



A coding tool for examining the substance of teacher professional learning and change with example cases from middle school science lesson study



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HIGHLIGHTS

- A coding scheme to document components of teacher professional learning and change.
- Seven coding categories are presented with indices of the quality of teacher learning.
- Example findings from middle school science lesson study teams are presented.

ARTICLE INFO

Article history:

Received 18 December 2015

Received in revised form

17 August 2016

Accepted 22 August 2016

Keywords:

Lesson study
Professional learning
Teacher change
Middle school
Science
Coding

ABSTRACT

Although lesson study is increasingly adopted in the United States (U.S.), the impact of lesson study on teacher learning is uncertain. This study presents a theoretically grounded set of codes to systematically document the various aspects of teacher learning and change (knowledge and beliefs, professional learning community, resources) in lesson study across contexts. To present examples of the codes in use, a subset of codes related to change in teacher knowledge and beliefs were applied to analyze teachers' professional discourse in three middle school science lesson study teams.

Published by Elsevier Ltd.

1. Introduction

Commitment to continuous teacher professional learning is crucial for the success of education reform, instructional improvement, and student achievement (Akiba & Liang, 2016; Darling-Hammond & Ball, 1998; Desimone, 2009; Wilson & Berne, 1999).

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In the United States (U.S.), new education reforms have significant implications for changes in instruction, including in-depth coverage of new topics, facilitating literacy in science, language, and mathematics disciplines, and addressing the needs of an increasingly diverse student population (Lee, Quinn, & Valdés, 2013; Morgan, Farkas, Hillemeier, & Maczuga, 2016; Porter, McMaken, Hwang, & Yang, 2011). A large body of research points to the importance of teachers working in professional learning communities to implement reformed teaching, as they share knowledge and resources, critically examine and reflect on one another's practices, and use evidence from student work and

classroom observations to inform instruction (Bertrand & Marsh, 2015; Clarke & Hollingsworth, 2002; Stoll, Bolam, McMahon, Wallace, & Thomas, 2006; Wilson & Berne, 1999). Lesson study has been advocated as a particularly productive professional learning model for helping teachers adapt and shift towards reform-based teaching (Doig & Groves, 2011; Perry & Lewis, 2009; Lewis, 2015; Stigler & Hiebert, 1999). However, while there is growing interest in scaling lesson study to support long-term improvements in teaching and learning (Dudley, 2013; Lewis, 2015; Perry & Lewis, 2009), there is a need to further explicate the theoretical underpinnings and substance of teacher professional learning to better understand how lesson study supports improvements in teaching (Dudley, 2013; Lewis, 2009; Stigler & Hiebert, 2016).

To comprehensively examine the complexity of teacher professional learning in varying contexts, flexible but robust methodologies and tools are needed (Dudley, 2013; Lewis, Perry, & Hurd, 2009; Lewis, Perry, & Murata, 2006; Ming Cheung & Yee Wong, 2014). Empirical approaches to understanding teacher learning need to not only capture the diverse components of what teachers learn, but also the range in quality of professional learning within each of the different components (Clarke & Hollingsworth, 2002; Lewis, 2009; Stigler & Hiebert, 2016). To this end, this study draws from theoretical models of lesson study and teacher change to examine teacher professional growth within inquiry-based learning communities (Clarke & Hollingsworth, 2002; Lewis et al., 2006; Perry & Lewis, 2009). A set of codes were developed to systematically document growth in teachers' 1) professional knowledge and beliefs, 2) professional learning communities, and 3) tools and resources for instruction (Clarke & Hollingsworth, 2002; Perry & Lewis, 2009) that include qualitative indicators of the depth of teacher learning and change. In order to illustrate the use of our coding tool, detailed descriptions of three middle school science lesson study cases are presented, in which a subset of codes related to professional knowledge and beliefs were applied to analyze transcripts of teachers' collaborative discourse in lesson study. Findings highlight the utility of the codes for systematically documenting, and providing concrete evidence of, the substance of teachers' professional learning and change, particularly useful for multiple, comparative, and longitudinal case study approaches in teaching and teacher learning research.

1.1. Lesson study as a high quality model of teacher professional learning

Lesson study gained international attention when results from the Third International Math and Science Study highlighted it as a powerful model of professional learning (Saito & Atencio, 2013; Stigler & Hiebert, 1999). Originating from Japan, lesson study involves teachers working closely in collaborative teams to plan, observe, and reflect on live lessons in the classroom (Fernandez & Yoshida, 2004; Isoda, 2010; Lewis et al., 2006). What distinguishes lesson study from many other types of professional development is that student learning is the centerpiece of study (Lewis & Hurd, 2011). In lesson study, a team of teachers co-plans a 'research lesson,' (*kenkyu jugyo*) and observes students' learning as a member of the team enacts the research lesson in their classroom (Fernandez, 2010; Perry & Lewis, 2009). Following the research lesson observation, teachers critically analyze data collected about students' learning, drawing out evidence-based implications for improving instruction (Fernandez & Yoshida, 2004; Isoda, 2010; Lewis & Hurd, 2011).

