Preservice Elementary Teachers' Curriculum Design and Development of Pedagogical Design Capacity for Inquiry: An Activity-Theoretical Perspective

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Curriculum materials are an essential resource for science teachers, particularly when designed to support inquiry-oriented, standards-based science teaching and learning. Teachers make professional decisions the use of curriculum materials, often evaluating and modifying them for use in their own classrooms, and need to learn to use curriculum materials effectively as part of their developing pedagogical design capacity. In order to become well-started beginners, preservice teachers need opportunities to begin developing their pedagogical design capacity for inquiry their formal teacher education programs. In this study, we employ multiple methods and an activity-theoretical framework to investigate preservice elementary teachers' curriculum design and development of pedagogical design capacity for inquiry during the final year of their teacher education program. Results show that preservice teachers were able to mobilize their espoused inquiry frameworks to adapt curriculum materials and make them more inquiry-oriented. However, their curriculum design efforts were constrained by features of their institutional contexts and subject to practice-based tensions that in many cases led to less inquiry-based planned and enacted science lessons. While the preservice teachers resolved some tensions by revising their espoused inquiry frameworks and their curriculum design practices, other tensions remained unresolved by the end of the study. These findings have implications for science teacher education and science curriculum development, as well to the use of cultural-historical activity theory in education research.

Introduction

Teachers need to engage in inquiry-oriented science teaching to promote student learning (NRC, 1996, 2000, 2007). Inquiry-oriented science teaching and learning engages students in these inquiry practices not only to promote students' learning of scientific concepts, but also the epistemological and ontological foundations of how scientific knowledge is constructed. By engaging in these practices as a community, teachers and students establish, negotiate, and reinforce a 'culture of inquiry' in the classroom (Llewellyn, 2007) within which learning occurs. This is true even at the elementary level, where young children can learn to engage in inquiry practices to construct understandings of scientific explanations for natural phenomena (Metz, 2000).

To engage in effective instruction, including the teaching of science as inquiry, teachers need to learn to maximize their *pedagogical design capacity* (Brown, 2008), or their ability to identify and mobilize requisite resources, including their own knowledge, beliefs, and curriculum materials, to craft learning environments in light of identified goals or objectives. Inquiry-oriented, standards-based science curriculum materials often serve as a crucial tool for teachers to engage in classroom inquiry. However, teachers also draw upon their knowledge, beliefs, and identities (i.e., teacher characteristics) to interpret, critique, and adapt curriculum materials (Enyedy & Goldberg, 2004; Roehrig, Kruse, & Kern, 2007; Schneider, Krajcik, & Blumenfeld, 2005). Additionally, these teacher-curriculum interactions are embedded within and bound to specific professional contexts that possess unique factors (Appleton, 2003; Kesidou & Roseman, 2002; Marx & Harris, 2006; Spillane, Diamond, Walker, Halverson, & Jita, 2001). In the end, the specific forms of science teaching and learning that emerge from teachers' practice are a function of relevant goals, these teacher characteristics, the curriculum materials teachers use, and specific features of context that teacher-curriculum interactions. These factors constitute teachers' pedagogical design capacities for inquiry.

It is crucial, then, for preservice teachers to begin to develop robust pedagogical design capacities for inquiry. Specifically, they must be afforded opportunities to construct usable inquiry frameworks and ideas about inquiry, as well as learn to employ them in conjunction with science curriculum materials to engage in inquiry-oriented science teaching while successfully navigating affordances and constraints of their professional contexts. However, the notion of pedagogical design capacity is new and, thus far, there has been no research on teachers' pedagogical design capacities for inquiry. To investigate this emergent construct, which is a complex phenomenon and challenging to operationalize, we draw upon cultural-historical activity theory (CHAT – Engeström, 1987) as an explicit theoretical and analytical framework to investigate how preservice elementary teachers employ their ideas about inquiry and science curriculum materials and negotiate emergent contradictions to plan and teach inquiry-based elementary science during the final year of their teacher education program.

Defining Inquiry

There are many perspectives on inquiry, including specific inquiry frameworks. For example, the 5-E model (Bybee, 1997) has become a paradigmatic inquiry framework within science education. These inquiry frameworks often vary around the degree of student autonomy, for example, from more structured 'guided inquiry' to more open-ended, sometimes project-based inquiry (Brown & Campione, 1994; NRC, 2000). Across these more holistic frameworks, science educators and science teacher educators have foregrounded specific, constituent inquiry practices, such as argumentation (Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006; Zembal-Saul, in press) and modeling (Schwarz, in press). These perspectives are by no means mutually-exclusive and each provides unique insight into the teaching and learning of science as inquiry. This diversity of inquiry frameworks illustrates the unique ways in which science educators have sought to translate scientific practices into classroom practices.

While inquiry frameworks abound, most reference the five-part inquiry framework explicitly articulated in science education reform (Davis & Smithey, in press; NRC, 2000). This framework, which has served as a foundation for most specific conceptualizations of inquiry-based teaching and learning over the years, is composed of five distinct but not mutually-exclusive inquiry practices. These practices include asking and answering scientifically-oriented questions; collecting, organizing, and analyzing data and evidence; constructing evidence-based explanations; comparing explanations to alternative explanations; and communicating and justifying methods and explanations. However, despite the important role the NRC's five-part inquiry framework has played over the years, most studies have not operationalized scientific inquiry and inquiry-based teaching and learning explicitly in this way (Davis, Petish, & Smithey, 2006). Much of the existing research on teachers' knowledge, beliefs, and orientations regarding scientific inquiry and inquiry-oriented practice has focused on specific process skills that are indirectly related to these five inquiry practices. As Davis and colleagues (2006) argue, "Without understanding these aspects of scientific inquiry, new teachers are unlikely to be successful at teaching through inquiry" (pg. 618). It is therefore important that more research be undertaken to investigate novice teachers' ideas and beliefs about, as well as orientations toward, scientific inquiry and inquiry-based science teaching and learning in light of those dimensions specifically explicated in *The National Science Education Standards*. This is one goal of this study.

Preservice Teachers' Pedagogical Design Capacity for Inquiry

To effectively engage students in scientific inquiry practices, teachers need to develop robust pedagogical design capacity. Pedagogical design capacity (Brown, 2008) is defined as teachers' abilities and competence to perceive and mobilize both personal teacher resources (knowledge, beliefs, identity, and orientations) and external curriculum resources to craft instruction/instructional contexts in light of instructional goals. It is especially important for preservice elementary teachers to develop robust pedagogical design capacity for science teaching since, as beginning elementary teachers, they confront many challenges to engaging elementary students in inquiry-based science (Davis, Petish, & Smithey, 2006). This perspective on pedagogical design capacity emphasizes teachers' existing ideas and beliefs about, as well as orientations toward, inquiry-based teaching and learning, how they mobilize these ideas and orientations to adapt and enact curriculum materials, and how their curriculum design efforts are embedded in particular professional contexts.

Preservice Teachers' Ideas about and Orientations toward Inquiry

Science teachers must possess knowledge and beliefs about purposes and methods of science teaching, student learning of science, assessment, and science curriculum resources and goals that are consistent with those articulated in science education reform (Abell, 2007; Magnusson, Krajcik, & Borko, 1999). Specifically, teachers' knowledge and beliefs about inquiry-based teaching and learning represent one critical element of their pedagogical design capacity for inquiry. Preservice teachers come to formal science teacher education with existing ideas about and orientations toward science teaching, specifically the teaching and learning of science as inquiry (Bryan, 2003; Bryan & Abell, 1999; Howes, 2002). However, many studies have shown that science teachers do not always articulate knowledge and beliefs that are consistent with tenets science education reform (Davis, Petish, & Smithey, 2006). In general, preservice elementary teachers tend to articulate ideas about elementary science that involve hands-on, active, and fun experiences for students (Abell, Bryan, & Anderson, 1998). They often view science itself as a body of facts rather than self-regulating community with shared practices through which knowledge is constructed and negotiated (Gess-Newsome, 2002). When exposed to inquiry, they can appropriate it as linear and lockstep rather and dynamic and iterative (Windschitl, 2003). They may also equate inquiry with highly student-directed, discovery-based science (NRC, 2000) and seek to engage students in inquiry practices to make science fun and engaging rather than to promote student sense-making. They often struggle to develop more coherent views of inquiry-oriented science teaching (Smithey & Davis, 2002; Windschitl, 2004).

Despite these limitations, there is encouraging evidence that preservice teachers can come to appropriate views of scientific inquiry that are more consistent with those articulated in science education reform (Bryan, 2003; Gess-Newsome, 2002). As Haefner and Zembaul-Saul (2004) observe, many science educators have only more recently begun to emphasize preservice teachers' expertise for inquiry practices as well as content. To help preservice teachers develop ideas about and orientations toward inquiry that are consistent with those called for in science education reform, and thus heighten their pedagogical design capacity for inquiry, they must be specifically targeted in teacher education. Experiences in authentic scientific investigations, for example, are a particularly powerful influence on preservice teachers' developing understanding of inquiry and inquiry-oriented (Haefner & Zembal-Saul, 2004; Windschitl, 2003). Science teacher educators continue to work to find effective methods to promote preservice teachers' learning about inquiry-based science teaching and learning.

Preservice Teachers' Curriculum Design for Inquiry

Preservice teachers' knowledge and beliefs about inquiry are an important component of their pedagogical design capacity for inquiry. Ultimately, however, teachers mobilize their knowledge and beliefs to engage in teaching practice, which can be conceptualized as two activities: planning and enactment (Remillard, 1999). In curriculum planning, teachers evaluate, critique, and adapt the curriculum materials they use. In enactment, they employ these curriculum materials as tools to structure classroom practice. While there are persistent questions as to how and the extent to which science teachers' knowledge and beliefs influence their teaching practice, there is limited evidence that teachers with more reform-minded ideas about science teaching engage in more inquiry-based science teaching (Roehrig, Kruse, & Kern, 2007). However, consistent with pedagogical design capacity, teachers' attempts to translate their ideas and beliefs into practice are also influenced by the curriculum materials they have and affordances and constraints of their professional contexts.

To develop their pedagogical design capacities for inquiry, it is important for preservice teachers to learn to use curriculum materials to plan for science teaching and engage students in inquiry in the classroom. Past research has shown, however, that while preservice teachers can develop inquiry-specific knowledge and beliefs, translating that knowledge into science teaching practice is more difficult. First, preservice teachers experience challenges to drawing upon their ideas and beliefs to use science curriculum materials (Davis, 2006; Dietz & Davis, in press; Forbes & Davis, 2008; Schwarz, Gunckel, Smith, Covitt, Enfield, Bae, & Tsurusaki, 2008). Because preservice teachers' possess existing ideas about science teaching, and these ideas may not be aligned with tenets of science education reform, they may critique existing curriculum materials in unproductive ways or not emphasize inquiry unless scaffolded to do so. Second, even if preservice teachers can effectively use science curriculum materials to plan inquiry-oriented science lessons, they may struggle to enact those lessons with students in the classroom (Bryan & Abell, 1999; Crawford, 1999; Southerland & Gess-Newsome, 1999; Zembal-Saul, Blumenfeld, & Krajcik, 2000).

Despite these challenges, there is encouraging evidence that preservice teachers can learn to engage in effective science teaching practices. If supported to learn about inquiry, develop robust, multi-faced inquiry frameworks, and visualize how inquiry can help them achieve instruction goals, preservice teachers may begin to emphasize inquiry in their use of science curriculum materials. Furthermore, through experience in the classroom, preservice teachers can learn to engage in effective, inquiry-oriented science teaching over time (Crawford, 1999, 2007; Schwarz, in press; Zembal-Saul, in press). These studies show that despite the obstacles preservice teachers face, their development of pedagogical design capacity for inquiry can be effectively promoted in formal teacher education.

An Activity-Theoretical Perspective on Pedagogical Design Capacity for Inquiry

While the notion of pedagogical design capacity for inquiry affords a novel perspective on teachers' expertise and learning, it is also a complex, multifaceted construct. Consistent with situated perspectives on learning, pedagogical design capacity is situated within interactions between teachers, curriculum materials, and contexts, and therefore requires an appropriate framework through which to investigate it. In this study, we use cultural-historical activity theory as a theoretical and analytical framework for examining preservice teachers' pedagogical design capacity for inquiry. In the sections that follow, we first provide an overview of CHAT and then present a CHAT-based framework for preservice elementary teachers' developing pedagogical design capacities for inquiry.

