructional practices are conceived of as recurring professional work, devoted to the support of student learning through teacher planning, enactment, or reflection. From a teacher education perspective, practices are *not* invariant scripts, broad principles, competencies, or behaviors. Rather, practices have the following characteristics:

- They are adaptable strategies utilizing specialized forms of talk, tasks and tools to achieve particular learning goals valued by education community.
- They create and maintain equitable conditions for students from all backgrounds to engage in rigorous intellectual work related to the subject matter.
- They follow prototypical (but adaptable) sequences of activity in which teachers interact with learners.

• They are shaped by underlying principles of teaching and learning that constrain "what counts" as an example of that practice. These principles also allow experimentation and innovations on talk routines, tasks, and tools that can deepen student learning or participation.

In science teaching, core instructional practices must be used frequently in classrooms and be consistent with goals for student learning. The preparation program featured in this study used the widely-cited proficiencies for students described in *Taking Science to School* (NRC, 2007), which have also been used to shape the *Framework* document (NRC, 2012) for the *Next Generation Science Standards* (NGSS Lead States, 2013). The core practices used in the focal program were developed from a synthesis of four literatures: studies of 1) student learning, 2) expert teaching, 3) equity in instruction, and 4) contemporary studies of the disciplinary activities of science. The practices were constructed based on findings from these literatures about the conditions that foster deep learning of science by students of all backgrounds.

The first set of practices is a series of planning practices that help teachers design learning experiences (at the unit level) focused on a limited number of important ideas in the science domain. Key concepts are embodied in a complex natural phenomenon that students will be asked to develop explanations for, and an overarching essential question that gives coherence and purpose to subsequent instructional activities. The second set of practices is referred to as "Eliciting students' ideas." Within this set the teacher engages in three practices: Finding out what students know at the beginning of a unit of instruction (including ways of talking about the focal phenomenon, their everyday experiences related to the topic, etc.), creating with students initial representations of their thinking (using student-created models, lists of hypotheses about what might be causing a phenomenon), and making adaptations to the upcoming lessons based on what students current ideas and puzzlements are. The third set of practices, "Supporting on-going changes in thinking," involve cycles of varied learning activities, followed by the public representation of new ideas and collective reasoning by the class about what was learned and how it informs their thinking about the big ideas of the unit. The final set of practices, "Pressing for evidence-based explanations," supports students in using evidence and information from all preceding activities to revise their current explanations and scientific models.

These four sets of practices are used frequently during teaching, can apply to any science topic or grade level, and are learnable by novices. What distinguishes them from those developed in other subject matter areas is that the practices are designed to work together to form a coherent vision of science teaching. Each of these sets of practices would build upon one another to extend student learning and meaningful participation over the course of a unit.

Equity is foundational in these core practices. For example, in terms of selecting content to be studied, novice teachers learn to choose events and processes that are related to students' everyday experiences and interests. These are often real life science phenomena that happen in the community (e.g. local ecosystem changes), in homes (e.g. chemistry of food preparation), within families (e.g. how physical traits appear in siblings), or at school (e.g. sound-proofing the gym). These highly contextualized situations are preferred over generic textbook tasks because they allow students from any background to use everyday knowledge to participate in building explanations or solving problems. Instructionally, students' ideas are regularly elicited and their partial understandings are framed by the teacher as resources for the entire class to work with. Because discourse plays such a central role in these core practices, novices are taught how to support students from varied backgrounds to participate in conversations by using scaffolds and providing extra time for young learners to think and rehearse responses. These novices reinforce norms for respectful and accountable whole class dialogue, making students feel safe about exposing "rough draft" understandings or critiquing peers' ideas. Formative assessment is built into the recommended strategies that make student thinking visible, such as modeling, writing, or oral explanations. All of these facets of teaching work to level the playing field between students from dominant and non-dominant backgrounds (see Windschitl & Calabrese-Barton, 2016).

Opportunities to Learn

Characterizing the quality of first-year teaching by focusing on students' opportunities to learn. Studying the impact of preparation on new teachers' classroom practices involves recognizing the quality of instruction and of learning activities in new teachers' classrooms and connecting these back to pre-service experiences. In this section we articulate the links between preparation experiences and the quality of first-year teaching. We characterize the quality of instruction by focusing on students' opportunities to learn (OTL) observed in first-year science teachers' classrooms. Drawing upon a situative perspective (Greeno & Gresalfi, 2008), we view learning by an individual as "a trajectory of that person's participation in the community—a path with a past and present, shaping possibilities for future participation" (Greeno & Gresalfi, 2008, p. 170). From this perspective, opportunities to learn (OTL) are defined as the *affordances of a setting for changing learners' participation in communities of practices.* OTL are shaped by both learners and the features of a setting that consists of tasks, tools, resources, etc. Teachers' instructional practices—such as selecting and setting up *tasks*, providing *resources* (e.g., tools, information, scaffolds) for students' engagement, or *facilitating* small group or whole group discourse—create conditions for groups of students to participate in disciplinary practices valued by the scientific and classroom community. In this sense, students' OTL observed in science classrooms reflect the quality of instructional practices—the degree to which the teacher's actions create conditions conducive for a group of students to participate more meaningfully in reasoning and knowledge-building activities over time.

Focusing on students' OTL is useful in three ways. First, this approach directs our attention to *meaning-making* and *forms of participation* enabled by observable aspects of teaching practices, rather than to the pedagogical strategies themselves. Within this framework, the purpose of characterizing teaching quality is less to see the reproduction of teaching practices from preparation in the classroom, and more to document teachers' deliberate moves toward achieving particular *student learning goals* in varied and complex contexts. This helps us to recognize whether and how students are provided opportunities to achieve disciplinary learning goals as expected by the Next Generation Science Standards (NGSS Lead States, 2013) in K-12 classrooms.

Second, focusing on OTL enables us to capture activity and conditions in novices' classrooms regardless of their preparation backgrounds. Researchers who qualitatively study the impact of teacher preparation often search for "proof" that particular practices taught during preparation carry over into the first year of teaching. This strategy may not be sensitive to practices that have been substantially adapted for unique classroom circumstances or to valuable practices other than those explicitly taught during preparation.

Finally, recognizing teaching quality by focusing on OTL helps to reduce the validity threat in the process of making claims of the impact of preparation experiences measured by teaching quality. From the situative perspective, we view teaching as goal-oriented ensembles of activities that create conditions for learners' interactions with others and with informational resources in a setting. The results of these interactions, such as changes in learners' practices or knowledge, can be affected not only by the nature of interactions set up by the teacher, but also by learners themselves—their prior knowledge, their historical relationship with the disciplines, and various other circumstances inside and outside the classroom. These impact learners' intellectual, social, and emotional engagement. In other words, various confounding variables can threaten the validity of the claims on teaching quality when researchers use a measure that is too distant from a teacher's instructional decisions, such as student achievement scores. By using a more proximal measure, such as OTL that is set up and facilitated by a teacher's pedagogical decisions, we intend to document more directly the impact of preparation experiences on teaching quality.

Linking the quality of new teachers' instruction to preparation experiences.

Researchers who study the influences of pre-service preparation on instruction have theorized two ways in which these experiences affect students' OTL through teachers' pedagogical decisions. One is providing conceptual tools (Grossman, Smagorinsky, & Valencia, 1999) or a curricular vision (Kennedy, 2006) that guides high-level decision-making about students' interactions, and that contribute to particular learning goals advocated by the teacher education community. The other is providing practical tools (Grossman et al., 1999), such as strategies or routines that can be directly used to set up classroom interactions. In the context of first-year teaching, any ideas or practices from the preparation experiences can become one of a body of resources that new teachers can draw upon to plan and enact instruction (Horn et al., 2008; Kang, Windschitl, Stroup, & Thompson, 2016; Nolen et al., 2011).

The "conceptual tool and practical tool" frame can be a useful lens for tracing any first year practice back to preparation. Some forms of shared conceptual or practical tools developed during preparation should therefore be observable in student learning activities as well as teachers' accounts on their instruction within the group of teachers who share preparatory experiences. These groups of teachers would have family resemblances about learning goals and strategies that would indicate a common and influential preparation. Another way to recognize preparation influence is tracing back the resources novices leverage to set up particular forms of students' learning experiences in classrooms. By resources, we refer to both conceptual and practical tools used to do the work of teaching. New teachers (as well as experienced teachers) are exposed to various curriculum resources, instructional norms, and ideas of teaching in schools. The ways in which teachers select and use resources for planning and enactment significantly affects students' OTL in classrooms—and the ways they select the resources may be a product of preparation. Examining whether and how conceptual or practical tools provided during preparation are used as resources by the first-year teachers will allow us to infer the impact of preparation experiences on subsequent instruction.