In many ways, lesson study embodies features of teacher professional learning supported by research. First, lesson study is an ongoing cycle of inquiry, in contrast to short-term workshops that

do not provide multiple opportunities for teachers to implement, test, and critically reflect on pedagogical strategies in their classroom (Borko, 2004; Clarke & Hollingsworth, 2002; Desimone, 2009; Wilson & Berne, 1999). Second, lesson study engages teachers as active, adult learners who construct personal and collective understanding about shifts in teaching and learning, rather than passive recipients of information (Borko, 2004; Bransford, Brown, & Cocking, 1999; Clarke & Hollingsworth, 2002; Garet, Porter, Desimone, Birman, & Yoon, 2001). Third, teachers' professional learning in lesson study is embedded in their daily work and situated in classroom practice, promoting localized instructional improvement that meets the unique needs of their students (Doig & Groves, 2011; Putnam & Borko, 2000). Perhaps most importantly, lesson study hinges on skilled observations and discussions of how students learn, which guide teachers' decisions around changes to curriculum and instruction (Lewis et al., 2006; Mutch-Jones, Puttick, & Minner, 2012). In these ways, lesson study is structured for teachers to collaboratively experiment with classroom practices while keeping students at the forefront of their instructional decisions (Darling-Hammond & Ball, 1998; Doig & Groves, 2011; Perry & Lewis, 2009).

Although the lesson study model is aligned to research on quality teacher professional development, the research guiding lesson study in the U.S. currently lacks a strong theoretical foundation and research base (Clarke & Hollingsworth, 2002; Ming Cheung & Yee Wong, 2014; Rock & Wilson, 2005; Stigler & Hiebert, 2016). In this paper, we present a theoretically grounded coding tool for systematically capturing the features of teacher learning and change in lesson study, that could serve as future reference for educators and researchers seeking to not only document whether lesson study works, but to better understand lesson study as a model for teacher learning and change across contexts.

1.2. Variation in lesson study implementation in the U.S

Given that lesson study is adapted from Japan, it is important to document how lesson study is implemented in different education systems, and the ways in which lesson study may support improvements in instruction and student learning across contexts (Chokshi & Fernandez, 2004; Fujii, 2016; Saito, 2012; Stigler & Hiebert, 2016). Whereas the model of lesson study in Japan has a well-defined tradition in teacher learning and school reform, researchers examining U.S. lesson study have documented varying adaptations in terms of the format and types of activities involved (Fernandez, Cannon, & Chokshi, 2003; Lewis, Perry, Hurd, O'Connell, 2006; Perry & Lewis, 2009; Saito & Atencio, 2013; Stigler & Hiebert, 2016; Wang-Iverson & Yoshida, 2005). For example, during the research lesson observation in Japan, it is typical that the teacher poses a problem (*hatsumon*) to the entire class, and allows students to work individually or in small groups as they walk around the classroom to observe students' thinking (*kikan-shido*) (Doig & Groves, 2011; Fernandez & Yoshida, 2004). This is followed by a whole class discussion to summarize the key ideas of the problem (*matome*), where the chalkboard or blackboard is used extensively to organize and compare students' ideas (Chokshi & Fernandez, 2004; Doig & Groves, 2011; Fernandez & Yoshida, 2004). In contrast, there are many variations in how the research lesson is implemented in the U.S., all of which do not typically follow the format of Japanese lesson study (Chokshi & Fernandez, 2004; Doig & Groves, 2011; Lewis & Tsuchida, 1997; Saito, 2012).

It is fathomable that lesson study will be adapted as a function of the norms, beliefs, and systems of different cultures and contexts, and an exact replica of the Japanese model in other countries may not be possible (Stigler & Hiebert, 2016). After all, teaching is a

cultural activity and some of the assumptions and practices underlying Japanese lesson study may not replicate in the U.S. or other countries (Bjuland & Mosvold, 2015; Doig & Groves, 2011; Fernandez, 2010; Perry & Lewis, 2009; Saito, 2012; Stigler & Hiebert, 2016). In examining how lesson study is imported from Japan to the U.S., Chokshi and Fernandez (2004) provide the following consideration:

“Lesson study is a process through which teachers can explore the effectiveness of many different practices, some of which they might learn from Japan. But the central idea of lesson study is that it is meant to be a generative process through which teachers continually improve and redirect their teaching as needs arise from their students and classrooms. Lesson study is therefore not meant to be a vehicle for teachers to assume an entire set of static teaching practices. On the contrary, it is intended to encourage teachers to adopt practices based on dynamic experience and deep reflection.” (p. 524).

While differences in the adoption of lesson study may in of itself not be an issue, there is a need to carefully examine what makes lesson study (in its varied forms) effective in different contexts. Unfortunately, emerging research comparing practices between teachers in Japan to those in the U.S. indicate that there are markedly distinct norms in how teachers approach collaborative professional learning, which create barriers for implementing the fundamental features of lesson study (Bjuland & Mosvold, 2015; Doig & Groves, 2011; Fernandez et al., 2003; Ming Cheung & Yee Wong, 2014; Perry & Lewis, 2009). For example, studies have shown that during the research lesson, teachers in the U.S. tend to primarily focus on teachers' behaviors rather than students' learning, and take subjective notes rather than empirical observational records (Fernandez et al., 2003; Perry & Lewis, 2009). Similarly, studies have shown that in the U.S., teachers spend less time on the research process (*kyozaiikenkyu*) in which instructional materials and subject matter references are carefully examined for lesson planning (Chokshi & Fernandez, 2004; Doig & Groves, 2011; Fernandez et al., 2003; Fujii, 2016; Takahashi & McDougal, 2016). Other common pitfalls also include resistance among teachers to provide critical feedback with colleagues regarding the observed research lesson, and wrongly viewing lesson study as an activity to perfect a lesson, rather than to uncover students' understanding of the subject matter (Chokshi & Fernandez, 2004; Fernandez et al., 2003; Perry & Lewis, 2009; Stigler & Hiebert, 2016; Takahashi & McDougal, 2016).