Cultural-Historical Activity Theory

Cultural-historical activity theory (Engeström, 1987) is an activity-based perspective on human activity and learning that developed within the Vygotskian tradition of Soviet psychology. As such, it shares similarities with Vygotskian learning theory, particular the emphasis on mediation. However, activity theory takes social activity itself as the fundamental unit of analysis, emphasizing the interactions that emerge from activity, the purpose- and object-oriented material production achieved through activity, the cultural mediation of these processes, and how a particular activity is nested within broader networks of systems. These complex relationships are embodied in the CHAT activity triangle, a generalized model for analyzing social activity, which is shown in Figure 1.

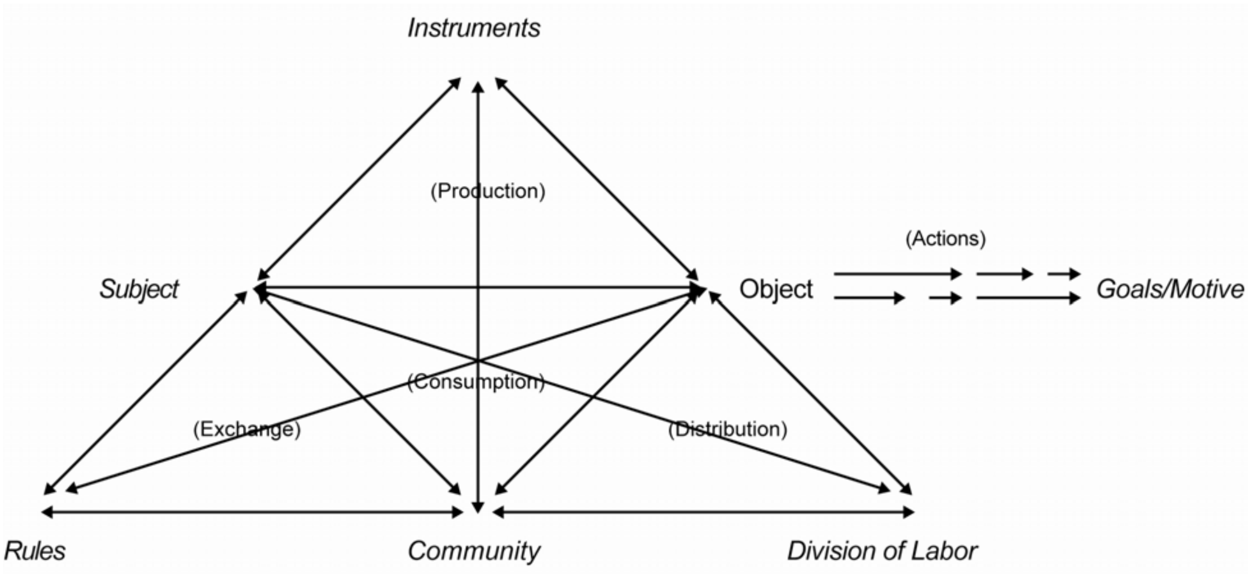

Figure 1. Cultural-historical Activity Theory Model of Human Activity (Engeström, 1987, 2007)

Activity undertaken by an individual or group (subject) whose particular need(s) (motive) impels action oriented toward a particular problem or purpose (object). Consistent with the foundations of cognitive science laid by Vygotsy, such activity is also mediated by tools and artifacts (instruments) and by other human beings (community) within the activity system. The nature of activity as it develops is also structured and shaped by norms of the community (rules) and specialization or social stratification (division of labor).

Activities are also products of historical development and themselves nested within broader activity networks. What this means is that each node of the triangle model in Figure 1 (except the object) can be both shaped from with the activity of interest but also from outside of the activity through related activities. Rules and norms, for example, can be negotiated by those involved in a particular activity but may also be imported from without in the form of official regulations which themselves were the object of a rule-producing activity. A primary emphasis of third generation activity theory is to explore how interactions between activity systems emerge, develop, and contribute to the shaping of one or both interacting activities.

While activities may appear stable, there exist ever-present tensions within and between nodes of activity systems and neighboring activity systems. These contradictions arise as “the clash between individual actions and the total activity system” (Engeström, 1987, pg. 30) and are the motor for and harbinger of change in activity. There are four primary types of contradictions (Engeström, 1987). Primary contradictions (1) are those that manifest themselves within each constitutive component of the CHAT triangle. Secondary contradictions (2) arise between these nodes. Tertiary contradictions (3) arise between the object and goal of the current form of the activity and the object and goal of a fundamentally-different, often more advanced form of activity. Finally, quaternary contradictions (4) arise between the central activity and neighboring activities. These contradictions are important because they lie at the heart of learning in practice. Through the resolution of emergent contradictions, participants in activity can learn to engage in new, more culturally-advanced and articulated forms of activity.

CHAT-based Model of Preservice Elementary Teachers' Curriculum Design for Inquiry

There have been increasing calls for CHAT-based research in education. CHAT has been employed recently, for example, in studies of studies of elementary science (Reveles, Kelly, & Duran, 2007), school leadership (Spillane, Halverson, & Diamond, 2004), teacher professional development (Yamagata-Lynch, 2007), and identity development of preservice elementary teachers (Smagorinsky, Cook, Moore, Jackson, & Fry, 2004). Thus far, however, CHAT has not been explicitly employed in research on teachers' practice and learning for and about inquiry. However, because teacher learning is both temporal and situated (Feiman-Nemser, 2001; Putnam

& Borko, 2000), CHAT is positioned as a particularly powerful tool to study teachers, teaching, and teacher learning (Grossman, Smagorinsky, & Valencia, 1999). This is particularly the case for preservice teachers who traverse multiple setting in learning to teach science and, at this stage, typically experience their first experiences engaging students in science in the classroom. To investigate preservice elementary teachers' curriculum design and development of pedagogical design capacity for inquiry, we present the CHAT-based model in Figure 2.

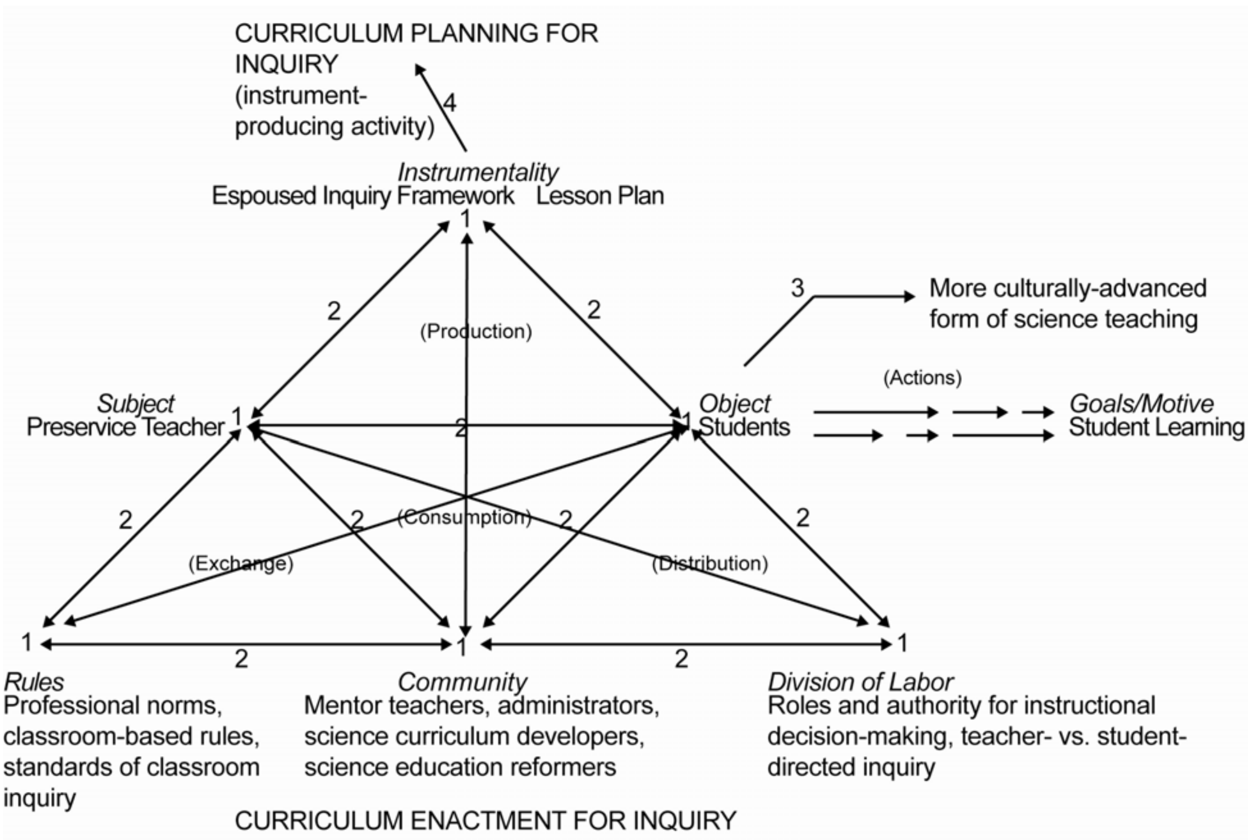

Figure 2. Activity-Theoretical Model for Preservice Elementary Teachers' Curriculum Enactment for Inquiry

This model is a study-specific version of Figure 1 and is consistent with activity-theoretical models for 'schooling' discussed by Engeström (1987). In the model if Figure 2, preservice teachers (subject) employ their espoused inquiry frameworks and lesson plans (instrumentality) to promote students' learning (object and motive). This triadic relationship, which has been articulated by other education scholars, is also mediated by various rules/norms, other community members, and divisions of labor that characterize elementary classrooms. Contradictions may exist within each node of the model ('1'), between nodes ('2'), between the object-motive and an alternative object-motive of classroom inquiry ('3'), and between classroom inquiry (lesson enactment) and lesson planning, the instrument-producing activity ('4'). This model affords the ability to characterize and describe the preservice teachers' science teaching, contradictions that emerge within the classroom and between teaching and planning, as well as how their teaching practice and espoused inquiry frameworks evolve over the course of the study.

This study draws heavily from recent research on teachers' use of curriculum materials that has, by and large, revolved around a contemporary perspective on teachers' use of curriculum materials. This perspective assumes the necessary role teachers play in critiquing and adapting curriculum materials and that curriculum materials can be flexibly-adaptive and educative for teachers to support this interaction (Brown, 2008; Remillard, 2005). The use of CHAT here is timely and appropriate because this contemporary perspective on the teacher-curriculum relationship has been grounded in many assumptions that are shared in Vygotskian and activity-theoretical perspectives on learning, including the essential mediating roles of tools and the locating of expertise in interactions. As such, in addition to illuminating preservice elementary teachers' development of pedagogical design capacity for inquiry, this study also contributes to the ongoing development of this perspective on teachers' use of curriculum materials and the teacher-curriculum relationship.

Methods

This study took place during the fourth year of a four-term, cohort-based undergraduate elementary teacher preparation program at a large, Midwestern university in the United States. During the fourth year, preservice teachers are enrolled in the elementary science teaching methods course (fall semester) and a full-time student teaching experience (winter semester). The methods course is organized around central tenets of effective science teacher education. Specifically, two significant themes in the course are learning to teach science as inquiry and to critique and adapt science curriculum materials as representations of practice.

This study involves in-depth case studies of four preservice elementary teachers carried out over the year. It is part of a larger, mixed-methods study of preservice elementary teachers' curriculum design and development of pedagogical design capacity for inquiry. Other findings from this study, including quantitative assessment of the preservice teachers' curriculum design efforts, have been reported elsewhere. The component of the study presented here allows for rich, substantive analysis of these preservice teachers' learning to use curriculum materials because it spans the methods semester and subsequent student-teaching semester, allowing for analyses over time and across contexts.

Study Population

During the fall semester, seven preservice teachers were identified and invited to participate in an in-depth study centered around their science teaching both during the methods semester and the subsequent student teaching semester. These preservice teachers were selected from the methods course using maximum-variation sampling and typical-case sampling (Patton, 2001), or highly variant participants and those who are more representative of the population as a whole. This plan followed a similar selection approach used in previous research on preservice elementary teachers in the elementary science teaching methods course (Forbes & Davis, 2008). Over the course of the year, three of the original seven preservice teachers dropped out of the study. One was asked to decommit due to course performance, one was no longer teaching science during student teaching, and the third chose to end her participation during student teaching due to demands placed on her time. The data for the case studies are therefore drawn from four preservice elementary teachers followed over the course of the 2007-2008 academic year.