Research Questions

The research questions guiding the analyses are:

1. What are the characteristics of OTL for students of first year teachers, one group of whom learned core instructional practices in the preparation program and the other group of whom were not exposed to core practices?
    a. Are there any differences in instruction between two groups of teachers?
    b. Is there any "family resemblance" among the teachers who were exposed to core practices during the preparation period?
2. Who provides opportunities for students to engage in meaningful disciplinary practices as outlined in the NGSS, during the first year teaching, if any? How did they create such opportunities?

a. How do these teachers describe their goals, strategies, problems of practices, and leveraged resources to set up classroom interactions?
b. What role do the preparation experiences play in the teacher's planning and enactment?

Methods

Participants and Context

Cohorts. Participants were 41 secondary science educators in their first year of teaching (see Table 1). The 28 participants in the Core Practice Group (CPG) represent two consecutive cohorts of novice teachers who enrolled in a university based teacher preparation program. The CPG participants were recruited at the beginning of their preparation as part of a large research project that studied new teachers' learning trajectories. The 13 teachers from the Comparison Group (CG) received their teaching credentials from other college-recommending programs. The 13 CG teachers were recruited at the beginning of their first year teaching. The selection of the participants in CG was based on four criteria that paralleled the characteristics of individuals in the CPG, each of them: (a) graduated from a post-baccalaureate preparation program lasting at least one year (b) was certified to teach in one or more areas of science, (c) had a degree in science or engineering field or equivalent, (d) was currently teaching at least two periods of science at the secondary level (6th to 12th grade). The length of student teaching varied from six to 12 months (CPG teachers had six months of student teaching experience). Among the 41 teachers, about one third worked at under-resourced schools located in low-income communities (13 out of 41 teachers, 31.7%). With respect to each group, more than one third of CPG teachers (10 out of 28, 35.7%) and less than one quarter of CG teachers (3 out of 13, 23.1%) worked in those settings, respectively. About one third taught sciences at middle schools.

A Practice-embedded Methods Course. Members of the CPG participated in two 10-week methods courses as part of the year-long preparation program. Both cohorts of CPG participants were taught by the same instructor, the second author of this study. This methods course was built around the four sets of core practices described previously. Because the core sets of practices are all characterized by responsiveness to students' ideas and thinking, the novices were initially introduced to classroom discourse as the primary tool for supporting individual reasoning and collective knowledge-building. The beginning of each methods course immersed novices in conversations about talk and in situations where talk norms and moves (pressing, re-voicing, wait time, encouraging peer-to-peer talk, etc.) were rehearsed at length in the context of science lessons. Most other teaching skills and responsibilities were addressed within the context of these core practices, including the use of formative assessment, classroom management, and working with English Language Learners. The core practices themselves were explored in cycles. Novices began by analyzing videos of former graduates using these practices in high-needs classrooms; they then participated in the role of "students" as the practices were modeled by the instructor during science lessons; following this, they planned for and enacted their own attempts at these practices in simulations multiple times, with their peers acting as students and then offering critique about their experiences; the novices then enacted these practices in their clinical settings and received feedback on how their students participated in the intellectual work they had designed. The observations of their students and the work produced by these students, often became the basis for modifications to the core practices themselves, in order to suit the needs of that particular class.

Data generation

The data were generated by a team of researchers through observations of teaching and interviews during school visits in the first year of teaching. The research team consisted of two science education faculty, one postdoctoral researcher and three doctoral students. Researchers observed each participant's lessons at least three times from three different units. We requested that participants invite researchers when their students were engaged in sense-making conversations, such as "having discussions after a lab." The observation was conducted, then, upon the invitation from the teachers. Each observation generated a set of data including: (a) 10 to 15 pages of field notes, (b) an audio-recording of post-observation interview, (c) teaching and learning artifacts, such as instructional slides, hand-outs, guides for the students' activities, and (d) samples of student work. In addition, we conducted an hour-long semi-structured interview with each participant at the end of the first year. Both post observation interviews and end-of-year interviews were transcribed. A total of 116 lessons were analyzed for this investigation (77 lessons by CPG, 39 by CG).

Data analysis

The analyses of the 116 lessons were conducted collectively and iteratively during weekly research meeting while collecting data for two years. The first and second author coded a sample of data, identified areas of disagreement and refined the coding process over time. The initial coding scheme around opportunities to learn was discussed and revised in weekly research meetings until researchers reached consensus about the code definitions and their applications to data passages. Each lesson was coded by the researcher who observed the lesson using the final coding scheme (see Table 2). In-depth qualitative case analyses were conducted by the two authors to further examine whether the influences of preparation experiences, if any, could be identified and the mechanisms by which the preparation affected classroom teaching.

Characterizing student learning opportunities (OTL) in science lessons. Guided by the conceptual framework, the first year teachers' instructional practices were analyzed, focusing on four dimensions of OTL (see the coding scheme in Table 2). The first dimension of OTL relates to students' chances to engage in active sense-making—an important condition that supports learning. These opportunities are at least partially shaped by how the learning goals of a lesson are framed by the teacher (Hand, Penuel, & Gutierrez, 2012; Jansen, Bartell, & Berk, 2009; Jiménez-Aleixandre, Bugallo Rodríguez, & Duschl, 2000). *Framing of learning goals* puts the meaning of the work that students are asked to do into a specific context, which can foster or constrain their participation in disciplinary activities. Learning goals could be framed as: (a) solving authentic problems for which there are multiple plausible answers, or making sense of phenomena (code="high"), (b) engaging in the processes of science in relation to one or the other discrete science idea (code="medium"), or (c) primarily acquiring facts, becoming familiar with a topic through the use of vocabulary, or following a procedure (code="low").

Two dimensions of OTL have to do with how students engaged in tasks set up by teachers. A task is a fundamental component of instruction because the major learning experiences in a classroom take place in the context of challenging activities designed by teachers. The *practice demand of tasks* characterizes the level at which students engage in disciplinary practices ("doing science") while completing the tasks. A high practice-demand task affords students the opportunity to exercise agency as a means to accomplish disciplinary goals that have learning value beyond the activity itself (Pickering, 1995). An example is evaluating evidence to support or reject competing arguments about natural phenomena that students have been investigating over time. The medium level of practice demand refers to activities that allow students to "do science" but in conceptual isolation from other potentially supportive science activities. For example, tasks may prompt students to use models, collect and analyze data, or engage in mathematical thinking, but these efforts are not coherently integrated with one another to expand students' understanding of natural phenomena. A low practice-demand task refers to students' activities that are limited to following an established procedure or method (limiting the exercise of disciplinary agency, see Pickering, 1995). Some examples are activities in which students use formulaic protocols like "the scientific method" or "cookbook labs." Some skills (measuring, graphing, etc.) may be acquired during these activities, but not in a meaningful context and the activity does not involve generative and authoritative use of disciplinary concepts and principles.

Whereas practice demand characterizes affordance for experiencing the "doing" aspect of science, the *conceptual demand of tasks* focuses on affordances for students to advance their understanding of science concepts and how they are related to one another. Scientific thinking or reasoning involves making multiple and coherent relationships among observable and unobservable (theoretical) aspects of natural phenomena (Kang, Thompson, & Windschitl, 2014; Kang et al., 2016) to make sense of how and why it occurs. A high conceptual-demand task requires generating multiple and coherent relationships between and among observable and unobservable aspects of natural phenomena, which results in an expanded understanding of the world. For example, tasks in which students construct scientific explanation based on the evidence collected from the multiple activities and ideas from readings likely facilitate complex reasoning. A medium level conceptual-demand task refers to the activities where students make simple, linear connections between one or two conditions in a natural system. For example, after conducting a floating/sinking lab, students explain that things that are more dense sink in fluids that are less dense, but are not pressed further to understand why this relationship exists. A low conceptual-demand task requires minimum level of thinking or sense-making with simple or no connections between instructed and pre-existing ideas. For example, students may describe what they saw during the lab without making further connections to conditions or underlying causes.

The last dimension of OTL is *responsiveness of classroom discourses*. This variable captures whether and how a teacher uses talk during interactions with students to uncover, clarify, compare, and refine their ideas about science. In a highly responsive discourse environment, teachers routinely elicit students' ideas, press for further reasoning, and ask peers to comment on ideas that have been voiced, all directed toward the goal of collectively deepening understanding about the natural world in a supportive classroom learning community. A medium level of responsiveness refers to discursive interactions in which teachers elicit students' ideas and commentary, but do not help students build upon their ideas or use them as resources for the intellectual work of the class. Crosstalk among students is not explicitly encouraged. A low level of responsiveness is characterized by teachers' talk moves that focus on monitoring student contributions for correctness, doing the correcting itself (e.g. IRE), or funneling them toward using particular vocabulary. In these situations, student responses are brief and teachers dominate the talk.