In summary, the relatively new adoption and growing popularity of lesson study in the U.S., and the diverse ways in which lesson study is implemented across different education contexts, presents both an opportunity and challenge for researchers aiming to build a coherent body of evidence for the value of adopting lesson study as a model of teacher professional learning. Our study presents a theoretically grounded set of codes to empirically examine the mechanisms through which lesson study drives teacher learning and change towards instructional improvement and student learning.

1.3. Current state of lesson study research in the U.S

The descriptive knowledge base regarding the U.S. lesson study is growing; however, the impact of lesson study remains uncertain and further research is needed to justify claims about the usefulness of lesson study as a model of teacher professional learning (Stigler & Hiebert, 2016; Takahashi & McDougal, 2016). To date, the research on lesson study is largely characterized by in-depth descriptive case studies that draw upon post-lesson study

reflections using interview data (e.g., Bjuland & Mosvold, 2015; Lee, 2008), and/or detailed summaries of recorded lesson study team meetings and related artifacts (e.g., Doig & Groves, 2011; Fernandez & Yoshida, 2004; Fernandez et al. 2003; Lewis et al., 2009; Perry & Lewis, 2009; Rock & Wilson, 2005), most of which lack detailed methods or code systems to apply to other contexts.

From existing studies, results demonstrate positive outcomes such as deepened content knowledge among teachers (e.g., Fernandez & Yoshida, 2004; Perry & Lewis, 2009) and awareness of the complex needs of individual students (Dudley, 2013; Nilsson, 2014). These findings point to the potential that lesson study can have for establishing productive communities of professional learning in the U.S., and provide evidence to support continued research in this area. For example, Perry and Lewis (2009) presented a case study examining the degree of acceptance and sustainability of lesson study within a district. Using a grounded theory approach, they analyzed transcripts from semi-structured interviews with approximately 70 teachers and administrators, notes from observations, audio or video recordings of about 20 lesson study meetings and research lessons, and lesson study artifacts. Four major areas of teacher change were documented, including increased emphasis on student thinking, use of broader knowledge sources, reflection and feedback loops, and use of protocols (Perry & Lewis, 2009). Similarly, a descriptive case study of a language arts lesson study team documented shifts in instruction to support students' comprehension of expository texts, as teachers collectively built their professional knowledge about differentiated reading strategies, learning activities to raise student engagement, and consequences of different groupings for collaborative classroom tasks (Hurd & Licciardo-Musso, 2005).

These findings are also echoed in a descriptive case study of an elementary mathematics lesson study team (Rock & Wilson, 2005). Interview transcripts, field notes, and written journal entries were qualitatively coded for emergent themes and patterns, and results showed that teachers reported increased professional confidence to improve instruction as a result of ongoing testing of pedagogical strategies in the classroom (e.g., differentiation for small group math instruction), collaborative reflection of the impacts on student learning, and time for reading current articles to inform practice (Rock & Wilson, 2005). While these and many other qualitative cases (Doig & Groves, 2011; Fernandez & Yoshida, 2004; Fernandez et al., 2003; Lewis et al., 2009) illustrate rich examples of the processes and outcomes of lesson study, varying qualitative analyses grounded in different theoretical and methodological traditions were used making it difficult to compare findings across cases to build a coherent research base for lesson study in the U.S.

Furthermore, with the exception of a recent study that examined teacher learning in lesson study by applying 'talk' and 'knowledge' codes to teacher discourse (Dudley, 2013), few of the qualitative studies documented above provide detailed descriptions of codes used in the qualitative analyses of lesson study cases. Drawing from sociocultural theory, which underscores the centrality of social discourse in the process of learning, Dudley (2013) developed a set of codes to analyze the different 'talk types' (e.g., qualifying or disputational, exploratory) and 'knowledge types' (e.g., subject matter, pedagogical knowledge) in elementary mathematics teachers' discussions. His findings showed that teachers took meaningful steps towards challenging their beliefs about students' abilities, becoming more aware of how to frame open-ended questions to promote student meaning-making with mathematical concepts, and using a wider range of formative assessment techniques (Dudley, 2013). Our study builds on Dudley's (2013) approach to systematically documenting the 'micro-exchanges' that occur in professional discussions among teachers, which when studied over the course of lesson study, can

demonstrate significant improvements in teachers' personal and collective learning.

Worth noting, recent studies also include quantitative outcomes of lesson study using randomized trials to show more causal or inferential evidence of improved teacher pedagogical content knowledge and student achievement (e.g., Lewis & Perry, 2015; Lewis et al., 2006; Mutch-Jones et al., 2012). For example, a recent randomized control trial of mathematics lesson study showed that teachers in the lesson study intervention group demonstrated significant increases in measures related to expectations for student achievement and collegial learning effectiveness, which in turn predicted gains in teachers' subject matter knowledge as well as gains in students' knowledge about fractions (Lewis & Perry, 2015). Making important contributions to lesson study research, these quantitative studies however do not provide answers to questions regarding the substance of teachers' professional learning across and within different lesson study contexts.

In summary, research about what teachers learn and how they change in lesson study is needed (Dudley, 2013; Lewis, 2009; Nilsson, 2014; Wilson & Berne, 1999). This study aims to contribute to this area of literature by presenting a theoretically grounded set of codes that can be applied systematically across multiple lesson study cases to document and compare the multi-dimensional components, and level of depth, in teacher professional learning and change across contexts.