Data Sources and Collection

Data for this study centered around artifacts associated with preservice teachers planned and enacted lessons. During the methods semester, the preservice teachers were asked to plan and develop, teach, and reflect upon two science lessons. These assignments are called *reflective teaching assignments* (RTs) in which the preservice teachers take an existing science lesson or set of science curriculum materials, critique them, modify them to develop an inquiry-oriented lesson, enact the lesson in their placement classroom, and reflect upon their teaching. The case study preservice teachers also taught two science lessons during student teaching semester. The four lessons each of these preservice teachers taught over the course of the year were observed by the first author. Additional data included multiple interviews, curriculum- and lesson-specific artifacts, and written journal entries. The case studies of the four preservice teachers are therefore built around this corpus of data, collected throughout the year, and centered around the four science lessons (2 each during the fall and winter semesters) each taught over the course of the year.

Data Coding and Analysis

Because this study is grounded in cultural-historical activity theory, methods of data coding and analyses were aligned with activity-theoretical constructs (i.e., Figure 2). To characterize the preservice teachers' curriculum design decisions, or specific *actions* they undertook, coding keys were developed to characterize the types of curriculum materials the preservice teachers used and adaptations they made. Additionally, to assess how inquiry-oriented their lessons were before and after adaptation, an inquiry scoring rubric was developed that is informed by existing instruments and is explicitly designed to capture crucial elements of inquiry as defined in current science education reform (Bodzin & Beerer, 2003; Luft, 1999). These inquiry scores provided a standard against which to compare the outcome of the preservice teachers' curriculum planning efforts and the efficacy of the tools they used to mediate lesson enactment. In coding these data with a colleague, inter-rater reliability yielded 82% agreement prior to discussion and 100% after discussion.

This approach helped illuminate specific curriculum design actions the preservice teachers carried out, but not the activity as a whole. A crucial aspect of characterizing the preservice teachers' learning and development of pedagogical design capacity for inquiry involved the identification of underlying contradictions. To do this, we first coded the data using the coding key in Table 1.

Table 1

Coding Key for All Research Questions

Codes	Curriculum Enactment Codes
Preservice Teacher	Espoused feelings of self-efficacy, confidence, subject-matter knowledge, etc.
Object	Lesson enactment object
Outcome/Goal	Preservice teachers' goals/motives for curriculum enactment
Instrument(s)	
Instruments/Tools (other)	Subject-matter knowledge, physical materials, etc.
Asking scientifically-	Espoused ideas about the role of questions and questioning in

oriented questions	inquiry-oriented teaching
Gathering and organizing data/evidence	Espoused ideas about the role of gathering and organizing data and evidence in inquiry-oriented science teaching.
Constructing explanations from evidence	Espoused ideas about the role of constructing evidence-based explanations in inquiry-oriented science teaching.
Evaluate explanations in light of competing evidence	Espoused ideas about the role of evaluating explanations in light of competing evidence in inquiry-oriented science teaching.
Communicate and justify explanations	Espoused ideas about the role of communicating and justifying explanations in inquiry-oriented science teaching.
Inquiry-General	Espoused ideas about inquiry-oriented science teaching in general.
Science Lesson Plans and Curriculum Materials	Espoused ideas about what scientific concepts and tasks curriculum materials should represent, how, why, and for whom curriculum materials should represent them, and who should contribute to their development.
Rules	Professional norms, school- and classroom-based rules, etc.
Community	Cooperating teacher, other teachers and administrators, field instructors, etc.
Division of Labor	Who does what? Negotiations between preservice teachers and cooperating teachers, role of students and teachers in inquiry-oriented practice, etc.
Instrument-Producing Activity	Curriculum planning
Culturally-advanced form of activity	Advanced forms of curriculum enactment

This coding key was employed to characterize the preservice teachers' curriculum planning and curriculum enactment contexts, their use of their espoused inquiry frameworks and curriculum materials in their development and enactment of science lesson plans, and how their espoused inquiry frameworks and curriculum design practices changed over the course of the year. The coding key is based upon and explicitly aligned with the CHAT-based model of preservice teachers' pedagogical design capacity in Figure 2.

To analyze the coded data from the focal group of four preservice teachers, we engaged in a stepwise process of data representation, reduction, and verification (Marshall & Rossman, 1999; Miles & Huberman, 1994), the goal of which was to provide empirical evidence for claims. These analyses were directed towards the development of case studies (Yin, 1994) and involved two code queries. First, we performed coding queries of data coded with codes in Table 1.   These code queries illustrated the number of instances in which individual codes overlapped, which was critical to identifying contradictions that preservice teachers articulated within curriculum enactment contexts. Second, we performed code queries of codes in Table 1 and codes for curriculum design decisions. This was necessary to link specific contradictions to specific curriculum design decisions.

To summarize these contradictions and curriculum design decisions, I used the coding matrices in Appendix A and B. The coding matrix in Appendix A summarizes contradictions and curriculum design decisions for a given lesson. The coding matrix in Appendix B summarizes the curriculum design decisions that preservice teachers made in relation to a particular contradiction over time and across lessons.   At this stage of analysis, however, the goal was to trace the influence of *a given contradiction* over time rather than map *all contradictions* influencing a particular curriculum planning and enactment cycle. Therefore, a separate coding matrix (Appendix B) was produced for *each* contradiction the preservice teachers articulated over the course of the study as it pertained to their curriculum planning and enactment.

Finally, after having analyzed the relationships between contradictions and the preservice teachers' curriculum design decisions over time, we constructed complete cases for each of the four preservice teachers. These comprehensive cases illustrated the preservice teachers' espoused inquiry frameworks, curriculum design goals and decisions, articulated contradictions within and between curriculum planning and curriculum enactment, relationships between all three, and their evolution over the course of the study.   We employed member-checking to insure that findings were consistent with the curriculum design experiences of the preservice teachers rather than to derive and present universal, albeit defensible, 'truths' about the nature of this work (Patton, 2001). Based on findings from each of the cases, we performed cross-case analysis of the focal preservice teachers to identify relevant patterns and themes. Emphasizing cross case themes helped illustrate consistent trends across the four preservice teachers' use of science curriculum materials over the course of the study. As definitive patterns emerged through coding, the data was reduced to isolate and illustrate key factors. We tested emergent themes by actively seeking conflicting data that contradicted my developing interpretations. This process continued until dominant themes were refined and substantiated.

Results

In the study of preservice elementary teachers' curriculum design for inquiry in the methods course (Forbes & Davis, 2009), we found that their adaptations led to an improvement in the inquiry scores of the lessons. Additionally, the preservice teachers were able to accurately self-assess how inquiry-oriented their revised lessons were. Despite the impact of their adaptations, however, the inquiry scores of the curriculum materials the preservice teachers used to plan their lessons was the single-most significant determiner of how inquiry-oriented their revised lessons were. the more inquiry-oriented their initial curriculum materials were, the smaller the change in inquiry score due to adaptation. These findings provide a gross-level description of the preservice teachers' curriculum design decisions as well as explanations for how inquiry-based their lessons were after adaptations. While illuminating, they do not provide detailed insight into how and why the preservice teachers adapted their lessons in light of their ideas about and orientations toward inquiry. In the remainder of the results section, we focus on results from the case studies of four preservice teachers studied over the entire year.

Repositioning Students to Create a Culture of Inquiry

A major focus of the four preservice teachers' curriculum design efforts over the course of the year was to emphasize specific inquiry practices. However, equally as importantly, they also sought to alter the nature of classroom activity more broadly. Through their adaptations targeted at specific inquiry practices, the preservice teachers sought to adapt their lessons to engage in more student-directed inquiry characterized by collaborative discourse and the identification, construction, and negotiation of shared problem-spaces through which evidence-based claims were made about lesson-specific natural phenomena. Most importantly, this shift required the repositioning of students from the object of classroom inquiry (as shown earlier in Figure 2), to contributing community members as shown in Figure 3 below.

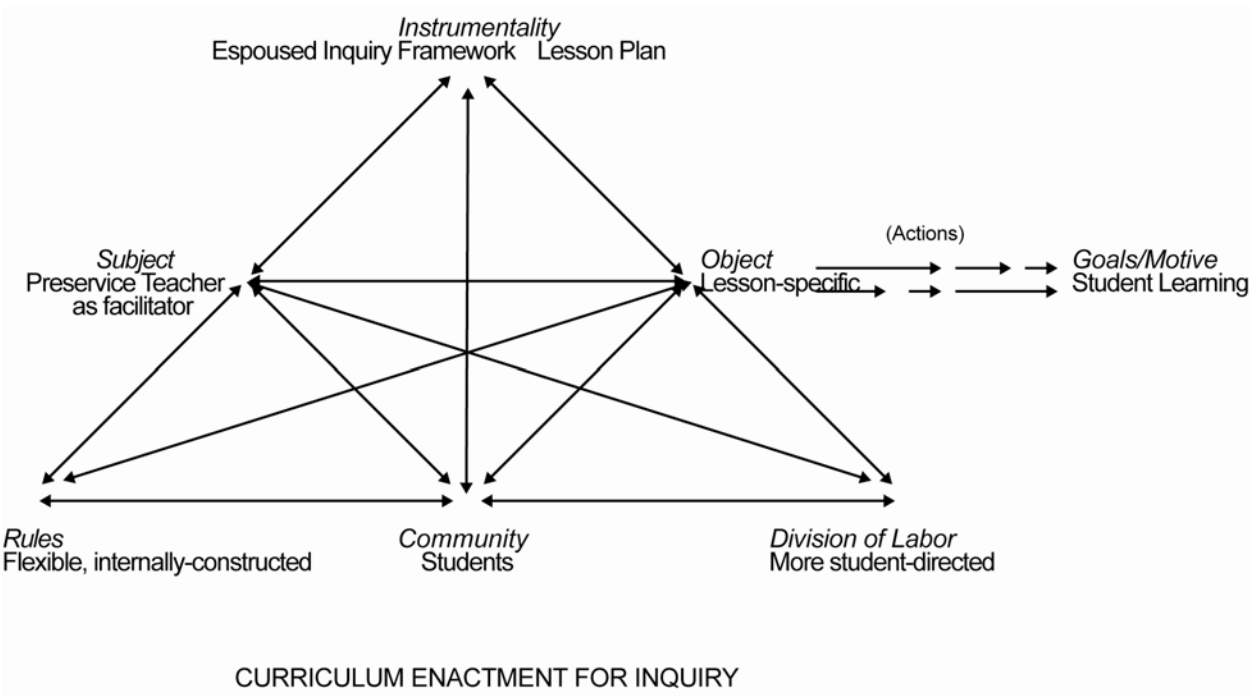

Figure 3. CHAT-based Model of Inquiry-based Science Teaching

The model of inquiry-based science teaching and learning in Figure 3 represents a fundamentally different activity system than the more traditional, default form of classroom practice discussed earlier in Figure 2. With students as community members, the object of activity was no longer the students themselves, but rather lesson-specific shared problem-spaces that were jointly constructed by the teacher, now acting as more of a facilitator than manager, and the students. These lesson-specific problem spaces were characterized by specific concepts, how they had been problematized, and relevant reifications of these concepts with which the teachers and students worked. In general, the form of science teaching and learning represented in Figure 3 is necessarily governed by more flexible, internally-constructed rules and norms, tended to be more student-directed, and saw the preservice teachers assumed more facilitation-oriented roles in the classroom. The primary motive for classroom inquiry remained students' learning of predefined scientific explanations for phenomena. However, whereas the goal of the more traditional form of classroom science (Figure 2) is students' appropriation of these explanations, here, in the form of activity more often instantiated in the preservice teachers' revised lessons (Figure 3), the primary goal was the construction of new knowledge through collaborative sense-making.

There were examples of this across the preservice teachers' lessons for specific inquiry practices. Kelly, for example, focused throughout the year on engaging students in scientifically-oriented questions. She noted early on that she hoped to engage in a more student-directed version of this practice, saying, "I want to prompt students to come up with good investigative questions, rather than myself….by giving them the prompt to create an investigation question and offering them scaffolding to do so, I would know if they could form effective scientific investigation questions on their own" (RT1). She argued that this approach made her lessons more inquiry-oriented, writing,

> …this makes the lesson more inquiry-based because I allow students to help me form the question for our experiment. While the experiment is pre-planned, I am

> not telling them what we are investigating here, but allowing them to figure it out. Further, an investigation question includes many subquestions that students can seek the answer to themselves (RT2)

After working with students to co-construct investigation questions in her first two lessons, Kelly again engaged students in this activity in her third lesson, which involved an investigation of factors affecting mold growth. Before turning to actually setting up their investigations, Kelly supported students to develop an investigation to guide their inquiry. In the discussion, Kelly drew on a number of students' ideas to make explicit the primary question they were addressing, as shown in the following excerpt:

> [Kelly] Alright, so we've come up with some ideas about what might affect bread mold growth. What are we trying to figure out today when we set up a fair test with our bread mold? What are we trying to discover today? What 's the one thing we're trying to find out with our bread mold? [Student 1]?
>
> [Student 1] How long, how long it might take for the bread to mold?
>
> [Kelly] Yep, and more specifically we're looking at all these variables. What are we trying to figure out about these variables? [Student 2]?
>
> [Student 2] The [inaudible]…
>
> [Kelly] You're along the right lines. I'm just trying to figure out…we're going to be setting up a fair test today where we're changing only one variable. So what are we trying to discover today? What's the main thing that's guiding us? What are we looking for? [Student 3]?
>
> [Student 3] How mold grows.