--Insert Table 2 about here—

Each of the 116 lessons was assigned four ratings, one for each dimensions of OTL, such as HHMH or LLLL (H= "High," M= "Medium," L= "Low"). Based on the results of OTL rating and some distinctive and holistic patterns of teaching observed in lessons, we grouped 116 lessons into four conceptual categories: (a) Type I: =Engaging in disciplinary practices for sense-making (e.g., HHHH, HHHM, HHMM), (b) Type II: Engaging in disciplinary practices for sense-making with less sophisticated practices (e.g., HMMM or HMML), (c) Type III: Engaging in disjointed practices focusing on topic or procedure (e.g., MMMM, MMLL, MLLL), and (d) Type IV: A focus on doing without expanding thinking (code=LLLL).

Comparing OTL observed in science classrooms between two groups of teachers. In order to examine how PETE may influence first-year teaching, we analyzed the OTLs within and between two groups of teachers (28 CPG vs. 13 CG). We first examined the overall distribution of lessons across four dimensions of OTL from each group. The analyses were then focused on each dimension of OTL to identify similarities and differences within and between two groups. Independent sample t-tests of mean scores of each OTL dimension were conducted to examine statistically significant differences between two groups with respect to the four dimensions of OTL. Because the study design was not based on randomized assignment, we were well aware that any differences between the two groups could be associated with other variations than the participants' exposure to core practices. Instead of interpreting the impact of preparation experiences by simply relying on the results from the group comparison, we further looked for "family resemblance" or clustering of patterns among the four dimensions of OTL across participants. In this process we took into account a wider spectrum of contextual data about each observation that allowed us to discriminate between the influences of preparatory experiences and other relevant variables situated in local contexts.

Analyzing the mechanisms of influences through in-depth qualitative case analyses. In addition to the quantitative analysis of overall program differences, we also engage in a qualitative analysis of two teachers in an effort to learn more about how their preparation experiences contributed to their current practices. With the qualitative cases, we intended to show concrete details about how different aspects of first year science teachers' practices that we rated quantitatively worked together to provide a particular type of instructional environment.

Also, these analyses enabled us to better understand *the processes or mechanisms* in which first year science teachers crafted high quality learning opportunities as suggested in the Next Generation Science Standards, and the role that practice-embedded preparatory experiences played in the processes, if any. The cases of Lora from the CPG and Martin from the CG were used for the following reasons. First, our goal was to understand the unique contribution and mechanisms of influence of PETE experiences in supporting new teachers to create high quality learning opportunities in classrooms (Type I OTL). Accordingly, we were interested in the teachers who taught the lessons coded Type I OTL. In the core practice group, eight teachers taught lessons that we coded as Type I OTL in at least one out of three lessons. In the comparison group Martin was the only teacher who had a Type I OTL observation.

We selected Lora in CPG group whose personal characteristics were most similar to Martin's. Numerous studies show the strong influence of teachers' backgrounds on their professional learning, features such as conceptions of the discipline, teaching experience, informal teaching or science-related backgrounds. Both Lora and Martin came from middle class backgrounds. They changed their careers from practicing scientists to science teachers. They had strong content knowledge based on their experiences as scientists. Lora and Martin have a similar view on science, scientific sense-making, and student learning that were well-aligned with the views supported by science education community. For example, Lora thinks of science as "a discipline of or the process of trying to explain the world around us." To Lora, students are doing science all the time, and "kids' ideas *are* science ideas" even though "the kids just don't necessarily have the terminology." Similarly, Martin thinks, "All the [student] ideas are based on some observations or some experiences that they made one or another. So in that way, they are very scientific."

Both Lora and Martin had a six-month student teaching experiences during a 12-month post-baccalaureate teacher preparation program. The student populations of their field placements were similar.

We also considered the first-year teaching contexts. Lora had more institutional constraints on her instruction than Martin did. Lora's school was located in an inner city that served a large population of diverse students from low-income families. About 94 % of students were non-white (Asian 42%, Black 36%, Hispanic 10%, Hawaiian Native/Pacific islander, 2%), and about 76% were eligible for free or reduced price lunch program. The school was newly transitioned into a STEM focused, project-based learning school when Lora got hired. She was paired with an experienced English teacher for team teaching because of the school's policy to fuse humanities and STEM classes. The observed classes that Lora and the English teacher team-taught were filled with over 50 ninth grade students. Lora and the English teacher switched the leading roles with each other during a 90-minutes long period. Lora was asked by her department to "do project-based learning", and had to team-teach. In contrast, Martin taught 11th and 12th grade physics in an affluent private high school. Most students came from high SES families that could afford the tuition fee of $27,000 per semester. About 70% of students were white, and the rest were mostly Asian. Martin commented about the students and their families using the words like "very motivated", "want to learn", "a lot of support at home", "pretty ideal." The department was very supportive and open to ideas from new teachers. Martin had the freedom to try out any form of instructional practices with highly motivated students in an academic oriented private high school during his first year teaching.

The two selected cases were analyzed focusing on *how* the teachers created Type I OTL during their first year. Our analysis focused on *how* and *why* they planned and enacted their lessons in a particular way using the interview transcripts and observation notes. Specifically, their talk was coded with respect to: (a) stated goals, (b) strategies, (c) problems of practices, and (c) resources they leveraged in the processes of planning and enactment. We paid particular attention to the use of either conceptual or practical tools that were taken from their preparation or from other sources.

Findings

Characteristics of student learning opportunities

Across groups, about 20% of lessons were coded as Type I or II (n=24, 20.7%), and the rest as Type III or IV (n=92, 79.3%). Type III or IV lessons differed from Type I and II lessons in two ways. The first difference is the ways in which learning goals were communicated with students. Whereas the learning goals were communicated to understand or figure out some real world phenomena or solve problem in Type I and II lessons, the goals in Types III or IV were framed to understand a single science idea (e.g., Newton's 2nd law) or develop a skill (e.g., make observation and record the data). The other difference was the tight connection among the activities. Whereas tasks in Type I and II were clearly linked to one another within and across the lessons as a way of building complex ideas, the tasks in Type III and IV observations were not explicitly connected to other tasks or ideas from previous lessons.

Type I: Actively engaging in disciplinary practices for sense-making. In about 14% of all lessons, students were provided opportunities to engage in disciplinary practices to expand their understanding about the natural world. In those lessons the learning goals were framed in relation to figuring out complex problems or phenomena. The tasks were contextualized by these "big picture" phenomena, and it prompted students to do science and deepen their thinking about a focal problem. Students were supported in talking together to build upon on another's ideas (i.e., coded= "HHHH, HHHM, HHMM"; n=16 out of 116, 13.8%).

Type II: Engaging in disciplinary practices for sense-making with uneven successes. In about 7% of observed lessons, students were prompted to solve a problem or figure out real world phenomena. Learning goals were framed as understanding the focal problem or event. However, the tasks set up by the teacher were relatively simple, such as describing patterns or making simple connections among one or two ideas, and following directions to do so. Teachers elicited students' ideas occasionally, but their discourse focused on correcting answers or checking if students used the right vocabulary (i.e., the lessons coded as "HMMM" or "HMML"; n=8, 6.9%).

Type III: Engaging in isolated practices to acquire abstract science ideas or procedures. About one third of the lessons were categorized as Type III (n=43, 37.1%). The type III lessons typically addressed a discrete topic or process, such as density or following the outmoded "scientific method." Students engaged in disciplinary practices, such as analyzing data to find patterns, but these experiences were disjointed and bounded as in-classroom activities rather than building toward deeper understandings about relevant experiences or solving problem that mattered to them. In those lessons, the classroom discourse was typically dominated by teachers seeking correct responses but not the development of ideas.

Type IV: Doing without expanding thinking (activity without understanding). In about four in every ten lessons science was presented as facts or "the final answers" using notes, procedural problem-solving, or cookbook lab (i.e., the lesson coded as "LLLL", "LLML", or "LLLM"; n=49, 42.2%). The learning goal was typically framed as completing tasks in order to know one or the other science idea. For the most part, tasks were designed to illustrate or confirm information. Students followed directions to receive or reproduce canonical scientific knowledge. The classroom discourse typically followed the conservative IRE pattern.