1.4. Theoretical framework of teacher learning and change in lesson study

We drew from Lewis et al.'s (2006, 2009) ideas of intervening changes in lesson study as the basis of our coding categories, as they explicate the mechanisms involved in teacher learning and change within the three clearly defined categories (knowledge and beliefs, professional learning community, teaching and learning resources). Of note, while the intervening changes are modeled as a set of mediators between lesson study participation and instructional improvement in the original framework (Perry & Lewis, 2009), in this study, we repositioned teacher learning and change as the outcomes of interest.

In addition, we took into account several theoretical frameworks regarding how teachers learn (e.g., Borko, 2004; Clarke & Hollingsworth, 2002; Cobb, Wood, & Yackel, 1990; Guskey, 1986; Lemke, 2001; Wilson & Berne, 1999) to characterize teacher change as a process that is naturally occurring within the context of their daily professional activities (Clarke & Hollingsworth, 2002), and situate it in an iterative model of professional learning. This is in contrast to linear models of teacher change beginning with professional learning, followed by subsequent changes in teachers' knowledge and beliefs, teachers' classroom practices, and student learning (Desimone, 2009; Guskey, 1986; Perry & Lewis, 2009). This linear process has been problematized across several bodies of literature, based on the argument that teacher learning and change undergoes iterative cycles of experimentation with instructional practices (Cobb et al., 1990), refining, re-examination, and re-evaluation of instruction (Tripp & Rich, 2012; Wilson & Berne, 1999), and testing the effectiveness of different pedagogical strategies against student learning outcomes (Darling-Hammond & Ball, 1998; Dudley, 2013).

Our theoretical framework of teacher learning and change in lesson study is based on the latter iterative idea, drawing specifically on the model of professional growth proposed by Clarke and Hollingsworth (2002) that views teachers' personal domain (e.g., knowledge, beliefs, and attitudes), domain of practice (e.g., experimentation with instruction), domain of consequence (e.g., student learning outcomes), and external domain (e.g., professional

development program) as interrelated domains that develop in a non-linear fashion. In the context of lesson study, the personal, external, and consequence domains presented by Clarke and Hollingsworth (2002) align to aspects of the three major 'intervening changes' presented in Lewis and colleagues' (2006, 2009) theoretical framework of lesson study (e.g., increasing teachers' knowledge and beliefs about content is an aspect of the personal domain, strengthening of teachers' professional communities is an aspect of the external domain). Taken together, whereas the original lesson study framework presents the relationship between participation in lesson study and subsequent intervening changes as a linear (cause and effect) process (Lewis et al., 2006; Perry & Lewis, 2009), we repositioned the lesson study cycle as the domain of practice in which teachers are undergoing change in an iterative fashion as they engage in continuous cycles of enactment and reflection (Fig. 1).

In summary, we draw on the intervening changes from Lewis and colleagues' (2006) theoretical framework of lesson study, but situate teacher learning and change within the iterative, cyclical domain of practice from Clarke and Hollingsworth's (2002) model. In addition, the codes developed according to this theoretical framework are aimed to document the components of teacher learning and change not simply as an outcome of participating in lesson study, but as a process that is occurring throughout the different lesson study stages as teachers investigate and plan their research lesson, observe students' learning, and analyze and reflect evidence of student growth to improve instruction. In the next section, we draw from a broad literature base to discuss each of the three teacher changes from Lewis et al.'s (2006, 2009) framework in more detail.

The first category of codes concerns the **knowledge and beliefs** teachers hold regarding their content, pedagogy, and students. Content knowledge refers to subject-matter specific, disciplinary ideas (Fujii, 2016; Takahashi, 2014; Wang-Iverson & Yoshida, 2005). Deep subject matter understanding is an important prerequisite for a range of pedagogical decisions, such as critically examining and adapting existing curriculum materials to align with learning objectives (e.g., Ball & Cohen, 1996; Bencze & Hodson, 1999; Nilsson, 2014; Schoenfeld, 2010) and effectively structuring inquiry-based activities to support students' understanding of the content (Krajcik, McNeill, & Reiser, 2008; Lemke, 2001; Van Driel & Berry, 2012). Unfortunately, particularly in middle school science, teachers commonly hold limited content knowledge, as many are teaching outside of their area of expertise (Stern & Roseman, 2004). The investigation and planning stages in lesson study provides the opportunity for teachers to collaboratively delve into science-specific reference materials as they examine and discuss a wide range of resources (e.g., reading articles, consulting national standards, contacting knowledgeable others) (Doig & Groves, 2011; Fujii, 2016).

Pedagogy refers to the complex sets of knowledge and beliefs teachers hold about instruction, which in turn influence their approaches to teaching (Hiebert, Gallimore, & Stigler, 2002; Korthagen, 2010). Shulman's (1986) concept of pedagogical content knowledge was drawn upon, described as knowledge of subject matter integrated with knowledge of teaching to support the translation of disciplinary content in ways that can be understood and learned by students. This includes knowledge of curriculum, instructional strategies, assessments, the needs of students being served, and the social and cultural contexts of the learning environment (Bausmith & Barry, 2011; Korthagen, 2010; Nilsson, 2014; Van Driel & Berry, 2012). Decades of research since Shulman (1986) demonstrates the complex nature of pedagogical content knowledge in being highly specific to the subject matter, individual teacher, and situation (Depaepe, Verschaffel, & Kelchtermans,