[Kelly] That's one good question. 'How mold grows' [talking while writing]. [Student 4], did you have another question that we're trying to discover today? What do you think?

[Student 4] Um, yeah, what conditions, how different conditions will affect how mold grows.

[Kelly] Did everybody hear [Student 4]? Say that one more time really loudly.

[Student 4] How different conditions will change how mold grows.

[Kelly] So 'how do different conditions…How do different conditions affect mold growth?' [reading while writing on overhead]. So look down to page 32 and we're going to fill out this table together… [Lesson 3 Enactment, 13:39-15:58]

This episode illustrates Kelly's attempt to engage her students to co-construct an investigation question that directly addresses the lesson's learning goal. She wrote that "this definitely creates a more inquiry-oriented investigation" (Lesson 3). Following her lesson, Kelly also said that "students had no trouble coming up with a question about how fungi survive or how they get their nutrients" (Lesson 3) and indicated that she liked having students participate in developing an investigation question. For Kelly, then, facilitating the articulation of a shared problem-space through the construction of an investigation question had emerged an effective means through which to position students as co-contributors.

There were also examples of where the preservice teachers adapted their lessons to engage students in more collaborative data collection and organization. Aliza, for example, sought to adapt her first lesson to make existing opportunities to engage in data collection and organization more student-directed. In this lesson, students set up an experiment to test plant growth under different conditions. Aliza had students discuss and negotiate, as a class, what specific variables they could and should measure as effective evidence of plant growth. This was part of a broader whole-class discussion that Aliza facilitated to support students to set up their plant experiments in the lesson. After students had offered up and described an experimental design, Aliza facilitated a discussion in which they agreed upon a number of variables upon which to focus their data collection.

> [Student 1] …and see which one grows better, which one's more healthy.
>
> [Aliza] I really like that idea. Do people agree that that would be a good experiment?
>
> [All] yeah, um-hmm
>
> [Aliza] Ok, so that sounds like a good idea, I think we can do that, but then as we're growing our plants, how can we tell which one's growing better? Yes?
>
> [Student 2] Look at which one's green and grows a lot?
>
> [Aliza] Right, so all of those would be qualities of the plant that we'd be observing, right? And if we were watching our plants grow, we could write down our data, right, our information about the different qualities of plants? So [student 2] just said the color, right, if it's green, if it's tall, so it's size [writing on board]. And what else did you say?
>
> [Student 2] If it's not decomposing
>
> [Aliza] If it's not decomposing, right, how it's growing. So do you have some other ideas?
>
> [Student 3] This was something to add. Since plants need worms in the soil, you could take a couple of redworms out and put them in so the worms can help them decompose.

> [Aliza] That is a good idea. Our pots aren't going to be very big so I don't know if that would be good for the worms. But we could take some of the worm castings, right, because that's really rich nutrients and we could add that to our organic pot so it could grow better. So those are really great ideas, I think we should try that. (Lesson 1 Enactment, 34:22-37:02)

Aliza argued that "this makes the lesson more inquiry-oriented" because the lesson was "more student-oriented than teacher-oriented, elicits students' ideas instead of feeding them ideas, and engages them in scientifically-oriented questions" (RT1). She also suggested that "students will remember the [data] criteria we are looking to observe better if they come up with it themselves than if I just give it to them" (RT1). This collaborative discourse was an important element in her lesson in which the students participated as community members, jointly-constructed the problem of designing their plant experiments to answer their investigation question. In the end, Aliza supported students to articulate variables that would ultimately support their sense-making about their results.

Finally, there were additional examples were the preservice teachers engaged students in collaborative work to formulate and communicate evidence-based explanations. Mike's second lesson, for example, involved students modeling bird feeding using various tools and items meant to represent bird beaks and food. One of the adaptations Mike made to the lesson was to add a whole-class discussion at the end during which students used data to make claims about the bird beak models and reexamined their initial predictions in light of the data they collected. Mike noted his goal with the concluding discussion was to "try to connect [the models] to adaptations...so I could…talk about like how the different beaks served different purposes and because they served different purposes birds live in different places" (Post-Enactment Interview

2). Mike said his revised approach was useful “so [students] can compare their answers and see if they predicted right or got it wrong, and then we could talk about that”, specifically noting it, combined with the data tables, “allows for students to support their explanations with evidence” (RT2). Here, then, Mike was explicitly drawing upon the evidence and explanations-focused components of his inquiry model to adapt his second science lesson to make it more inquiry-based. Mike noted his “hope is students will refer back to their table to give me an answer dealing with the quantities of worms they picked up” (RT2). Ultimately, Mike’s intent with this adaptation was to support students to understand that different bird beaks are better suited for certain types of food, one of his explicit learning goals for the lesson.

However, whereas examples of the preservice teachers making changes to engage students in more student-directed scientific questioning and data collection were relatively common, the example of Mike is one of a select few in which the preservice teachers were able to engage students in more student-directed, collaborative sense-making. As we show in the next section, this was the result of contradictions that emerged in the enactment of the preservice teachers’ lessons.

Emergent Contradictions in Curriculum Enactment for Inquiry

Though the preservice teachers adapted lessons to engage students as contributing community members in classroom inquiry, lesson enactments did not always play out as envisioned and instantiated in their planned lessons. Their attempts to reposition students as contributing community members in scientific inquiry (as shown in Figure 3) led to set of contradictions that emerged in the classroom. These contradictions are shown below in Figure 4.

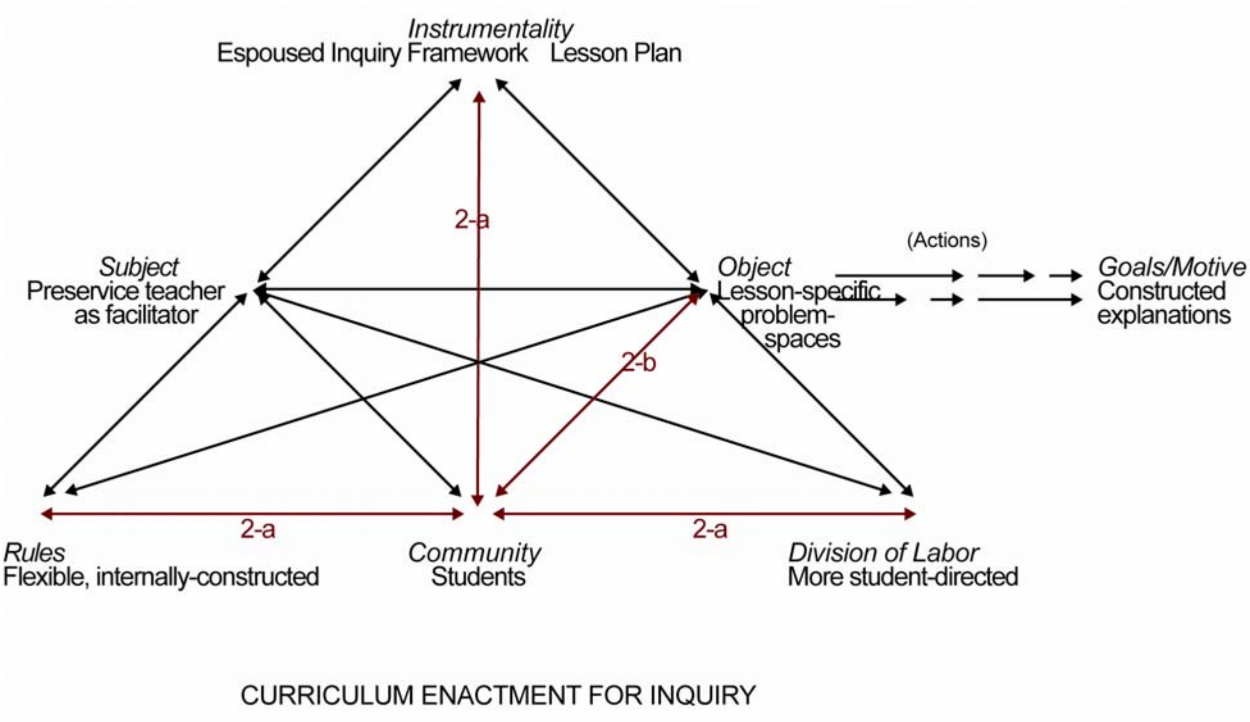

Figure 4. Emergent Contradictions in Preservice Elementary Teachers' Enacted Lessons

First, one or more secondary contradictions emerged between, on the one hand, students new role as community members and, on the other, divisions of labor, instrumentality, and/or rules/norms that governed activity (labeled as '2-a' in Figure 4). These three contradictions, which sometimes appeared individually or in combination, were evident in issues of classroom management often articulated by teachers. These secondary contradictions often resulted in another secondary contradiction between students as community members and the shared problem-spaces (objects) the preservice teachers hoped to co-construct and negotiate in the lessons (labeled as '2-b' in Figure 4). In effect, this latter contradiction was not only concerned with the lesson's capacity to position students as community members through their adherence to rules/norms and the assumption of roles, but also accomplishing particular lesson-specific goals by doing so. These contradictions ultimately limited sense-making and explanation-construction, thus limiting the inquiry-orientaiton of the preservice teachers' lessons, as shown in the sections that follow.

Marshalling Instrumentalities for Classroom Inquiry

First, and foremost, the preservice teachers' planned lessons and ideas about inquiry (i.e., their instrumentality) had to support their positioning of students as co-contributors in more collaborative, object-focused classroom inquiry. While Kelly, Mike, and Aliza taught many lessons that afforded them opportunities to do so, Lauren's case illustrates how curriculum materials and a teachers' ideas about inquiry can limit his/her efforts to engage students in more student-directed inquiry. For Lauren, a consistent contradiction emerged between, on the one hand, her instrumentality and, on the other, students' roles as community members (see Figure 4). While Lauren emphasized student learning of predefined learning goals, it was not until her fourth lesson that she had an opportunity to teach an existing lesson that engaged students in substantial post-investigation formulation, communication, and comparison of evidence-based explanations. In her fourth lesson, students investigated properties of light by shining light through a host of different materials. Lauren had noted that in this lesson, "there's a class discussion…where kids discuss what we decide as a class each material would be" (Pre-enactment Interview 4) and that in this discussion, "the students have to justify/explain why they think lots of light passes through some materials and less light passes through other materials [and] what they think happens to light that doesn't pass through a material (RT4).

The lesson, however, while it did include an investigation and post-investigation sense-making component, was largely confirmatory in nature, in that students were first introduced to three scientific concepts and terms (translucent, transparent, and opaque) and were then asked to investigate and rank different materials using these terms. The end-of-lesson whole-class discussion that emerged was highly teacher-directed and, after Lauren reviewed the definitions of translucent, transparent, and opaque with students, mostly involved students sharing their findings and categorizing the various materials. For example, the following segment from the discussion illustrates how Lauren facilitated her students' communication of explanations

> [Lauren] Great, so you had foil and cardboard as opaque. Plastic square? Raise your hand and tell me what you had it as. [Student 1]?
>
> [Student 1] Um, opaque?
>
> [Lauren] Opaque? Opaque means no light got through. No light got through this?
>
> [Student 1] Which one?
>
> [Lauren] This, plastic square. Can you see me through this [Student 1]?
>
> [Student 1] Um, most…
>
> [Lauren] Most light through…what's that called? Transparent. Raise your hand if you had this as something other than transparent. No one? Good, we're all on the same page [Lesson 4 Enactment, 49:40-50:16]

Lauren noted after her lesson that "once [students] were given the opportunity to investigate, they found the correct answers on their own" (Lesson 4). However, as shown in this excerpt, rather than being provided an opportunity to construct knowledge collaboratively in this discussion, students were limited to categorizing objects as translucent, transparent, or opaque. Lauren noted afterward that she "tried to get [students] to explain their findings…they didn't necessarily have to compare theirs to anyone else's or justify why they did something" (Post-Enactment Interview 4) and that, as a result, she wished "there would have been a section to write about their findings and compare them to their initial predictions. I think those elements are important to understanding why we do certain things, and correct previous misconceptions" (Lesson 4).