Students' OTL observed in core practice (CPG) vs. comparison group (CG)

Figure 1 shows the distribution of 116 lessons on the spectrum of student learning opportunities from LLLL to HHHH. The lessons taught by each group were represented using different symbols. Independent-sample t-tests showed that there are significant mean differences across all four dimensions of OTL between CPG teachers' lessons (n=77) and comparison teachers' lessons (n=39) (t=3.1~8.9; $p < .001$), favoring CPG teachers in all dimensions. Because the sample size of the two groups differed, the four charts in Figure 2 show the percentages of the lessons taught by two groups of teachers with respect to each dimension of OTL.

--Insert Figure 1 and 2 about here--

Four patterns emerged within and between the two groups of first year science teachers' classrooms. First, there were more variations of the quality of student learning opportunities in core practice group (CPG) than in the comparison group (CG). Among the 77 lessons taught by CPG teachers, 19.5 % of lessons were categorized as OTL Type I (n=15), 6.5% as Type II (n=5), 41.6% as Type III (n=32), 32.5% as Type IV (n=25). Eight out of 28 CPG teachers provided Type I OTL at least once during their first year (28.5%). The Type I lessons were observed in various school contexts, including the high-needs schools that served diverse students from low-income families. In contrast, the quality of student learning opportunities observed in CG was overall skewed toward Type IV. Only one out of 39 lessons in CG was categorized as Type I OTL (2.6%). About 90% of the lessons in CG group were categorized as Type III or IV, suggesting that students mostly experienced science as learning facts, procedures, or correct explanations (n=35 out of 39, 89.7%).

Second, the teachers in CPG were more likely to frame learning goals in ways aligned with the vision of NGSS. In about one quarter of observed lessons in CPG, the learning goals were framed around making sense of a real world phenomenon or puzzle (Type I or II OTL; n=18 out of 77, 26.0%); whereas this was the case only about 10% of lessons taught by CG (n=4 out of 39, 10.3%).

Third, high quality tasks that were coded as both high practice- and high conceptual-demand were rarely observed in both groups of first year teachers. Specifically, over 80 percent of the lessons taught by the CPG teachers (n=63, 81.8%) and over 90 percent of the lessons taught by CG teachers (n=38 out of 39, 97.4%) were coded at either "low" or "medium" levels of practice demand. In terms of conceptual demand, 85.8% of CPG lessons and 97.4% of CG lessons were coded as either low or medium level. This result suggests that, in general, new science teachers have difficulties in designing and enacting high quality tasks with students.

Finally, the classroom discourses that facilitate students to build upon ideas toward expanding their thinking is known to be difficult, especially for novice teachers (Kang et al., 2016; McNeill & Pimentel, 2010). In our dataset, overall less than two in every 10 observed lessons were coded as highly responsive (n=21 out of 116, 18.1%). Notably, highly responsive classroom discourses were five times more frequently observed in CPG teachers' classrooms (n=20 out of 77, 26.0%) than CG (n=2 out of 39, 5.1%). 82.1% of the lessons taught by the CG was coded as "Low," whereas less than 30% of the lessons taught by the CPG teachers were coded as "low." In those lessons, the classroom discourses were teacher-dominated, delivery-oriented, and displaying I-R-E patterns.

Linking the quality of teaching to preparation experiences

We present two cases, representing each group, in which Type I learning opportunities were created. The lessons however looked quite different. Lora is one of the eight teachers who provided Type I opportunities in the CPG (n=8 out of 28 CPG teachers, 28.6%). All three lessons that Lora taught were coded as Type I as well. Importantly, there were some shared features among the Type I lessons in CPG, such as the presence of real world phenomena that anchored students' learning activities and the routine use of public displays that represented students' changing ideas. In contrast, Martin was the only one who provided Type I opportunity in CG (n=1 out of 13, 7.7%), and this was his only lesson rated at this level. The other two prior lessons observed in Martin's classrooms were coded as Type III.

Each case begins with the description of student learning opportunities observed in the focal lesson. It follows the analysis of the teachers' instructional goals and the resources used to plan and enact the lessons. These revealed *how* Lora and Martin created those learning opportunities.

Lora's lesson: what causes the cancer and how may ricin treat the cancer?

This focal lesson was observed in January of Lora's first year. The classroom was filled with about 50 9^{th} grade students from mostly African American, Asian, Hispanic racial/ethnic backgrounds and low-income families mirroring the characteristics of student population in the school. The dimensions of OTL in this lesson were coded as "high" except the practice demand (codes= HMHH). In the previous unit, students studied a toxic material, ricin, and its unique effects on human body systems. Building upon this, the next unit explored recent findings about ricin, that it can be used as a possible treatment for cancer. At the end of the project, students as members of the Union of Concerned Scientists were expected to write persuasive letters to the FDA either advocating for or against the production of ricin for this purpose. On the first day of this project-based unit, students sketched out models that showed their initial ideas about what the cancer is and how ricin might interfere with cancer mechanisms. In the following five days, students engaged in several activities, including readings, lab, discussion, online tutorials, etc. that helped students to develop their ideas about what the cancer is and how ricin may treat forms of cancer. On the last day of the unit, students revised their initial models.

The focal lesson was taught on the fourth day of this project-based unit. The day prior, students had observed different phases of cell division using onion roots under the microscope. The lesson objective written on the board was to "connect our lab observations to the process of cell division and cell cycle," therefore "we can understand what cancer is and how a dangerous toxin like ricin can treat patients with cancer" (framing of learning goal=high).

Debriefing lab: Connecting observations to the unobservable. The first 30 minutes of the class was spent to debrief the lab in the prior lesson. Lora highlighted that a cell spends most of the time as interphases (15 hours) and actual cell division (mitosis) only last about 1.5 hours, indicating that some important things happen during the interphases. Near the end of the discussion, Lora prompted students to connect plants' cell division to the focal phenomena of the unit—cancer in humans. She asked, "Do you think plants can get the cancer? One student said, "No." Lora then pressed further, asking, "Why? Why do you think that based on the information that we got?" This questioning generated conversation for about eight minutes among students who agreed or disagreed with each other. Some students asserted that plants could not get cancer because "it has to do with blood" and "plants do not have blood", "because plants have cell walls", or "the cancer has to do with inheritance and we don't know where the baby plants come from." Others countered with: "Cancer has to do with cell division. Plants do cell division, therefore it can get cancer." Instead of funneling their talk toward correct answers, Lora used discourse strategies like re-voicing, pressing, probing and wait time. At the end of the discussion

Lora remarked that they needed more information to answer these questions: “Okay, that brings us, we gotta know what the cancer is in order to answer this question.”

Gathering more information about cell cycle to understand cancer. Lora launched a new individual task where students gather new information about the process of cell cycle. While launching this task, Lora told that the goal is to figure out “What is actually going on during the cell cycle? What is happening?” For about six minutes, Lora circulated the classroom while checking each student’s progresses. After students gathered more information about cell cycle, she invited students to share what they found out from the animation about what is happening in each phase and the role of checkpoints. The whole group discussion ended with a new question, “What happens when you take out checkpoints or if it is not working?” “If there no checkpoints, what do you think will happen in the cell cycle?”

“What happens if checkpoints are not working?”: connecting unobservable science ideas back to observable phenomena, cancer. The last task during the remaining time was brainstorming as a pair about the cause of the cancer based on what they learned about normal cell division and cell cycle thus far. Lora first showed a video that vividly illustrated the actual images of dividing cells along with the scientific representation of each phase of cell cycle. The video also showed the images of normal cells vs. cancer cells division side by side. Students shout out, “it is really fast”, “it moves out”, “it is clotted” while watching the video. Lora drew students’ attention to the key observable pattern (i.e., the differential rate of cell division between normal vs. cancer cell). After watching the video, students as a pair talked about the causes of the cancer for about 15 minutes. Lora visited each pair and continuously pressed, “Based on what you know about normal cell, what do you think? What do you think causes the cancer?” until the bell rang.

The quality of learning opportunities. Overall the framing of the learning goals was coded as "high" because at the several points of the instruction, the goal was clearly communicated as figuring out the complex real world phenomena—what causes cancer and how it might be interrupted. Responsiveness of classroom discourse was also coded as "high" given how Lora supported intellectually rich and engaging conversations, during both small group and whole class conversations. The conceptual demand of the task was coded as "high" because students were prompted to make multiple connections between observations and unobservable science events as they explored what cancer really is and what causes it ("high"). The practice demand was coded as "medium" because in this lesson the tasks were less about the "doing" aspect of science than thinking or connecting.