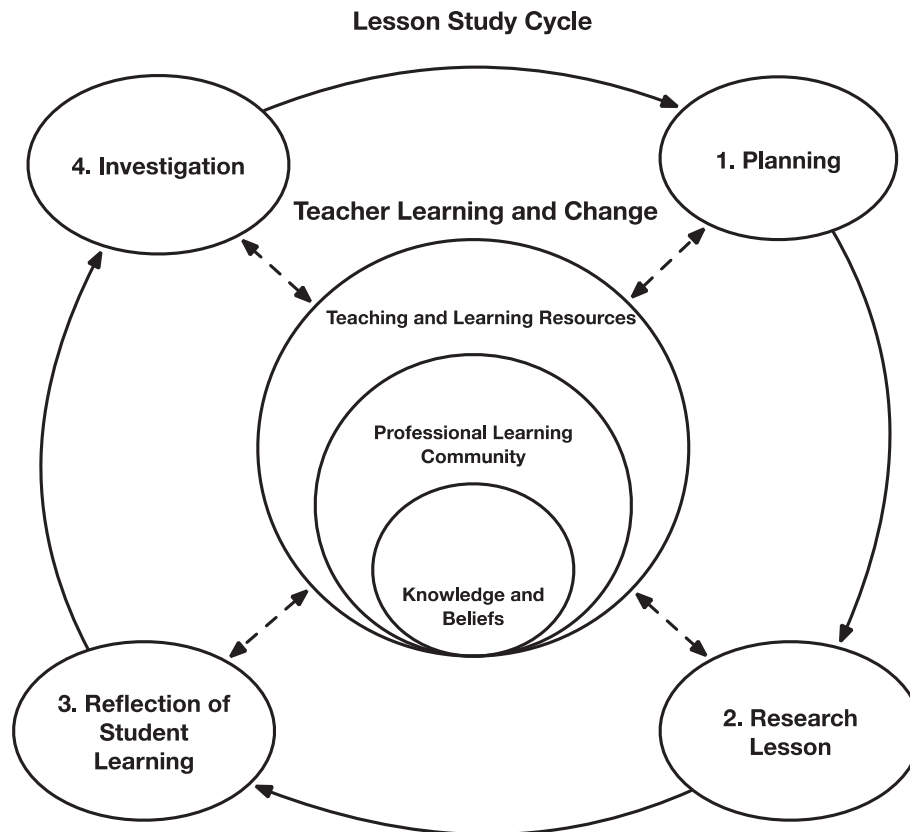


Fig. 1. Theoretical model of teacher learning and change in regards to knowledge and beliefs, professional learning community, and teaching and learning resources, as an iterative process occurring within the four phases of lesson study. Note that the knowledge and beliefs category includes content, pedagogy, and student subcategories.

2013; Van Driel & Berry, 2012). Thus, capturing how teachers' knowledge and beliefs of pedagogy develops in specific disciplinary contexts (e.g., subject-specific student learning goals, curricular materials) has significant educational value.

Finally, teachers' knowledge and beliefs about students include their understanding of student learning goals, beliefs about students' abilities, awareness of the diverse ways students are likely to respond to a lesson, students' funds of knowledge, and students' process of understanding. These knowledge and beliefs about students and how students learn have profound influences on teachers' instructional practices (Bandura, 1993; Fishman, Marx, Best, & Tal, 2003; Lumpe, Haney, & Czerniak, 2000; Pajares, 1992; Savasci & Berlin, 2012). Converging evidence points to the importance of professional learning opportunities that allow teachers to unearth and make explicit their deeply rooted beliefs of students, and to critically examine whether or not their practices are supported by the evidence of student learning in the classroom (Lewis et al., 2006; Savasci & Berlin, 2012; Wilson & Berne, 1999). These professional learning opportunities are critical for moving teachers away from relying primarily on implicit or anecdotal knowledge for making instructional decisions (Bryk, 2015; Wilson & Berne, 1999) to systematically challenging personal ideas and beliefs in service of better understanding the variation in students' learning needs and making informed steps towards targeted instructional improvement.

The second category of codes relates to the development of teachers' **professional learning community**. The development of strong and effective professional learning community requires teachers overcoming the 'culture of nice', and collectively moving towards a trusting environment where they are able to expose and

confront their assumptions, beliefs, and struggles in the classroom. Lesson study provides a platform for transparent discussions and critical debates, observations among their peers, and careful examination of data related to their students' learning (e.g., sharing student work that does not meet expected outcomes) (Doig & Groves, 2011; Hargreaves, 2003; MacDonald, 2011; Stoll et al., 2006). Lesson study is a professional learning model that inherently builds opportunities for teachers to have frequent points of contact in which they engage in deep reflection of their practice and student learning. This type of proximity to, and ongoing collaboration with colleagues, is instrumental in de-privatizing teaching and improving student outcomes (Bausmith & Barry, 2011; Fullan, 1993).

Critical to developing teachers' professional community involves developing norms of true collaboration that move beyond superficial exchanges of assistance (Bausmith & Barry, 2011; Hord, 2004; Lewis et al., 2009; Stoll et al., 2006; Wilson & Berne, 1999). In addition to challenging assumptions and holding collective responsibility towards a shared vision, professional learning also encompasses use of evidence to inform practice. Currently, there is a need to clarify whether and how deep and sustainable professional learning communities develop in lesson study, characterized by shifts in teaching and collaboration norms that move away from general discussions of students and teaching, to critical dialogue that uses concrete evidence (e.g., observation data, outside references) to support specific claims about effective instruction and student learning (Stoll et al., 2006; Wilson & Berne, 1999).