Ultimately, Lauren's emphasis on correcting students' misconceptions as a form of explanation-construction caused her to perceive students' confirmation and appropriation of scientific explanations in her fourth lesson as the construction evidence-based explanations. In short, largely because of the particular lessons she taught and her espoused ideas about inquiry, Lauren had little opportunity to truly engage her students in collaborative sense-making through inquiry and never truly repositioned her students as community members in classroom inquiry.

Mediating Influence of Rules, Norms, and Divisions of Labor on Classroom Inquiry

Unlike Lauren, Mike, Kelly, and Aliza were able to teach lessons that afforded opportunities for students to participate and contribute as community members. However, in enacting these lessons, they often experienced secondary contradictions between students as community members and both rules and divisions of labor. By shifting students' roles in classroom activity, they often found it difficult to engage in new forms of classroom science within existing rules and using existing divisions of labor. In Mike, Kelly, and Aliza's lesson, contradictions often emerged between elements of the classroom activity system and students' placement as community members.

For example, over the course of the study, Mike struggled, particularly in his first three lessons, to effectively engage students as contributing community members in his lessons. In effect, Mike struggled to facilitate students' engagement with lesson-specific problem spaces in their new collaborative roles. These problem-spaces, which were ultimately focused on discourse-based explanation-construction in Mike's second and third planned lessons, ended up being cut from his lessons due to the emergent contradictions. In his second lesson, because the modeling activity took longer than anticipated, Mike ran out of time to have his students return to their predictions from the beginning of the lesson and to make claims about the bird beak models using evidence they collected and recorded during the lesson. Similarly in Mike's third lesson, Mike modified the structure of the activities to have students working more collaboratively, arguing that group work allowed students to "review the parts of the seed and how their seed differs from someone at their table" (RT3). In lesson 3, for examples, Mike had students make predictions at the beginning and then said, "I'm going to try to wrap it up by talking about the similarities and differences they noticed in the seeds,..then I'm going to ask about the predictions and whether they thought everything in that initial seed was going to be in the other ones" (Pre-enact 3). However, again due to classroom management issues, Mike ran short of time and did not engage students in these sense-making discussions. Afterward, Mike noted "I thought I had planned a good lesson, but my execution was below par" (Lesson 3). The students' new roles resulted in a series of contradictions that ultimately led to in situ adaptations that made Mike's first three lessons less inquiry-based.

Unlike Mike, Kelly generally did not have major challenges to her first three lesson enactments. However, unlike her first three lessons, Kelly's attempt to enact her adaptations in her fourth lesson proved problematic. Kelly struggled to keep students engaged during the part of her fourth lesson in which they graphed their results from the bread mold investigation, in large part due to students' lack of familiarity with the rules/norms governing the construction of graphs. Kelly noted that "once I let them go and start graphing, a lot of people were like, 'I don't get this', 'I don't know what I'm doing' [which] was frustrating because I'd just explained it" (Post-Enactment Interview 4). This resulted in a secondary contradiction between Kelly's students and the object of the lesson. In part because of Kelly's struggles to keep students engaged in constructing their graphs, another secondary contradiction emerged between students (community) and the rules governing time. Finally, time became a mediating factor in having students actually make evidence-based explanations, evidenced in yet a third secondary contradiction between rules governing time and the shared problem-space of their graphs. After her lesson, she said, "if you just ask them a few questions last minute about their data and what happened, it won't stick with them. I think to really leave 10 to 15 minutes at the end to just ask them questions that really get them thinking and having them communicate their ideas with one another…it's definitely worth it" (FI3). Moving forward, Kelly acknowledged this would be an important challenge for her, saying, "that's the main struggle for me, just making sure that I leave enough time to have a culminating conclusion at the end of the lesson" (FI3). She noted that having substantive collaborative discourse as a part of inquiry was time consuming. She said that "I think you need to leave more time than you think for that communication of results, and conclusions, because it just takes time to connect ideas in like a dialogue…The part that was difficult was the communicating at the end and connecting ideas and one another's explanations. Like I said, I usually ran out of time for that, and need more time for it" (FI3).

Finally, like Kelly, Aliza did not experience classroom management issues in her lessons. However, she did consistently struggle to engage students as community members within the allotted time. In each of Aliza's four lessons during the study, a secondary contradiction emerged between Aliza's goal of co-constructing a shared problem-space with students and the rules governing the time that she was allotted to do so. In her first, lesson, Aliza noted that because of the lengthy discussion she facilitated during her first lesson, she "ran out of time at the end" and, as a result, "was unable to do a wrap-up to the lesson" (RT1). Similarly, in her second lesson, Aliza ran out of time to have her students write their explanations in their journals, the final element in her planned lesson.

Aliza's third lesson was an introductory lesson on minerals in which students made observations of various minerals, recorded their properties, and looked for patterns in these properties. One of Aliza's adaptations to the lesson was to have students collaborate in small groups to record observations and then have a whole-class discussion to discuss similarities and differences. Aliza argued this was "a good way to close a lesson is to have students talk about what they've learned as opposed to just writing it down" because "when they're talking about it… it's more inquiry-oriented…it's like extending the thinking process… like the next step in inquiry" (Pre-Enactment Interview 3).

Aliza noted that accounting for time in her enacted lessons was an area for future growth, writing, for example, that she "need to work on time management" (RT1). In some ways, Aliza was confused by her apparent inability to conclude her lessons in the time she was allotted to teach science, saying, "It's so weird because I have taught other lessons [and] I feel like the timing has usually worked out before in the other [subjects]" (Post-Enactment Interview 2). In this sense, then, this an issue that was, for Aliza, unique to her curriculum design for science. She began to prioritize the need to complete her lessons on time, saying after her second lesson that "even if I run out of time, I need to leave some time to do some closure" (Post-Enactment Interview 2).

Shifting Students back to Objects in Response to Enactment Challenges

In response to the emergent contradictions discussed in the previous section, Mike, Kelly, and Aliza made additional changes to their lessons during enactment. These in-situ adaptations typically had two effects. First, they shifted students back to objects of enactment, as originally described in Figure 1. Second, in doing so, they more often than not made the preservice teachers' enacted lessons less inquiry-based than the lessons they had planned, particularly in relation to sense-making and explanation-construction.

Mike, for example, reflected how in his third lesson, "management and modeling went poorly and my control over the students was eventually lost" (Lesson 3). He described how, as a result, he was unable to enact any of the adaptations he had made to make his lesson to promote students' explanation-construction. He recalled that he "was going to have [students] make predictions…but I don't think I actually did that…I just kind of labeled right away for them, so I think I kind of totally defeated that purpose." (Post-Enactment Interview 3). Mike recalled that, "where I had built in all those opportunities to speak and to talk and talk with their group members and analyze their data…I lost all of that" (Post-Enactment Interview 3) and "I didn't do my end of the lesson discussion" (Post-Enactment Interview 3). As a result, Mike's third lesson was far less inquiry-oriented than he had originally planned.

Similarly, while Kelly had been successful in engaging her students in co-constructing investigation questions, she acknowledged that her modified whole-class discussion in her fourth lesson was "more difficult than I thought to try" (Post-Enactment Interview 4). In the end, to alleviate the contradictions that emerged in her lesson described in the previous section, Kelly shifted her role from facilitator to manager, taking control of the discussion and essentially telling students what they should have found. In effect, in that in situ instruction decision, she shifted students from their role as collaborating community members back into the role of objects so as to cover the lesson objectives within her allotted time. She recalled after her lesson, "I just didn't leave enough time and I think it seemed like pushed or contrived because I was trying to connect ideas really quickly but we didn't have much time to talk about what happened" (Post-Enactment Interview 4). As a result, Kelly's fourth lesson ended up being less inquiry-oriented than that which she had planned.

Aliza had a similar experience in her third lesson. During the lesson, and like her first two lessons, Aliza began to run short of time due to the amount of latitude she gave students to collaborate and engage in discourse about their mineral samples. Unlike her first two lessons, however, in which Aliza continued to attempt to enact her lesson as planned as time ran short, in her third lesson she made additional in situ changes to her lesson. Aliza recalled,

> …there was a point where, you know, there was a lot of discussion in inquiry-based learning and especially when they're observing something and making notes about it. But I realize and probably also because of the materials issue that there was a lot of talking and maybe not so much of writing things down. So that was when I sort of just stepped in and was like, 'ok', and I took each mineral and held it up and said, 'ok, what did we learn about this mineral?' or 'what did we discover about it?' and had some student give examples. Then I said 'ok, if you haven't written anything down about this mineral, those would be some good things to write down'. So we did that for the minerals (Post-Enactment Interview 3)

Due to the limited amount of time she had remaining, Aliza stepped in and focused the students on the observations she wanted them to make in light of predetermined learning goals she had articulated for the lesson. This instructional decision resulted from the same secondary contradiction between Aliza's goal of having students' collaboratively construct evidence-based explanation and the rules governing time for her to enact her lesson. This in situ adaptation essentially repositioned students as objects of the activity themselves, while also removing their opportunities to construct explanations about their minerals, thus making Aliza's lesson less inquiry-oriented than she had originally planned.

These examples are but three of many examples, especially in the preservice teachers later lessons, in which they resolved emergent contradictions through in-situ curriculum design decisions that repositioned students as the objects of activity and engaged in more teacher-directed classroom activity. These actions were oriented towards students' appropriation of predefined learning goals that students were either not making or did not have sufficient time to construct given other factors. In this sense, these adaptations, and the contradictions upon which they were based, were largely focused on students' sense-making and explanation-construction through inquiry.

An Essential Contradiction between Two Object-Motives of Curriculum Enactment for Inquiry

Ultimately, the preservice teachers represented their experiences enacting their lessons as a tertiary contradiction between two objects and goals of curriculum enactment that should lead to student learning of predefined learning goals. This contradiction is illustrated in Figure 5 below.

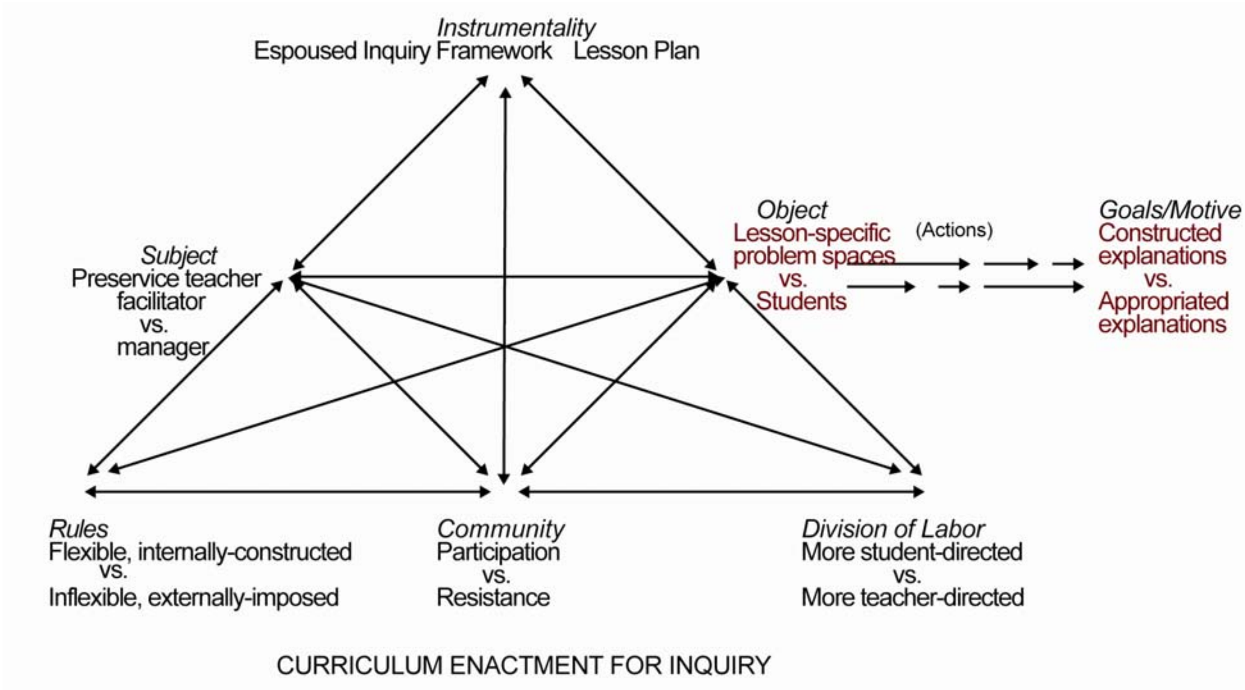

Figure 5. Tertiary Contradiction between Traditional, Didactic and Inquiry-based Science Teaching

This contradiction revolved around the need for students to meet predetermined learning goals. On the one hand, classroom science could position students as objects of activity to appropriate these learning goals. While this perhaps afforded a greater degree of certainty that students could meet these learning goals, it also, to these preservice teachers, necessitated engaging in more teacher-directed, often direct, instruction. On the other hand, students could be positioned as community members who, through the construction and shaping of shared problem spaces, could be provided the opportunity to construct scientific explanations. However, the preservice teachers both perceived and experienced doing so as forgoing some of the certainty that students would construct the predetermined, scientific explanations which their lesson-specific learning goals emphasized. All were still struggling to reconcile it at the end of the study.