How did Lora craft this OTL? Lora's discourse: goals, strategies, and resources

Goal: "I want kids to identify as scientists themselves." Lora's goal as a science teacher is helping students to "identify as scientists themselves." Lora said, "Ultimately, what I really want…one of my goals is like, from the beginning of the year to the end of the year, I want [students] to be confident and feel like they are scientists, or they could be. They're on that path." Therefore, it was far more important for Lora to help students to experience the practices of science and understand the process and mechanisms, instead of memorizing list of esoteric science terms represent the process. She thought, "students can't really do full on cancer biology, but they can do science and still learn about cancer."

Resources for Lora's instructional practices. Post-observation interviews with Lora revealed four major resources that she used to develop and teach the lesson: (a) a unit plan framework that included the core practices introduced during preparation, (b) students' experiences and ideas, (c) teacher friends and coaches she knew from her preparation experiences, and (d) the Internet. In the following, we present *how* Lora used the resources in her planning and enactment.

The focal lesson was situated in a large investigation where students developed arguments about the FDA's regulation of ricin. The planning for this project reflected several elements of the unit design framework and core practices Lora had experienced during the preparation program. Lora described the day's lesson in this context: "I am always trying to return to the puzzling phenomena, and trying…pushing for explanation even though students may not be writing it. This is one of the things that I really appreciate from methods, is having this phenomenon." She added, "I even still put on my lesson plan, like I write D1, D2 [shorthand for the core practices] at the top of each lesson plan, so I know where I am in the process." Lora also relied on her teacher friends as well as a coach from the previous year's preparation. She noted them as "resources" with whom she could share ideas about instruction.

The other important resource that guided Lora's planning was students' unfolding ideas. This stance was shared by nearly all the teachers who were observed doing Type I and Type II lessons. Lora said, "Because I'm always thinking about my students, and I was kind of like probing them for, "Are they going to be interested in the cancer piece?" or "Are they going to be totally done with ricin?"…so I feel like they've informed my planning." Lora noticed that some students thought of cancer as "some weird kind of disease," instead of a problem of stopping uncontrolled cell growth. Lora used various activities that she found from the Internet to expand students' ideas.

Summary: The OTL mediated by Lora's instructional practices reflected a vision of effective science teaching advocated during her preparation. She grounded her unit design in the idea of an anchoring event, and intended that lessons would be recognized by students as developing their understanding of this phenomenon more deeply over time. Lora used versions of the core practices as conceptual tools to guide day-to-day instructional decisions while addressing various contextual challenges and institutional constraints (requirements to do “project-based teaching”, team teaching, 50 students in her class). The enactment of daily activities was driven by her attention and responsiveness to students’ developing ideas.

The case of Martin in comparison group

Martin received his teaching certificate from a credentialing program at a small local university near Lora’s in the Northwest United States. During the preparation period, he completed six-months of student teaching at a public urban high school. His experience was influenced by students’ attitudes toward science:

> “It surprised me to see what it means to try to teach somebody, try to teach a bunch of people at the same time, a small bunch of people who don’t want to be there. A lot of people were not sure why they were there. So there are a lot of things going on. To me, the new thing is constantly trying to convince folks that this is important.”

During his student teaching, Martin was introduced to a set of physics curriculum materials developed by a university-based research team. He saw his mentor teacher using this curriculum and found the curriculum “pretty authentic to scientists’ work.” This set of lessons and materials became the “backbone” of Martin’s instruction in his first year teaching.

Martin’s lesson: “Tricky Science” project & spring lab

This focal lesson was observed near the end of Martin’s first year. A total of 15 senior students engaged in three distinctively different tasks during the 50 minutes of instruction. This observation was the only one coded in the Type I OTL family (codes= "HHMH") for the comparison group.

Discussing "Science in the News." After a short greeting and announcements, Martin opened the class asking, "Does anybody have any Science in the News for us?" After waiting for a few moments, Martin began to describe a study published in the journal *Science* three years ago. He introduced the topic as "what makes the group smart." Martin recalled that, "researchers found out that it does really have to do, like, what you characterize as group cohesion or how friendly the groups are," and "the other thing that made a group smarter is that the group had, like, the best distribution of thoughts…everybody kinda shares the air." After his remarks, a student commented, "So we should talk." Following this science news, two other students shared science-related news that they heard from the media.

Peer feedback on a semester long independent investigation project, "Tricky Science." This introductory conversation was followed by student presentation on Tricky Science project. This was a semester-long independent investigation in which pairs of students selected a topic that they were interested in, wrote a proposal and plan for conducting research over the several weeks, and then collected data. The goal of this project was to figuring out students' *own* puzzle, such as whether it is safe to swim in the local lake (framing of learning goal=high). Every Friday, one team presented the progress of their project and received feedback from classmates. Our observation was conducted on a Friday. Martin launched the task, reminding students of their role in peer review: "I want you guys to think about, while they are presenting again, what would you say their place is right now, and what you can think of, that would help their presentation be better." The title of the presentation that day was "To Swim or Not to Swim." Two students intended to measure the water quality of a local lake. A team of two students presented for about five minutes then fielded different questions from their peers about clarifying their goals and how they would measure for pollution. Students ask, "Do you think if there are other factors that will affect [your measure]?" "Are you gonna choose random, or are you gonna choose the same spot?" Martin encouraged students to give thoughtful feedback saying, "I want to see how much you were thinking during the presentation, and if you give constructive criticism [to the presenters]."

Completing the Spring Lab activity. The last about 10 minutes of the remaining class time was devoted to completing the spring lab activity. This activity came from the curriculum materials that Martin used as the "backbone" of his instruction throughout this year. The previous day, students collected data measuring the stretch length of a spring and its force, and began to draw on a "whiteboard" summarizing their data as recommended by the curriculum. On the whiteboard, students as a group were expected to provide a description of what happened in the experiment and write an equation describing the relationship. Martin launched the task, "So folks, I am gonna give you about ten-ish minutes to finish your whiteboards. If you've already finished your boards, grab your laptop and write your informal lab." Martin visited each group, looking at the representation of the data on the whiteboard, and asked a few questions that pressed students to reason about the relationship between the stretch of the spring and the amount of applied force reflected on their graphs. For example, Martin asked, "I like this equation. So what do you think happened between here [zero] and here [the starting point of the graph]?" and in another case, "So here is another question then. What does that mean that, there is an intercept that's not zero for this equation? Does it have any physical meaning?"

The quality of learning opportunities. Students engaged in three distinctively different tasks in this lesson. Overall the framing of the learning goals was coded as "high" because the main task of this lesson, Tricky Science project, as set up was to figure out students' puzzle. Responsiveness of classroom discourse was coded as "high" given the intellectually rich and engaging conversations observed among students throughout the lesson, and Martin's attention to students' ideas during his interactions with them. The practice demand of the task was also coded as "high" because of students' engagement in various kinds of scientific practices. During the spring lab task, for example, students collected quantitative data using a spring and represented the data both graphically and mathematically while discussing the observed pattern represented with the graph with the teacher. The conceptual demand, however, was coded as "medium." Their reasoning reflected in student's talk was primarily focused on procedure to ensure data quality or identifying the relationship between the two variables (the stretch of the spring scale and the mass) instead of making multiple and coherent connections among ideas to advance their understanding about the focal phenomena or problem, such as whether they should swim or not in the lake given what they've learned so far and why.

How did Martin craft these OTL? Martin's discourse: goals, strategies, and resources

Goal: "crafting a way for students to feel the whole scientific practices for themselves." Martin's goal in designing his instruction was to help students experience science authentically and to develop scientific skills. Across interviews, Martin noted several times that a major challenge he encountered was dealing with the "right or wrong business", and students' frustration with not being given the right answer. He repeatedly talked about the idea of "uncertainty in science" both during the interview and conversations with students. "I am trying to make a point that there is no right answer… Not everybody is going to get twelve and a half or some value. They are going to get something around that, maybe. And so there is no right answer there." From Martin's point of view, science is all about "resolution and predictive skills." He stated, "It is how closely you got to some objective truth, but there is always some uncertainty. I wanted to craft a way for [students] to feel like the whole scientific process for themselves." Therefore, in general, Martin's curriculum in his classroom was, in his own words, "the scientific process."

Resources for Martin's instructional practices. There are four major sources leveraged by Martin that influenced the practices observed in this focal lesson: (a) his personal experiences as a scientist, (b) curriculum materials, (c) ideas from his preservice preparation, and (d) students' responses to his instruction. In the following, we present *how* Martin narrated in ways in which each resource shaped his instructional practices.