Finally, the third category of codes relates to **resources for teaching and learning** that result from lesson study. For example, past studies have shown that teachers develop a toolkit of useful

resources (e.g., effective lesson templates, educative curriculum, observation protocols, tasks to reveal student thinking) and strategies to facilitate student engagement in deeper reasoning, which will serve to inform best practices in future lessons (Lewis & Hurd, 2011; Lewis et al., 2006; Perry & Lewis, 2009). Lesson study also addresses the call to provide time for teachers to critically examine curriculum within a practice-based context that takes into account teachers' individual approaches to teaching, their understanding of the unique needs of their students, and iterative testing and revising of the instructional materials in their own classrooms (Ball & Cohen, 1996; Fogleman, McNeill, & Krajcik, 2011). For instance, curriculum and related instructional resources play particularly important roles in guiding teachers' pedagogical approaches in secondary science classrooms (Kesidou & Roseman, 2002); however, research shows that teachers often select and adapt materials in diverse ways with little time to critically evaluate the curriculum in relation to their students' learning (Ball & Cohen, 1996; Fogleman et al., 2011). Documenting tangible teaching and learning resources in lesson study will contribute to building a robust repertoire of evidence-based resources developed by teachers that address the needs of diverse student populations.

1.5. Purpose and research questions

The purpose of this study was to develop a set of well-defined and theoretically grounded qualitative codes that can be used to systematically analyze the substance of teacher learning and change. Lewis and colleagues' (2006, 2009) theoretical framework served as the basis of the categories of teacher learning and change; however, the codes developed from this framework models teacher learning and change as an iterative process situated within the practice domain of lesson study (Clarke & Hollingsworth, 2002) rather than simply as a set of outcomes. Used more widely among scholars researching lesson study, our proposed theoretical framework and codes can serve to build a coherent body of evidence across different lesson study teams, in different contexts, towards better understanding how this form of professional learning can lead to improved instruction and student learning. To provide examples of how the codes can be used, we applied a subset of the codes to transcripts of teachers' discourse in three middle school science lesson study teams and present findings from the detailed analysis of these cases.

This study was guided by the following research questions: 1) What are the key indices within each of the three categories of teacher learning and change that may occur as teachers engage in lesson study? and, 2) How do the codes serve to develop a coherent body of evidence regarding teacher learning and change in lesson study?

2. Methodology

A case study design (Yin, 2013) was applied, in which the unit of analysis was defined as grade-specific middle school (grades 6, 7, and 8) science lesson study teams. Based on the social constructivist perspective that views teacher learning and change as a socially situated process, in which new knowledge is developed through cooperative interactions and exchanges of language and tools (Clarke & Hollingsworth, 2002; Vygotsky, 1986), teachers' professional dialogues can provide a window into their process of learning and change (Dudley, 2013). Thus, teachers' collaborative discourse during the lesson study meetings was used to both develop and apply the codes presented in this study.

2.1. Context of study and sample

This study was conducted as part of a large, multi-year middle school science professional development project serving eight school districts in the western region of the United States. In the 2011–12 and 2012–13 school years, the grade-specific lesson study teams consisted of 4–7 teachers. The handbook by Lewis and Hurd (2011) was used as the main guide, and project science coaches served as the primary facilitator of the lesson study teams. The broad aim of lesson study during these two years was to shift towards more student-centered and guided inquiry approaches to science instruction (AAAS, 1993; NRC, 1996). With the advent of the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013), lesson study teams built upon their work on inquiry practices to include a focus on engaging students in the NGSS science and engineering practices (NGSS Lead States, 2013). Teachers continued to participate in grade-specific lesson study teams over the entire course of data collection (3 years).

The three lesson study teams were selected using a maximum variation selection strategy (Patton, 1990) to represent a range of novice to veteran teachers (based on years teaching), range of years of participation in lesson study (1–3 years, depending on cohort), science content areas (earth, life, and physical), and district context. The participating teachers were from nine schools across four districts. The number of team members and demographic information of the schools represented across the three lesson study teams are presented in Table 1.

2.2. Data collection

The lesson study meetings were either video or audio-recorded and transcribed verbatim. This method of data collection allowed for an in-depth examination of teachers' professional learning and change in real time, rather than post-meeting reflections or interviews. Four to five team meetings were recorded per year, two of which included full day observations of research lessons. Aside from the full day lesson observations, lesson study meetings lasted an average of 1–2 h, and were focused on developing student learning goals, planning and/or revising the research lesson, and analyzing student work. An average of 7.14 h of audio data was gathered from each team (total audio data = 28.55 h). In the example cases, we chose to apply a subset of the codes related to knowledge and beliefs, and present findings from the analysis of teachers' discourse during the research lesson debrief where teachers were focused on discussing how to shift instruction based on evidence of student learning in the classroom.

2.3. Development of lesson study codes

Two researchers collaborated to identify, apply, and develop a set of codes through a hybrid deductive and inductive coding process, described in further detail below (Crabtree & Miller, 1999). Codes were assigned to segments of the lesson study meeting transcripts (e.g., phrases, paragraphs) to catalogue key concepts drawn from either the literature or empirical indicators in the data (Grbich, 2007; Miles & Huberman, 1994). The codes were refined through a constant comparison method (Glaser & Strauss, 1967; Miles & Huberman, 1994) to include enough detail so that each code can be differentiated from one another and unambiguously observable (Evertson & Green, 1986).