Lauren. Unlike the other three preservice teachers, Lauren articulated this tertiary contradiction at the beginning of the year between, on one hand, her goal of having students construct understanding through participation in inquiry and, on the other, having them appropriate predetermined learning goals. This contradiction emerged in response to a videocase of inquiry-based science teaching used in the methods course. She wrote that her "only concern [with inquiry] is that the teachers may rest too much responsibility in the hands of the students, and possibly frustrate them" (Journal, 9/11/07). She also said that inquiry must eventually lead students to predetermined learning goals, saying, "it doesn't really seem beneficial at the end if you just let the kids go away with their own ideas…you have to know that your students have grasped a concept before you can move on" (FI1). She recalled a video of inquiry-based science teaching from the methods course, saying,

> I was so confused after watching the video and how [the teacher] never really wrapped it up…if you're going to dedicate 3 days or however much time to getting students to wrap their heads around this certain idea you have to at some point give them some sort of resolution and say this is what you're supposed to take out of it. (FI1)

In this way, Lauren was concerned, at least early in the study, that it would be particularly difficult to support students to achieve predetermined learning goals through engagement in inquiry.

As shown in previous sections, Lauren did not have significant opportunities to engage her students in collaborative sense-making. As such, there is little evidence that Lauren ever resolved this tertiary contradiction over the year. At the end of the year, she again recalled the video from class, saying, "the videos, it went on and on forever, just kept fueling misconceptions, that one, with that woman, but going on and on and on". (FI3). Lauren noted that in her own teaching, she didn't "want to step in and say, ok, this is the right answer, this is what you were supposed to have taken out of it" but, simultaneously, "was also nervous about letting it go on and on and on and on" (FI3). She wrote,

> I've learned, through my several attempts at inquiry-oriented science teaching, that patience is necessary. It is so difficult to bite my tongue and avoid jumping in and saying, "No, this is how you're supposed to do it," or, "This is what you're supposed to be getting out of this." It's really a struggle to remove myself from the activity and really just serve the purpose of facilitating. I often get frustrated watching students do something incorrectly, or not get at the aim of the lesson… It makes me realize that I need to watch myself; there is a difference between "teaching" and "telling." (Lesson 4)

Lauren had come to appreciate the challenges of facilitating inquiry in the classroom. Ultimately, Lauren noted she "consider[ed] inquiry to be more student-led than teacher-led but, at the same time, I don't consider it to be totally student-led" (FI3). However, she acknowledged that it was still difficult to put more autonomy in the hands of students and that this was an area for further development. While Lauren said she was not entirely comfortable facilitating students' construction of knowledge through inquiry, she did believe, "there's a way to guide it enough to where students are going to come out with the same ideas but not guide it so much that they're still having the majority of the involvement" (FI3). Here again is evidence of Lauren's emphasis on students' attainment of predetermined learning goals. Lauren had, throughout the year, articulated a fundamental tertiary contradiction between various elements of inquiry practice and her goal of promoting student learning of predefined learning goals rather than supporting misconceptions. By the end of the year, she had not resolved the tertiary contradiction between, on the one hand, students' construction of knowledge through the articulation of shared problem-spaces and, on the other, acting on students as objects in curriculum enactment to support their appropriation of scientific explanations.

Kelly. Over the course of the year, Kelly also articulated the same tertiary contradiction as the other three preservice teachers between, on the one hand, engaging students as co-contributing community members to construct knowledge through inquiry and, on the other, positioning students as the objects of the teachers' activity for whom knowledge needs to be appropriated. For example, though Kelly had felt increasingly comfortable engaging her students in the co-construction of investigation questions, she was critical of how she supported her students to do so in her second lesson. She said that she "felt like it was a little contrived just because I was like, 'so what kind of question would you ask if you wanted to know how fungus survives?', I was like saying the question when I was asking them that" (Post-Enactment Interview 2). Kelly discussed how she might have scaffolded students more effectively to produce an investigation question, saying, "I could have left it a little bit more open, like 'what type of question could we ask to drive this investigation?', but then I didn't know if they'd get to that point" (Post-Enactment Interview 2), referring to an investigation question that would support a the lesson she had planned. By suggesting a more open-ended approach to supporting students' development of an investigation question, Kelly acknowledged that she would have relinquished some control over her ability to emphasize an investigation question that highlighted her predetermined learning goals.

Similarly, Kelly highlighted the discussion in her third lesson in which students came up with variables they would test in their mold experiments. Kelly wrote that she wanted students "to come up with most of the ideas (about variables affecting mold growth, etc) themselves" (Lesson 3), again positioning students as co-contributors to the investigation. However, she also acknowledged that her role in this discussion was also to draw students back towards the specific variables the lesson provides as options for their investigations, saying, "there were also points that I felt it necessary that I tell them the variables that we would be working with" (Lesson 3). Negotiating a balance between students' contributions and Kelly's predetermined variables was facilitated by what Kelly described as congruence between the two. Kelly said that "I did have a list of variables that I wanted to list on the board eventually but they came up with them themselves across the board" (Post-Enactment Interview 3). In effect, Kelly's students articulated the same variables as she had hoped, thereby easing the emergence of a tertiary contradiction between predetermined objectives and those constructed by the students. After enacting her third lesson, Kelly described the biggest challenge she faced, which was to harness students' existing ideas to steer them back toward her predetermined learning goal and investigation question. She said,

> …just knowing how to use their questions and ideas to relate them back to the main idea for our lesson... staying on track. Not being too thrown off or getting off topic. Making sure it stays focused and trying to answer the investigation question and what we're doing. (Post-Enactment Interview 3)

Kelly noted that accounting for students' ideas and contributions while still addressing predermined concepts and learning goals "is still an area in which I am struggling to find the right balance" (RT2).

Aliza. Like the other three preservice teachers, Aliza reiterated the tertiary contradiction she experienced in her lesson enactments. She said that "it seems like one of the main purposes of inquiry is having the students be the ones kind of exploring things on their own…student-oriented experiments" (Post-Enactment Interview 3). However, as had been evident in her third lesson, Aliza recalled the tension between more student-directed inquiry and predefined learning goals, saying, "I think it's the same problem in the videos we were watching in your class really, where they were doing those experiments about, what was it, water and condensation. It was just like days and days of the students trying to figure things out on their own and just not really getting [it]" (Post-Enactment Interview 3). This represented a fundamental shift in Aliza's conception of what 'student learning' meant. Whereas earlier in the semester she had focused much more on students' collaborative construction of knowledge, she seemed to be focusing more now on predetermined learning goals. She reiterated that "I think that the goal was always student learning definitely" but said that "maybe I was like more aware of that towards the end" (FI3). Aliza recalled making on the spot changes to her lessons, saying, "as I would be running out of time for things, I would sort of like make those split-second decisions to focus on what was most important to you know, have student achievement of those objectives that I had for that lesson from the beginning. And while I mean I think that was the goal from the beginning, I probably improved on actually being able to do that, maybe towards the end" (FI3). She contrasted this approach, which had been increasingly evident by her third lesson, to her facilitation of more student-directed discourse in her first two lessons, saying, "like earlier, and, again, not that this is necessarily bad, but we would have really long discussions and I realized that you do really need to, I mean it's great to have these discussions but you also need to be moving on to like the more concrete parts of the student learning also" (FI3).

Ultimately, then, Aliza articulated a vision for inquiry-based science teaching that represented a compromise between her own goals for student learning and the affordances and constraints of curriculum enactment contexts. Consistent with her renewed emphasis on student learning as the goal of inquiry, Aliza began prioritizing eliciting students' existing explanations as a means through which to make inquiry more student-centered, though perhaps not student-directed. By preassessing what students already know, Aliza felt she could better engineer her lessons to insure that students achieve predefined learning goals through participation in inquiry practices. This is evident in her emphasis on students' existing ideas and preassessment (FI3). Also, again, Aliza recalled the video case from class, saying,

> …you know how when we were in class and we were watching those videos where they were trying to let the kids figure out for themselves about, what was it, perspiration on a bottle when it's hot outside? And it was taking them forever to get there. I don't know, I kind of feel like maybe if the teacher somehow tried to sort of set up the experiment in a way where it would like address their particular misconceptions, maybe it would have cleared them up more quickly. (FI3)

In this way, then, Aliza's developing model of inquiry represented a way to prioritize discourse while still accomplishing pre-determined learning goals in a more time-efficient manner.

Mike. Over the course of the year, Mike began to resolve the contradictions he experienced enacting his science lessons by planning his lessons differently. As Mike had stated, his new curriculum planning strategy involved scripting out his lessons, thus helping him better internalize the lesson prior to enacting it. However, this new approach to planning brought to light the fundamental tertiary contradiction in curriculum enactment discussed earlier. While this helped insure Matt did not forget parts of his lesson and supported better classroom management practices, it also conflicted with Mike's developing orientation toward more student-directed inquiry practices. This contradiction developed because of the inherent difficulty of helping students achieve predefined learning goals by scripting out and heavily planning lessons in which Mike sought to draw so heavily on students' predictions and student-directed data collection and evidence-based explanations. Mike still argued that the purpose of concluding discussions was to "verify and then explain what's going on…all the students are on the same page but we still have a chance to explain what they're talking about and what their results were" (FI3). However, based on his experiences enacting his lessons throughout the year, Mike noted that "with teaching science so far as inquiry-based, being able to plan the conclusion part, I think it's difficult" (FI3). Mike elaborated, saying,

> You can plan up through predictions but once you get your predictions, that's when the lesson kind of goes its own way… I got up to the prediction point real well I think but after that point I'm still trying to…it's more challenging for me to plan beyond that point…cause I have the learning goals I want [students] to achieve and I'm going to try to achieve them but I'm not going to not take [students'] ideas and predictions. (Post-Enactment Interview 4)

Here, Mike notes the fundamental tension between achieving predefined learning goals while still positioning students as contributing community members in the classroom through the explication of their ideas and questions. Mike noted he still need to learn how to support students to make evidence-based explanations, thus achieving his goal of promoting student learning, while also allowing them to engage in more student-directed inquiry, saying, "I'm still working on making those decisions at the end and deciding what questions to ask and how to do that" (FI3). This contradiction represented for a Mike a core area for future professional growth.

Summary of Results

In the previous sections, we have shown how these four preservice elementary teachers' first experiences engaging in curriculum design for inquiry-oriented science led to a fundamental contradiction that none of them had resolved by the end of the year. In their planned lessons, the preservice teachers made changes that not only better supported students to engage in specific inquiry practices, but that also shifted them into collaborative, contributing roles as members of inquiry communities. However, this shift resulted in contradictions between, on the one hand, the students' new roles as community members and, on the other, the cultural elements of the activity system (rules, divisions of labor, and instrumentalities). To resolve these emergent contradictions, the preservice teachers often made additional changes to their lessons during enactment that made them less inquiry-oriented, particularly in regard to collaborative sense-making and explanation-construction.

Synthesis and Discussion

The preservice teachers in this study were able to plan and enact inquiry-based science lessons. These typically targeted specific inquiry practices promoted in the methods course and consistent with science education reform (NRC, 1996, 2000, 2007). However, to actually translate their planned lessons into classroom practice, the preservice teachers also had to actively shape the classroom learning environments in which they enacted their lessons. To do this, they attempted to assume the role of facilitator to engage students as meaningful participants in the shared construction of lesson-specific problem-spaces. This generally involved affording students a more active role in classroom inquiry and relying on internally-constructed standards of practice. In effect, the preservice teachers were doing more than engaging students in particular inquiry practices – they were taking steps to create a culture of inquiry in the classroom (Llewellyn, 2007).