Formulating the vision of good science teaching from both his personal experience as a scientist and the ideas introduced by the preparation program. Martin's goal—helping students develop scientific skills—and his choice of curriculum were directly related to the ways in which Martin thought of "what science is" and "what should be taught in science classroom." In response to the question of how he designed his semester-long independent projects that Martin was most proud of, Martin said, "I kinda generated this idea for myself, I mean my experience as a researcher going through this." Martin also noted that his emphasis on group work stemmed from the ideas introduced by his preparation program. He explained,

> I was always brainstorming this [the idea of helping students the uncertainty of science and teaching scientific process] in my ED class. This project is kinda brainstorming that came out like, they [the instructors in the program] were telling us all about group work and how important it is. It was really about collaborative work, and so, I was trying to think about how it works out in science class because there were a few scientists who teach at [the University]. They have like social justice focus. But they don't have a lot of

> science curriculum. I have to really think hard how to translate [the University] into science class. So this is my brainstorming from that.

Students in Martin's classroom were continuously engaged in some form of writing as they conducted either the independent investigation projects or conducting a lab provided by the modeling curriculum. Martin thought of writing as an essential scientific skill. He said, "One thing that I realized in my career as a scientist is that if you want to be a good scientist, you have to be a good writer. It is a scientific skill. That is something that I try to teach." It seemed that his vision of good science teaching, including what science is was deeply rooted in his personal experience as a professional scientist. In order to enact this vision, it appeared that he had to formulate the instructional practices for himself.

Setting up instructional routines by working through the curriculum and working with students' ideas. One instructional practice and routine observed across all observed lessons was what is called, "whiteboarding." Martin used a set of curriculum materials as the backbone of his instruction throughout the whole year. White-boarding was "a big component of modeling curriculum." Martin said, "As you know, I am basically working through the modeling curriculum, which I think is a pretty authentic simulation of the scientific processes." Martin initially did not see the value of whiteboarding, but then became "really sold on it" as he worked with students. He noticed how whiteboard became a useful tool to visualize and publicize students' ideas in a safe way, therefore facilitating conversation and collaboration.

> …it does get students to put their work down but in a temporary way. They don't have to, it is not like writing it in their notes, which is permanent, which some kids won't do if they can't erase it. And it gets kids working on the same thing as each other, and then see it, and then everybody sees it. And the whiteboards are great because you can just store

> them in the corner, and come back to the same conversation later. Everybody kinda remembers what the conversation was about.

Martin was keen on students' ideas, how they made inferences from observation and how students treated evidence. He said, "If [students] are reflecting, refining their process of making inferences, I think that is a success." In working through the curriculum, one problem that Martin noticed was "location specific thinking." Students were asked to engage in scientific thinking in classroom, but then "it hasn't translated into anything significant, and their reasoning process outside of the classroom. They are coming here and realize like, we gotta think like this now. And then they go through the door, like I don't think it anymore." This recognition led Martin to form this idea of "getting students to do something outside of classroom scientific," which made an appearance as the Tricky Science project.

Summary: Martin set up tasks that mimicked scientists' work, such as writing and reviewing a proposal, working as a member of a review committee, collecting and analyzing data, and presenting the results to others. Martin's instructional practices reflected a vision of good science teaching that was rooted in personal experiences as a practicing scientist. Martin was then exposed to several ideas about teaching, such as group work, during his preparation period. It was up to him to translate these ideas into instructional practices for himself, and to arrange these practices in ways that served larger goals. The curriculum materials leveraged by Martin became a "backbone" of his instructional practices and routines throughout the year, however the other two observations that were made in his classroom were qualitatively different from the one we described and were coded as Type III. Other ideas from his preparation program appeared in his instruction occasionally as special events, such as service learning projects or discussions on women in science.

Discussion

Our analyses suggest two roles that PETE plays in improving the quality of instruction in beginning science teachers' classrooms. One has to do with generating an actionable curricular vision of science teaching. The other involves preparing new teachers to create classroom conditions where they can notice and work on students' ideas. We unpack these two points by highlighting key patterns emerging within and between the two groups' lessons.

Formulating a shared vision of science teaching centered on sense-making

The analyses suggest that pre-service teachers' exposure to core practices during the preparation period more likely helped them to formulate a concrete curricular vision of science teaching centering on students' sense-making. This vision was more in evidence for the CPG than the CG during participants' first year of teaching. Our argument is consistent with others researchers' theorizing about the role of preservice education as helping form new professional visions or frames that come to guide practice (Feiman-Nemser, 2001; Grossman et al., 1999; Kennedy, 1999). This claim is particularly evident from the analyses of the learning goals communicated in the lessons taught by the two groups of teachers. In about one quarter of lessons taught by CPG teachers, learning goals applied over entire units rather than only individual lessons and were framed around understanding some real world phenomena or solving a complex problem (Types I & II OTL). For example, the aim of Lora's debriefing of the onion cell lab and online simulation of cell-cycle activities was to figure out what causes cancer and how a dangerous substance like ricin might interfere with genetic processes that cause cancer. In contrast, only about 10% of the lessons taught by the CG teachers were framed around students' sense-making and challenging goals for learning over the course of the unit. In the majority of the lessons in the comparison group, goals for lessons were communicated as either understanding canonical science ideas as described in texts or developing procedural skills (Type III & IV OTL).

The in-depth case analyses further show how core practices affect classroom instruction. There were salient "family resemblances" across all three lessons taught by Lora, as well as the lessons taught by other CPG teachers who provided Type I OTL. These lessons were situated in a unit typically anchored in some real world phenomena or puzzling problem. Students' initial ideas about the cause of the phenomena or problem were elicited at the beginning of the unit, and then students were asked to revisit and revise their initial ideas near the end of the unit. These resemblances were more prevalent and appeared to work in concert with one another in the lessons taught by the CPG teachers. This suggests that they developed a shared curricular vision—a shared image of science teaching—that was consistent with the images represented through the core practices from the program. It appeared that the CPG teachers whose observations were rated as Types I or II used this vision as a conceptual tool to guide pedagogical decisions, such as how to begin and end a unit, and how to design daily tasks with particular goals.

In contrast, Martin approached the doing of science in the context of a special semester long project, Tricky Science, later in his first year. A focus on complex real world problems and students revising ideas over time did not appear in his other observations. Martin's three lessons were quite different from one another, suggesting continued experimentation. The lesson we observed was the only one coded as Type I. The other two prior lessons were coded as Type III. The Type I lesson was also an exception in the comparison group, there was no other lesson coded as such in this group. In some way, this Tricky Science project is similar to the unit design framework provided for the CPG teachers, in that it was supposed to engage students in authentic disciplinary practices to solve a problem that matters to students. This project also aligns well with Martin's view on meaningful science learning. It appears that Martin, who had to "really think hard how to translate [the idea from the preparation courses] into science class," formulated this curricular vision of teaching for himself. This project was, however, a special event, a supplement to the regular curriculum that Martin used as the "backbone" of his first-year teaching. In contrast, in CPG lessons rated as Type I or II, teachers were more likely to weave authentic science practices into the overall curriculum.

It is important to note that three quarters of the lessons taught by CPG teachers were still framed in a conventional way, such as acquiring knowledge or skills representing the traditional view of science (Type III & IV=74%). In the comparison group, 90% of lessons were framed in that way (Type III & IV=90%). On the one hand, this finding suggests that the exposure to the concept of sense-making and the value of core practices during preparation increases the likelihood of helping novice teachers to formulate actionable curricular visions of science teaching, as advocated by science education community (10 % in CG vs. 25% in CPG). On the other hand, the bigger picture reveals the depth of challenges facing teacher education community in transforming teaching and learning in K-12 science classrooms. It is difficult to change teaching practice because what is happening in classrooms is significantly controlled by cultural norms and school norms (Kennedy, 2005; Stigner & Hiebert, 1998). Teachers' belief, views, and identities also affect on the process of learning to teach, and transforming novice teachers' traditional images of science teaching and learning, developed during their years-long "apprenticeship of observation" as students themselves (Lortie, 1975) is no easy task.