This code development process involved nine cycles of 1) a literature review and development of a priori codes based on existing constructs and theoretical frameworks, 2) an application of a priori codes to the data and refinement of a priori codes as needed, 3) an addition of emergent codes that captured new

Table 1
Demographic information of schools represented across the three lesson study teams between 2011 and 2014.

Lesson study team/Content	School year	# of team members	Grade	Ranges for schools represented in lesson study teams during corresponding school year			
				% Free Reduced Lunch (FRL)	% English Language Learner (ELL)	% Math Proficient	% Language Proficient
Liquid Density/Physical Science	2011–12	7	8	25.1–80.1	15.1–30.6	38.9–64	51–74.3
Rivers/Earth Science	2012–13	5	6	36.2–69.2	15–44.9	37.1–52	51.1–68.9
Natural Selection/Life Science	2013–14	5	7	69.1–78.5	19.4–19.8	45.9–47.8	47.9–51

properties of the data through open-coding (Glaser & Strauss, 1967), and finally, 4) a re-application of a priori and new emergent codes to the data (Fig. 2). Each stage and cycle of code application, refinement, and development was first conducted separately by two coders, then discussed together to achieve consensus regarding the application of codes to the transcripts, as well as the adequacy of the codes for capturing the different components of teacher learning and change.

Larger categories of ‘parent’ codes were organized under one of the three categories of teacher learning and change (teachers’ knowledge and beliefs, teachers’ professional community, and instructional resources) (Clarke & Hollingsworth, 2002; Lewis et al., 2009, 2006; Perry & Lewis, 2009). More specific ‘child’ codes were identified within each parent code category as markers of the depth or quality of teachers’ professional learning and change (Table 2).

2.4. Lesson study codes

A priori specification of constructs based on existing theory

helped shape the initial development of the deductive codes (Eisenhardt, 1989). Specifically, we used the theoretical model of lesson study developed by Lewis, Perry, Hurd, and O’Connell (2006, 2009), situated in the iterative process model (Clarke & Hollingsworth, 2002), to generate an initial list of codes related to the substance of professional learning and teacher change. In order to fully develop the codes within the three categories of learning and change, we also drew on the literature regarding subject matter and pedagogical content knowledge (e.g., Ball & Cohen, 1996; Hiebert et al., 2002; Nilsson, 2014; Schoenfeld, 2010; Shulman, 1986; Van Driel & Berry, 2012), beliefs and attitudes towards students (e.g., Bandura, 1993; Fishman et al., 2003; Lumpe et al., 2000; Pajares, 1992; Savasci & Berlin, 2012), professional learning communities (e.g., Doig & Groves, 2011; Hargreaves, 2003; MacDonald, 2011; Stoll et al., 2006), evidence-based decision-making, and development and enactment of curriculum and instructional materials (e.g., Ball & Cohen, 1996; Fogleman et al., 2011; Krajcik et al., 2008).

Information from the excerpts of the transcripts that were not

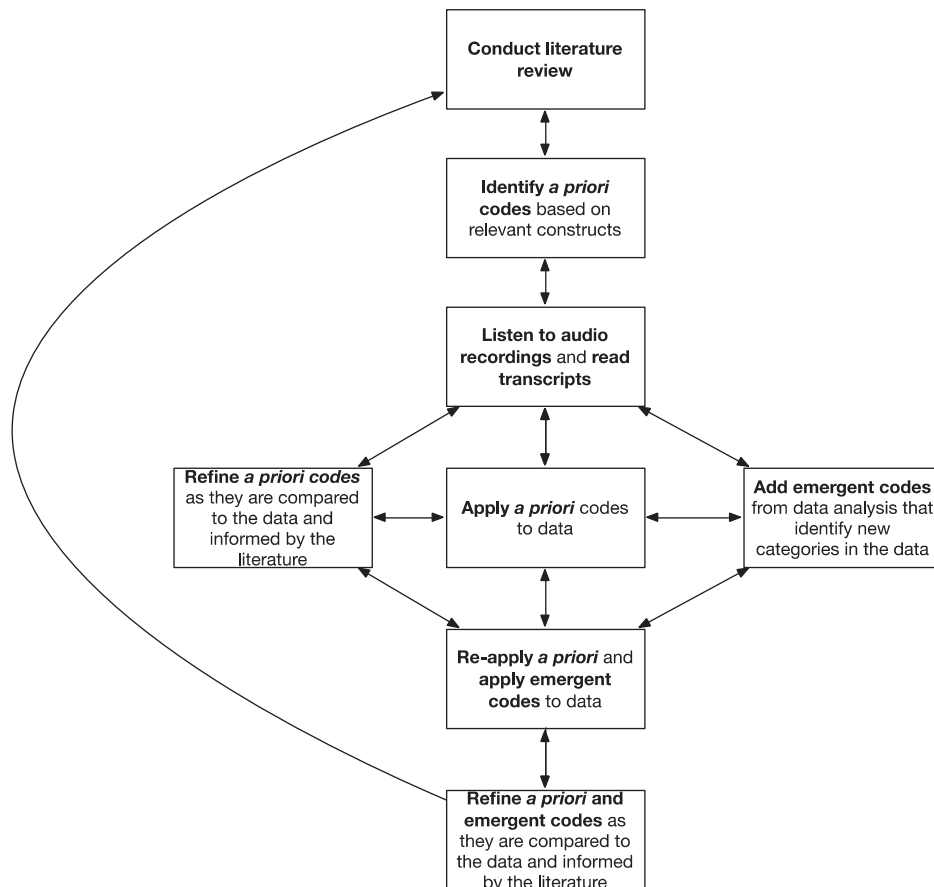


Fig. 2. Deductive and inductive process model for developing the lesson study codes.