In this way, the preservice teachers' curriculum design efforts worked to establish more constructivist, collaborative, inquiry-based learning environments focused on shared sense-making through inquiry. This contrasts starkly with more traditional, didactic instruction which has too often characterized school science and to which contemporary, reform-based models of science teaching and learning represent alternatives. The distinction between these two forms of science teaching and learning are consistent with a distinction Engeström (1987) makes between 'learning actions' and 'learning activity'. Learning actions, a less advanced form of learning, are indicative of the sort of rote memorization and recitation inherent to the many traditional school-based practices. Such learning actions are concerned primarily with the reproduction of text (or other representations of knowledge) which serve as the objects of activity rather than serving as tools or instruments in activity. In essence, Engeström argues that formal schooling has not yet transformed to enable true learning activity.

Why? A primary reason schools have not achieved this is because the dominant cultural dimensions of formal schooling still largely support the reproduction of text, or reproduction of knowledge, rather than knowledge-construction and shared sense-making. As shown in the results of this study, the preservice teachers' efforts to reconfigure their classroom learning environments to promote inquiry resulted in contradictions with pre-existing classroom practices and their underlying cultural dimensions. These dominant forms of schooling, as well as the norms through which they are reinforced, have a strong socializing influence that is difficult for novice teachers to overcome (Lortie, 1975). It should come as no surprise, then, that consistent with previous research (Appleton, 2003; Appleton & Kindt, 2002; Crawford, 1999, 2007; Enyedy & Goldberg, 2004; Haefner & Zembal-Saul, 2004; Songer, Lee, & Kam, 2002), the preservice teachers here experienced numerous barriers to engaging students in more inquiry-based science teaching and learning.

While the four preservice teachers in the focal group struggled with various challenges, none was more pressing than that of time. Invariably, their efforts to enact their planned lessons conflicted with the time they were allotted to teach their lessons. It is important to highlight that these norms governing time were institutional in nature and largely beyond the scope of the preservice teachers' individual classrooms. Their immediate curriculum enactment contexts (object-activity), like those of all teachers, are embedded within the broader cultural contexts of the institutions in which they reside (Lemke, 2000; Roth, Tobin, & Ritchie, 2008). As such, they are subject to its norms and structure. Here, the emergent demands of classroom inquiry contradicted with norms of time imposed by their institutions.

Past research has shown that for students to develop a rich understanding of scientific explanations, it is crucial that they have sufficient time to question, investigate, and construct explanations about those phenomena (Clark & Linn, 2003). Yet, as language arts and mathematics have enjoyed ascendant positions within the elementary school curriculum in recent years, science has become increasingly deprioritized (Marx & Harris, 2006; Spillane et al., 2001). Recently published data from the Schools and Staffing Survey (Morton & Dalton, 2007, May), for example, show that in grades 1-4, students receive an average of 3 hours per week of science instruction and that as a subject, science is afforded less than half of the instructional time as mathematics and less than one-fifth of the instructional time as language arts. With such a limited amount of time available for science teaching, it is no wonder that elementary teachers, including the preservice teachers studied here, struggle to engage their students in often time-consuming inquiry practices.

Evidence from this study also provides insight into what specific practices are being lost in science instruction due to these constraints. First, as shown in these results, when contradictions emerged in the classroom, the preservice teachers often shifted themselves back into the role of manager and engaged in more teacher-directed instruction in an effort to economize time. Once the structure of activity changed, so too did the ways in which the preservice teachers engaged students in discourse. This is consistent with existing research that shows how discursive patterns serve as cultural tools and are inexorably tied to the nature of classroom activity (Lemke, 1990; Polman, 2004; Reiser, 2004; Tabak, 2004; van Zee & Minstrell, 1997; Wells & Arauz, 2006). In the end, it was most often the collaborative, discourse-based elements of the preservice teachers' lessons that were minimized or eliminated in response to the contradictions they articulated. This, unfortunately, conflicts what previous research suggests about the important role of classroom discourse in the context of inquiry-based science teaching and learning. Negotiatory, dialogic patterns of discourse are defining characteristics of inquiry-oriented science teaching and learning in elementary and secondary classrooms.

In the absence of such collaborative, dialogic discourse, however, classroom science is ultimately less inquiry-based. This is because student sense-making and explanation-construction are linked explicitly to discourse that arises from inquiry practices. It is also the formulation and communication of explanations, or the generative process of shared meaning-making more generally, that constitutes 'learning activity' (Engeström, 1987). Recall that the preservice teachers in this study did not draw strong distinctions between the formulation and communication of explanations as inquiry practices. As such, to them, the collaborative discourse in which they sought to engage students was a critical element not only of communicating explanations, but also constructing them. However, in making in-situ changes to their lessons to address emergent contradictions in the classroom, the preservice teachers most often ended up deemphasizing this discourse. This suggests that these contradictions, ultimately based on the conflict between emergent practices and the institutional features of schools largely resulted in lessons that were less inquiry-based, specifically in regard to sense-making and explanation-construction. When this shared sense-making is absent, classroom practice is indeed reduced to a series of 'learning actions', as Engeström argues.

The lingering question, then, is what is required to bring about conditions under which collaborative sense-making through inquiry, or Engeström's 'learning activity', can occur? A reasonable response, supported by both empirical results of this study and theoretical assumptions of cultural-historical activity theory, is that those who actually engage in the activity (i.e., teachers and students) must have a significant hand in shaping the activity itself. Engeström observes that the essential contradiction between activity and the economization of time results in, "an objective pressure, manifesting itself in various forms, toward *taking over the mastery of the whole work activity* [emphasis in original] into the hands of the people who participate in that activity" (1987, pg. 82). This means that the tools and instruments, rules and norms, and divisions of labor of a particular activity must, to some significant extent, be constructed and negotiated from within a given activity, not imposed entirely from without. To accomplish collaborative sense-making through classroom inquiry, teachers and students must be empowered to mobilize appropriate tools, as well as establish appropriate expectations and roles, that support inquiry practices and the development of a classroom culture of inquiry.

Some previous research has shown that more internally-driven forms of classroom-based inquiry practices can be effective, self-regulating, and self-sustaining. Inquiry, broadly defined, is a coherent practice focused on knowledge-construction. Others have explored the possibility that teachers and students can function as communities of learners engaged in inquiry practices (Brown & Campione, 1994). Particularly in the context of more project-based science learning environments, there are examples that illustrate how the barriers between school and life outside school can be reduced (Crawford, 2000; Krajcik & Blumenfeld, 2006; Metz, 2000; Petrosino, 2004). By engaging students in real-world problems that require scientific understanding, school science can reposition text, or representations of existing knowledge, from the object of activity to essential instruments that support the investigation of specific phenomena-related problems and issues.   For teachers this involves, among other things, engaging students as community members in articulating, investigating, and explaining particular phenomena, as the preservice in this study sought to do. This is a powerful vision for how school science can become true learning activity rather than disconnected sets of learning actions.

However, in contrast to assumptions of cultural-historical activity theory, tools and instruments, rules and norms, and divisions of labor are largely pre-set in schools. Teachers (subjects) and students (community), the problem-spaces with which they work (objects), as well as their goals, are largely defined by existing tools, rules, and divisions of labor within schools. This is precisely why schools have such a strong socializing influence on both teachers and students, as discussed previously.

The preservice teachers in this study, as well as their students, attempted to engage in collaborative, inquiry-based knowledge-construction and sense-making within preexisting cultural dimensions of their schools. Emergent demands of their classroom-based inquiry practices often conflicted with externally-imposed, institutionally-derived rules, norms, and expectations. What emerged in the preservice teachers' instruction, then, were *hybrid inquiry* *practices*. These practices were evidence of a negotiated application of inquiry given, on one hand, the preservice teachers' espoused inquiry frameworks and curriculum materials and, on the other, their unique professional contexts that often served to constrain implementation of their lesson plans.

Though often attributed to teachers as a 'teacher characteristic', pedagogical design capacity (Brown, 2008) is ultimately a property of systems, not just individuals. What this suggests is that the entire activity system, not just teachers and curriculum materials, ultimately afford a certain ability to engage students in inquiry to achieve particular goals and objectives. Therefore, the capacity for pedagogical design inherent to a given classroom system will be fundamentally unique since the combination of each teacher's knowledge, beliefs, identity, and other personal characteristics, the curriculum materials he or she uses, as well as features of his or her professional context, is itself unique. It should come as no surprise, then, that classroom inquiry can take different forms in different contexts (Songer, Lee, & McDonald, 2002).

What the construct of pedagogical design capacity also suggests, however, is that the overall capacity for pedagogical design afforded by a particular classroom system can be enhanced. The pedagogical design capacity of a particular system can improved by addressing teachers' personal characteristics (knowledge, beliefs, and identities), the curriculum materials they use, and their professional contexts. We next discuss ways to support teachers' pedagogical design capacity for inquiry.

Implications for Promoting the Teacher-Curriculum Relationship

Promoting Preservice Teachers' Knowledge of Inquiry

The findings from this study have implications for promoting preservice elementary teachers' developing conceptions of inquiry. As shown throughout the results, evidence here suggests that while preservice elementary teachers may initially hold ill-defined, vague, and perhaps somewhat simplistic ideas about inquiry-based teaching and learning, they are able to develop, through their work in elementary science methods courses and elementary classrooms, more robust and practice-specific inquiry models that are better aligned with models of effective science teaching promoted in contemporary science education reform. This finding reinforces the need to emphasize the teaching and learning of science as inquiry in formal teacher education (NRC, 1996; NSTA, 2003), as many science teacher educators already do (Davis & Smithey, in press; Gess-Newsome, 2002; Schwarz, in press; Zembal-Saul, in press). However, while this seems self-evident in the design of elementary science methods courses, existing methods courses tend to vary greatly in their goals and structure (Smith & Gess-Newsome, 2004). As a foundational tenet of current science education reform, inquiry-based teaching and learning should be a consistent feature of science methods courses.

However, in addition to helping preservice teachers develop usable inquiry frameworks, the primary objective of teacher education must be to help preservice teachers learn to teach science effectively. This should be the primary goal of all programs that offer opportunities for teaching learning (e.g., professional development), of which methods courses are just one of many. However, what often distinguishes methods courses from, for example, professional development, is the explicit emphasis on classroom practice as the object-activity. Historically, university-based teacher education has been far removed from school classrooms, a problem that has contributed to their lack of impact on teachers' practice (Grossman, McDonald, Hammerness, & Ronfeldt, 2008; Richardson, 1996).

To remedy this situation, teacher education, specifically methods courses, must become more oriented toward classroom practice and features of teacher education programs must be aligned to support this focus. Preservice teachers, while inexperienced, can participate in professional communities focused on problems of professional practice (Sim, 2006). Indeed, there are growing calls from within teacher education and across multiple subject-specific disciplines to increase the emphasis on professional practice in teacher education (Grossman et al., 2008). The preservice teachers' curriculum design in this study is just one example of how the divide between theory and practice can be bridged when preservice teachers are provided opportunities to apply theory *to* practice and derive theory *from* practice. Findings from this study lend theoretical support to the argument for practice-based teacher education.

However, there is need for research that can provide evidence for ways in which to promote preservice teachers' learning in methods courses and science teacher education more broadly. For example, there is still little research, as Davis and colleagues (2006) note, that has actually explored preservice teachers' conceptions of inquiry in terms of the five essential inquiry practices articulated in *Inquiry and the National Science Education Standards* (NRC, 2000). Similarly, there is a need for more research that investigates the impact of particular features of methods courses on preservice teachers' espoused inquiry frameworks, teaching practices, and student learning. The further development of these research bases is essential to inform science teacher education reform efforts. The lack of strong, empirical evidence for the impact of teacher education has been at the root of calls for reforming teacher education and teacher education research more broadly (Clift & Brady, 2005; Cochran-Smith & Fries, 2005).

Findings from this study also illustrate the need for curriculum developers to continue to develop inquiry-based curriculum materials. Unfortunately, many science curricula used by teachers, particularly at the middle and secondary level, do not meet this criterion (Kesidou & Roseman, 2002). In this study, as shown in Chapter 4, the more inquiry-based existing science curriculum materials were, the more likely the preservice teachers' planned and enacted lessons were to be equally or more inquiry-based. If inquiry-based teaching and learning is to be emphasized in teacher education (and professional development), it stands to reason that it should be instantiated in the curricular tools teachers use to engage in teaching practice. Ongoing curriculum development and research efforts should continue to explore how various inquiry frameworks can be effectively represented in the design of science curriculum materials (Barab & Roth, 2006; Krajcik, McNeill, & Reiser, 2007; Linn, Clark, & Slotta, 2003; Songer, Lee, & Kam, 2002).