Facilitating PSTs to create conditions to work on students' ideas in instruction

In addition to their curricular vision being shaped by program experiences, new teachers used strategies and tools introduced in their preparation courses. This uptake of practical resources has been documented by other studies (e.g., Nolen et al., 2011; Thompson, Windschitl, Braaten, & Stroup, 2013). This finding is consistent with recent theorizing about tools and artifacts as resources for novice teachers' opportunities to learn and develop, beginning during their preparation and continuing into the early stage of their careers (Nolen et al., 2011). In our study, the strategies and tools recommended by the program were designed to make student thinking visible, such as discursive strategies demonstrated in Lora's lesson (e.g., probing, pressing, and connecting students' ideas) or modeling strategies that press student to describe the underlying/unobservable mechanisms of observable phenomena. Despite the fact that the majority of the lessons taught by the CPG teachers included various strategies and tools adapted from their methods courses, the analyses showed widely varying levels of sophistication in how they were used, with uneven outcomes for engaging students. This analysis suggests that, currently, the exposure to core practices and its accompanying tools during the preparation is recognizable but limited in its impact on quality science learning opportunities in K-12 classrooms. Among the 24 lessons framed around real world phenomena or problem solving (Type I & II OTL) and utilizing the strategies from the PETE program, only nine showed that students' active engagement in science practices and discourses were mediated by high quality tasks set up by the teacher and by skillful facilitation (i.e., coded as "HHHH"; n=9 out of 24, 37.5%). In the other two thirds of lessons, the quality of tasks set up and enacted by teachers were at the medium level, and/or the classroom discourses facilitated by the teachers were limited to eliciting or listening, without building upon one other to advance thinking in a classroom learning community.

We speculate about why the exposure to core practices during preparation, in and of itself, is limited in improving teaching quality in K-12 classrooms. First, the successful provision of high quality learning opportunities depends on many things: the time teachers have available to plan and think about their instruction, the intellectual atmosphere, motivation and encouragement provided by colleagues, the strength of the cultural teaching scripts they acquired during their childhood, all of which facilitate or hinder teachers' ongoing self-conscious responsiveness to the processes of student learning on a daily basis. In the case of Lora, she skillfully built upon students' observations of cell division to problematize students' existing ideas about "what the cancer is" elicited at the beginning of the project, and then helped students recognize gaps in their ideas through discussions of whether plants can have cancer. In Lora's lesson, the daily tasks were designed adaptively in response to students' current ideas, which made it possible for her to routinely set up intellectually challenging tasks for her students. Second, designing a lesson in response to the progress of student ideas also requires that teachers have an in-depth understanding about the focal problem, one that often does not have a correct answer. Even when CPG teachers design lessons that bring in interesting and relevant real world phenomena, and they approximate strategies recommended by the program, it is unlikely that they can notice and build upon student ideas instructionally without nuanced knowledge of the science itself (Ball, Hill, & Bass, 2005; Ma, 1999; van Es & Sherin, 2002). Overall three quarters of the lessons by CPG teachers were rated low or medium level in terms of the responsiveness of classroom discourse, although highly responsive classroom discourses were five times more frequent in CPG teachers' classrooms than in comparison group classrooms (n=20 out of 77, 26.0% vs. n=2 out of 39, 5.1%).

In sum, CPG teachers' approximation of core practices, such as using program-provided strategies or tools that were designed to make student thinking visible, appeared to create ready access to student ideas. This likely creates better conditions to notice and build upon students' unfolding conceptions, resulting in their engagement and deepened understanding about the natural world. The provision of such high quality OTL, however, are then contingent upon other aspects of teaching, such as valuing students' ideas and skillful responses to them, based on in-depth understandings about science as a discipline.

Conclusion

The analyses suggest three implications for research, and policy in teacher preparation. First, core practices, as a set of strategies to achieve valued learning goals, have a potential as a useful curricular frame for teacher preparation, in particular with respect to achieving two important goals of teacher preparation (Feiman-Nemser, 2001; Kennedy, 1999): supporting new visions of teaching, or new understanding of how students learn and developing a beginning repertoire of effective teaching. Importantly, our analyses suggest that in order to improve the teaching quality in K-12 classrooms with use of core practices, the emphasis should be placed on the curricular vision and pedagogical goals that underlie the core practices, rather than the ungrounded use of strategies or tools themselves.

Second, this study calls for a new integrated approach to study the curriculum and pedagogy of teacher preparation, moving beyond the search for *what* should be taught (i.e., curriculum) and *how* it should be taught (i.e., pedagogy) as separate pursuits. In our study, the teaching quality of the CPG teachers' 77 lessons varied widely. Given that the vast majority of observed lessons from the comparison teachers were characterized as Type III or IV, the overall shift of the teaching quality observed in the CPG teachers' lessons toward Type I or II OTL is significant. At the same time, the wide distribution of teaching quality within CPG teachers' lessons implies that, as noted by numerous prior studies, the exposure to core practices and the concept of sense-making facilitated by the methods courses activities interacts with novices' personal backgrounds, such as their conception of the disciplines, of teaching, learning, and their own evolving identities as educators. In addition, the ways in which novices work with core practices in local school contexts matter. It may be important to attend *how* novice teachers experience the core practices, either individually or collectively both at the program and schools, during their preparation. We argue that more attention needs to be paid to the questions of what experiences need be provided for whom, when, and how to achieve particular learning goals for preservice teachers.

This study also contributes to research on teacher preparation by providing conceptual tools that guide a systematic examination of the impact of preparation experiences on the quality of teaching in novices' classrooms. We proposed a framework and strategies for linking preparation experiences to students' opportunities to learn in K-12 classrooms, in order to address the methodological complexities of studying graduates from different programs and avoiding the substantial assumptions with using students' standardized test scores as proxies for teacher quality.

Finally, one important question that has yet to answer is whether and how teaching core practice contributes to preparing teachers for diverse students who are historically marginalized in K-12 science classrooms. Future study on this topic with robust set of data that include student background information and their engagement in new teachers' classrooms will be necessary to better address this important question.

Footnote

[1]Collective intelligence, Evidence for a collective intelligence factor in the performance of human group by Anita Williams Woolley (Carnegie Mellon University), and Christopher F. Chabris, Alex Pentland, Nada Hashmi, Thomas W. Malone (Massachusetts Institute of Technology Center for Collective Intelligence), October 2010, Vol. 330. Science

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Table 1. Participants

		Name	Degree in science (major)	First year teaching contexts
Core	1	Marta	Biology	Under-resourced MS, General science
Practice	2	Simon	Earth science	Urban MS; General science
Group	3	Rachel	Cell biology	Affluent suburban HS; Biology & physiology
(CPG)	4	Amber	Biology	Under-resourced urban HS; Biology
	5	Susan	Forestry and earth sciences	Under-resourced urban HS; Biology
	6	Imee	Physiology	Urban HS; Physical science
	7	Sarah	Chemistry	Under-resourced urban HS, Biology, chemistry, physics
	8	Barbara	Biology	Suburban JHS; life science
	9	Leslie	Zoology	Affluent suburban HS; Biology & chemistry
	10	Carrie	Physiology	Under-resourced MS; General science
	11	Katie	Biology	Suburban MS; General science
	12	Robert	Physiology	Private HS; Biology
	13	Benjie	Environmental sciences	Suburban MS; General science
	14	Catherine	Biology	Affluent HS; Biology
	15	Elena	Zoology	Suburban HS; Physical science, biology, chemistry
	16	Emily	Biology	Suburban JHS, General science
	17	Laura	Biology	Suburban MS, General science

	18	Amanda	Chemistry	Under-resourced urban HS; Chemistry
	19	Luke	Physics	Suburban HS; Physics
	20	Lora	Biology	Urban HS; Biology
	21	Patricia	Engineering	Suburban JHS; General and physical science
	22	Adam	Biology	Affluent suburban HS; Biology
	23	Richard	Biology	Affluent suburban MS; General science
	24	Maria	Economics & Biology	Under-resourced MS; Grade general science
	25	Chris	Biology	Rural HS; Physical science, biology
	26	Mike	Technology	Affluent suburban HS; Biology
	27	John	Biology	Suburban MS; Life science
	28	Cali	Biology	Community college; Introductory biology
Comparison Group (CG)	1	Mary	Environmental education	Suburban MS; Integrated science
	2	Martin	Atmosphere physics/ PhD	Suburban private HS; physics
	3	Nicole	Molecular Biology	Suburban HS; Physical science
	4	Tim	Biology	Suburban HS; Biology
	5	Molly	Literature & Science endorsement	Urban HS; Physical science
	6	Jim	Physics	Suburban HS; Physics
	7	Ranya	Computer Science/ PhD	Suburban private HS; Physics and math
	8	Timothy	Cell Biology	Suburban HS; Chemistry and mathematics

	9	Nick	Physics	Suburban HS; Physical science and physics
	10	Sally	Philosophy; elementary program; teaching certification in math	Private HS; Chemistry
	11	Rach	MA in Zoology	Suburban MS; Integrated science
	12	Sarah	Drama & Biology	Urban MS; Physical sciences
	13	Dan	Environmental science & interdisciplinary arts and science	Urban MS; Physical sciences