Ultimately, however, it is not just teachers' developing espoused inquiry frameworks and the design of inquiry-based science curriculum materials that are important. It is also the interaction between the teacher, employing his or her model of inquiry, and the curriculum materials, that must be supported. Through the curriculum materials themselves, teacher-curriculum interactions can be supported through features that are intended to be educative and flexibly-adaptive for teachers (Ball & Cohen, 1996; Davis & Krajcik, 2005; Fishman & Krajcik, 2003; Schwartz, Lin, Brophy, & Bransford, 1999). These features could serve to support teachers' learning about inquiry teaching and learning, as well as specific scientific content. However, they can also scaffold teachers' curriculum design decision-making about when and how to adapt the curriculum materials to the needs of their students.

Of course, to develop such powerful curriculum materials, curriculum developers need a thorough understanding of those to whom such materials are meant to be educative for and by whom they are meant to be adapted. However, there is still little research that informs our understanding of how teachers use these educative features of curriculum materials (Davis & Krajcik, 2005; Dietz & Davis, in press; Schneider & Krajcik, 2002). By better understanding how preservice elementary teachers mobilize, adapt, and enact science curriculum materials in light of their espoused inquiry frameworks, these materials can be better designed to simultaneously support their use and teacher learning.

Even if using high-quality, inquiry-based curriculum materials that include educative features, teachers need opportunities to learn to use curriculum materials effectively. Existing research has shown that beginning teachers rely heavily on curriculum materials (Forbes & Davis, 2007; Grossman & Thompson, 2004; Kauffman, Johnson, Kardos, Liu, & Peske, 2002). Beginning teachers should not expect to begin their teaching careers with no experience using curriculum materials to engage in inquiry-based science, especially given the other demands placed upon them (Davis, Petish, & Smithey, 2006). Rather, teacher education should help ensure beginning teachers are indeed well-started beginners in this regard providing them opportunities to learn how to mobilize and adapt science curriculum materials to better promote inquiry in the classroom. This is especially important since previous research suggests preservice elementary teachers often do not independently emphasize inquiry in their critique of science curriculum materials (Dietz & Davis, in press; Schwarz et al., 2008).

Designing Professional Environments that Support Teachers' Curriculum Design for Inquiry

This study has important implications the design of professional environments that support preservice teachers' development of pedagogical design capacity for inquiry. Findings from this study inform efforts to more fully integrate university-based components with school-based field experiences by identifying those features of field experiences that support and constrain preservice elementary teachers' opportunities to put their espoused inquiry frameworks to use through curriculum design. They also provide insight into those institutional features of schools that constrain inquiry-based science teaching and learning in the classroom.

Field experiences are critical components of teacher education programs (Clift & Brady, 2005; NRC, 1996; NSTA, 2003). They can and should serve as powerful complements to university-based teacher education experiences. However, they too often become initial contexts in which preservice teachers begin to articulate a disconnect between teacher education and schools. This is essentially the beginning of the socialization process that continues during student teaching and the induction years of a teacher's career. Unfortunately, the dominant, institutional culture of school typically converts even the most committed teacher reformer to more widespread, institutionally-supported, and reinforced norms of professional practice (Lortie, 1975).

Why? Preservice teachers develop frameworks within which they engage and reflect on practice, as well as through which future learning can occur (Zembal-Saul, Blumenfeld, & Krajcik, 2000). These frameworks, consistent with Bourdeiu's (Bourdieu, 1990) notion of *habitus*, can be thought of as a "system of acquired dispositions functioning on the practical level as categories of perception and assessment... as well as being the organizing principles of action" (pg. 53). These frameworks, based in part on one's knowledge beliefs, and identity, afford a set of predispositions toward what is and is not possible in a given activity. However, context plays a role in that as individuals engage in practices within institutions, the institutions themselves are given form in the individual's subjective outlook on the world. As such, their early experiences with a particular practice weigh disproportionately in how their perceive the possibilities for such practices. The implication of this for teacher education is that early field experiences can have a tendency to disproportionately influence preservice teachers' predispositions toward teaching practice. Since, as already shown, elements of institutional cultures of schools tend to restrict inquiry-based teaching and learning, preservice teachers' perceptive frameworks for science teaching will tend to reflect and reproduce these challenges in their future teaching. This ultimately diminishes teachers' pedagogical design capacity for inquiry and leads to less inquiry-based science in the classroom.

These early field experiences, however, can instead serve a more productive role that is conducive to the promotion of inquiry-based teaching and learning. To promote the development of preservice teachers' pedagogical design capacity, as well as their habitus, for inquiry, they need to have experiences working in professional contexts where inquiry practices are supported. Effective field experiences for preservice teachers are long-term and stable, involve the careful selection of cooperating teachers, and are tightly integrated with methods courses that promote reflective, intellectual, and professional teaching practice (Sim, 2006; Zembal, Starr, & Krajcik, 1999). To insure that today's preservice teachers become tomorrow's well-started beginning teacher, it is crucial that these features of effective field experiences are made manifest in the opportunities for learning afforded preservice teachers in their teacher education programs.

Finally, and perhaps most importantly, findings from this study provide further evidence that reform is needed for the institutional culture of schools to fully support inquiry-oriented science teaching and learning at the classroom level. As science education research continues to provide evidence for institutional barriers to inquiry-based teaching and learning, significant questions have to be addressed. As Grandy and Duschl (Grandy & Duschl, 2007) state,

> …the institutional culture of public education is severely constrained by economical, ideological and pedagogical conditions. Such constraints have the effect of promoting certain forms of curriculum, instruction, and assessment practices while denying others on the basis of cost effectiveness; e.g., professional

> development for K-12 teachers. On the other hand, research on learning and research on science learning are contributing to a richer understanding of the classroom contexts and conditions that promote scientific reasoning and understanding. Do we fit the research on learning into the instructional culture of schools or do we change the culture of schools to accommodate the learning research? There are significant policy and practice issues that come to the table. (pg. 158)

As seen in this study, many of these questions lie outside teachers' spheres of influence. To promote teachers' and students' abilities to engage in inquiry practices in the classroom, policymakers, administrators, and others must work to reform schools as institutions.

Assumptions of Science as Inquiry

For over 20 years, the teaching and learning of science as inquiry has been a foundational element of constructivist, standards-based science education reform efforts (NRC, 1996, 2000, 2007). Yet, as described earlier, the sought-after widespread reform of school science has yet to be realized (Duschl, 1994; Grandy & Duschl, 2007). One explanation for this, as discussed earlier, is that the institutional features of schools are essentially misaligned with the goals and demands of inquiry-based science teaching and learning. However, the results presented here illustrate another related but distinct tension that was consistent in the preservice teachers' curriculum design for inquiry.

As an epistemological practice, inquiry is fundamentally a process of knowledge-construction. However, from a theoretical standpoint, as well as from the practical standpoint of the preservice teachers in this study, there exists an inherent contradiction between, on one hand, engaging in open-ended epistemological practices such as inquiry and, on the other, setting predefined goals for what new knowledge will be constructed through engagement in such practices. To insure that students arrive at *existing* scientific explanations for phenomena, classroom inquiry must be engineered in a way that the process itself is not entirely open-ended. This assumption is encapsulated in notions of the inquiry continuum (NRC, 1996, 2000, 2007), or inquiry practices that run the gamut from more teacher-directed to more student-directed. However, again, as shown in these results, the more tightly-controlled the learning environment becomes, the more likely it is that classroom practice will shift towards traditional, didactic teaching and learning practices that objectify students and promote the appropriation rather than construction of knowledge. There appears to exist a very fine line before more teacher-directed inquiry and traditional, didactic science teaching. Some workable balance must be found between these two visions of science teaching and learning.

Where is such a balance to be found? Clearly science teaching and learning must shift away from traditional, didactic methods which have not remedied U.S. students' comparatively poor performance on standardized science assessments (Baldi, Jin, Skemer, Green, & Herget, 2007; Gonzales, Williams, Jocelyn, Roey, Kastberg, & Brenwald, 2008). Yet, it is unlikely that classroom inquiry can ever be entirely emergent, either. Though scientific practice has served as the standard for inquiry-based models of teaching and learning, science itself, rather than being characterized by entirely open-ended inquiry, often involves the mobilization of methods within constraints and in light of desired outcome (Kuhn, 1996; Latour, 1999; Proctor, 1991). Perhaps engaging students in inquiry with predefined learning goals is not a break from true scientific practice, then, but rather a break from the idealized version of scientific practice often observed in abstract, inquiry-based instructional models.

Ultimately, the most effective model of inquiry teaching and learning can only be assessed in light of what we want students to know and be able to do. Unfortunately, with few exceptions (Geier, Blumenfeld, Marx, Krajcik, Fishman, Soloway, & Clay-Chambers, 2008), there is little existing research to help shed light on the impact of different models of inquiry or specific inquiry frameworks on student learning. This is a question of causality that needs to be addressed using appropriate methods (Association, 2006; Shavelson & Towne, 2002). Randomized trials in which groups are students are selectively engaged or not engaged in inquiry practices, or are selectively engaged in varying curriculum-based experiences designed around different inquiry models, are needed to establish causal relationships between student learning and inquiry-based instructional strategies. However, it is also important for such research to assess the effectiveness of various models of inquiry teaching and learning using different forms of assessment that are themselves aligned with particular learning goals and learning performances (Geier et al., 2008; Krajcik, McNeill, & Reiser, 2007; Ruiz-Primo, Shavelson, Hamilton, & Klein, 2002; Schneider, Krajcik, Marx, & Soloway, 2001). Ultimately, this kind of research will help inform the design of formal science teacher education, science curriculum materials, teacher professional development, and the reform of institutional features of schools themselves so as to better support the teaching and learning of science.

Conclusion

To engage their students in inquiry practices, teachers need to develop robust expertise for science teaching. To engage in curriculum design for inquiry, teachers need to develop robust pedagogical design capacity. This is especially true for preservice teachers, who lack the experiential basis upon which to base their pedagogical design capacity. To enter the teaching profession as well-started beginners, preservice teachers need to at least develop their ability to translate their conceptions of inquiry into curriculum adaptations, as well as their ability to do so in light of affordances and constraints of specific classroom contexts. For preservice teachers to begin to develop their capacity for pedagogical design, formal teacher education must provide opportunities for them to do so.

The results of this study begin to shed light of preservice elementary teachers' development of pedagogical design capacity for science teaching by examining how they engage in curriculum design for inquiry. On one hand, these results are encouraging, and show that preservice elementary teachers are able to adapt existing curriculum materials to make them more inquiry-based and articulate espoused inquiry frameworks that are reasonably well-aligned with those in science education reform. However, on the other hand, these results illustrate the constraints imposed upon teachers' curriculum design by their professional contexts and the fundamental contradictions preservice teachers articulate in their attempts to engage in inquiry-oriented science teaching practices.   Preservice elementary teachers' abilities to engage in inquiry-based science teaching practice in light of affordances and constraints of context should be leveraged to enhance their capacities to do so through teacher education and curriculum development. In promoting preservice elementary teachers' development of pedagogical design capacity for inquiry, we also better prepare them for challenges they will face in teaching reform-minded, standards-based, inquiry-oriented science as beginning elementary teachers. This is ultimately an effort to better support students' learning in science.

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Appendix A

Table 3.7

Contradictions and Preservice Teachers' Curriculum Design Decision-making for a Given Cycle of Curriculum Design for Inquiry

	Types of Curriculum Materials										Types of Changes to Curriculum Materials				
	Existing lesson plan (ELP)	Stand-alone investigation, experiment, or activity (AIE)	Textbook (T)	Content resource (science background information) (CR)	Video/DVD (VD)	Models, graphs, or images (MGI)	Trade book (story) (TB)	Computer software (CS)	Student worksheet (SW)	Other (O)	Insertions (Ins)	Deletions (Del)	Substitutions (Sub)	Duplications (Dup)	Inversions (Inv)
Contradictions	Pre-Enactment														
1. Codes															
Change															
Contradiction															
Evidence															
	Post-Enactment														
2. Codes															
Change															
Contradiction															
Evidence															

Appendix B

Table 3.8

Contributions of a Contradiction to Preservice Teachers' Curriculum Design Decision-making Over Time

	Types of Curriculum Materials										Types of Changes to Curriculum Materials				
	Existing lesson plan (ELP)	Stand-alone investigation, experiment, or activity (AIE)	Textbook (T)	Content resource (science background information) (CR)	Video/DVD (VD)	Models, graphs, or images (MGI)	Trade book (story) (TB)	Computer software (CS)	Student worksheet (SW)	Other (O)	Insertions (Ins)	Deletions (Del)	Substitutions (Sub)	Duplications (Dup)	Inversions (Inv)
Contradiction															
Curriculum Planning and Enactment Events															
1. Codes															
Description															
Evidence															
2. Codes															
Description															
Evidence															