Table 2. Four dimensions of opportunities to learn (OTL)

Dimensions	Description	Codes
The framing of learning goals	The ways in which learning goals are communicated with students in a lesson	**Low**: knowing one or the other facts, topic or procedure **Medium**: understanding processes or mechanism **High**: solving a complex problems, figuring things out, or making better sense of the worl
Practice demand of tasks	The affordances for students to experience disciplinary practices ("doing science") while completing the tasks	**Low**: students' activities that are limited to exercising disciplinary agency. Those tasks typically prompt actions taken by a student in which the outcome is determined by properti of an established procedure or method (e.g., cookbook lab) **Medium**: the activities that afford to do scier while exercising disciplinary agency a little b but in a disjointed way. **High**: students exercising conceptual agency, meaning actions taken by a student in which outcome is determined by choices made by th actor(s).
Conceptual demand of tasks	The affordances for advancement of	**Low**: minimum level of thinking or sense-making, pressing for what level (e.g., describ

	disciplinary thinking (the type and nature of connection among observables and unobservable/theoretical ideas)	what happens or what they saw during the lab) **Medium**: the tasks where students make a simple connection between one or two element; how/partial why **High**: generating multiple and coherent connections between observable and unobservable aspects of natural phenomena in the process of constructing explanation or evaluating arguments; causal why
Responsiveness of classroom discourses	The degree in which the teacher systematizes cognitive, social, and linguistic resources discursively to assist students' deeper engagement in disciplinary practices in a supportive classroom learning community	**Low**: Monitoring on-task behaviors & re-teaching (e.g. IRE) **Medium**: Some ideas are elicited and noticed **High**: Ideas are elicited, validated, and built upon one another in a way of collectively deepening understanding about the world

Figure 1. the distribution of 116 lessons on the spectrum of student learning opportunities from LLLL (left) to HHHH (right)

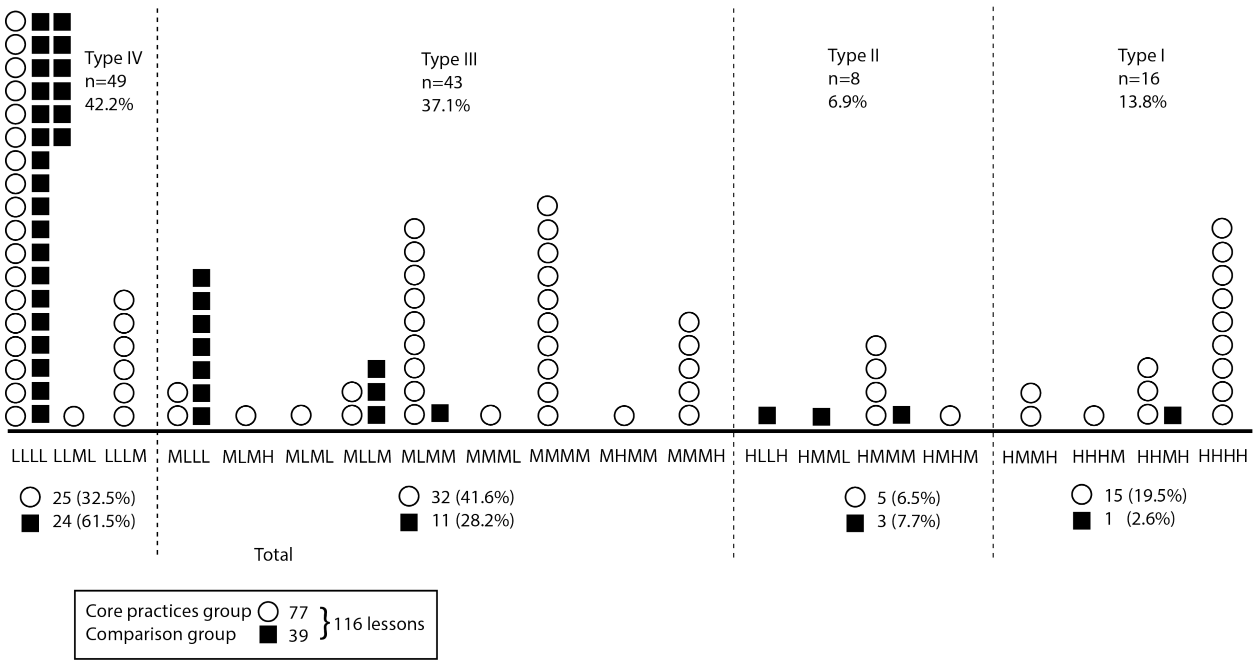
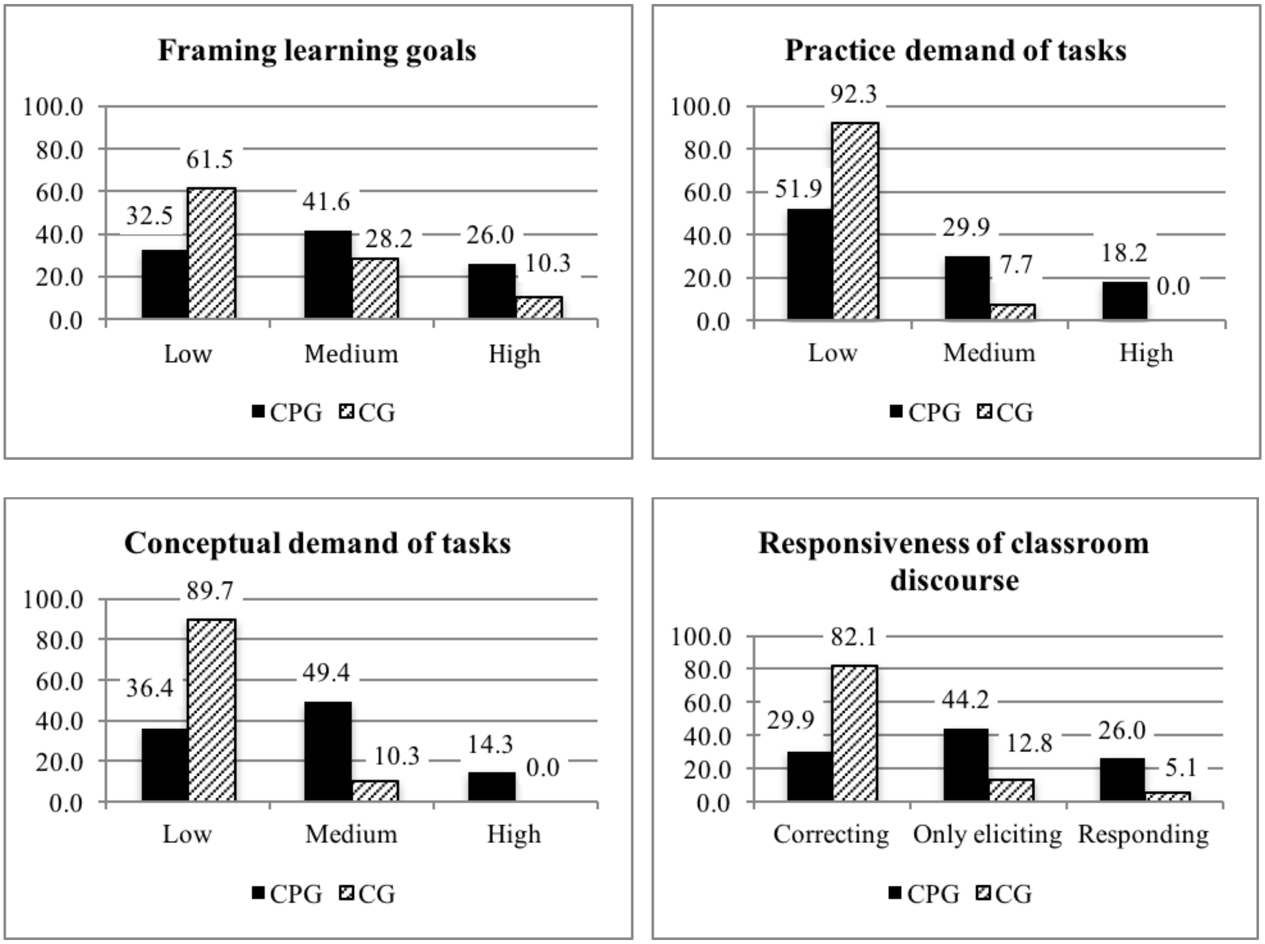


Figure 2. The percentages of the lessons taught by two groups of teachers with respect to each dimension of opportunities to learn (OTL)



** Note: Numbers above the bars indicate the percentage (%) of the lessons taught within each group at each level.*