Table 2

List and descriptions of parent and child codes within the three categories of teacher professional learning and change.

Coding category 1: Teachers' Knowledge and Beliefs	
Parent code: Science (SCI)	
Teacher learning and change in science content knowledge (e.g., specific science concepts/principles).	
Child Code	Description
SCI a	Teachers talking about science content knowledge. This could be as simple as teachers mentioning science topics (e.g., density) or can be mentioning science content in a general way.
SCI b	Teachers explaining science content to one another other. This could be one teacher explaining a science concept to the rest of the group, or the whole group explaining science concepts collaboratively.
SCI c	Teachers engaged in a debate or argument about science content—grappling with a science idea, but not necessarily coming to any conclusion.
SCI d	A teacher (or teachers) admitting to or showing evidence of becoming aware of either a gap in their science content knowledge and/or a change in their science understanding.
SCI e	Teachers describing their rationale or justification for selecting a specific science content or topic to examine more deeply.
SCI f	Teachers discussing using outside resources (reading articles, consulting national standards, contacting an expert, etc.) to deepen their science content knowledge.
Parent code: Pedagogy (PED)	
Teacher learning and change in instructional or pedagogical knowledge.	
Child Code	Description
PED a	Teachers mentioning or describing a pedagogical strategy or approach to each other (e.g., Claim-Evidence-Reasoning graphic organizer, talking sticks).
PED b	Teachers debating or grappling with how a pedagogically strategy or approach should be used (e.g., comparing different tools, adapting existing tools).
PED c	Teacher admitting to or showing evidence of becoming aware of a new pedagogical strategy/approach or describing a change in their own pedagogical knowledge.
PED d	Teachers describing their rationale or justification for selecting a particular pedagogical strategy or approach.
Parent code: Students (STU)	
Teacher learning and change in understanding of students (e.g., how students learn, students' abilities).	
Child Code	Description
STU a	Teachers talking about their view of student capacity including generalized set of beliefs that teachers hold about the intelligence, reasoning capability, amount of compliance, curiosity, motivation, or degree of effort, acceptance of risk, prior knowledge, select skills, etc. These ideas may not be based on evidence of actual student performance but on general beliefs and ideas that teachers hold.
STU b	Teachers talking about how their students learn (e.g., the process of learning in general, student group dynamics).
STU c	Teachers talking about their goals and/or objectives for students (e.g., general developmental goals, content-specific learning goals).
STU d	Teachers talking about how students will likely respond to elements of a lesson or the research lesson (i.e., anticipating students' responses).
STU e	Teachers talking about their students' science ideas and conceptions, including what they think students have learned and what students still need to learn based on specific evidence. Focus shifts from general statements about student capacity to specific student ideas.
Coding category 2: Teachers' Professional Learning Community	
Parent code: Professional Learning Community (PLC)	
Teacher learning and change in working collaboratively to enhance their effectiveness as professionals in service of student learning.	
Child Code	Description
PLC a	Teachers are developing shared values and a common vision. The focus of the conversation is on teachers' moving towards consensus (e.g., two or more teachers are reinforcing one another's statements).
PLC b	Teachers are holding one another accountable to commitments and focused on actions towards supporting student learning.
PLC c	Teachers are meaningfully reflecting on their own and on their colleagues' discussion and practices.
PLC d	Teachers recognize each other as colleagues and express the value of co-developed knowledge, tools, and other direct outcomes of collaboration.
PLC e	Teacher(s) makes link or reference to PLC outside the lesson study group (e.g., department meetings, district professional development).
PLC f	Teachers expressing confusion and/or seeking clarification in a collegial manner (e.g., teacher stops the flow of conversation to clarify/question/push back).
Parent code: Evidence (EVI)	
Teacher learning and change in approaches to collection, analysis, and use of evidence to examine student learning.	
Child Code	Description
EVI a	Teachers talking about what they will use as observable indicators to determine the degree to which students met their goals.
EVI b	Teachers talking about the specific indicators they have collected as evidence (e.g., discussing what students wrote, quoting what students said).
EVI c	Teachers developing criteria for assessing student work (from research lesson and/or unit under study) to examine evidence of students' learning.
EVI d	Teachers examining student work (as evidence) to make informed decisions about research lesson and/or instructional revisions.
Coding category 3: Teaching – Learning Resources	
Parent code: Curriculum (CUR)	
Teacher learning and change in critically examining, revising, developing, and enacting instructional materials.	
Child Code	Description
CUR a	Teachers talking about their existing, ready to teach lessons or activities (e.g., describing a lesson to the other teachers).
CUR b	Teachers stating a preference or dislike for a lesson or elements of a lesson, or teachers stating that they have or don't have a good lesson to teach a particular science concept (e.g., teacher stating that s/he struggles with his/her unit on density).
CUR c	Teachers discussing their criteria for revising elements of the lesson; teachers explaining or justifying changes to the lesson.
CUR d	Teacher taking about sequencing the order of lessons and/or activities (e.g., learning progression).
Parent code: Resources and Tools (RES)	
Teacher learning and change in general instructional resources.	
Child Code	Description
RES a	Teachers talking about how long each element of the lesson should take, or discussing changing the timing of lesson elements.
RES b	Classroom management strategies (e.g., routines, student roles, discipline, instructions).

(continued on next page)

Table 2 (continued)

Coding category 3: Teaching – Learning Resources	
RES c	Lesson study and/or professional learning meeting logistics (e.g., agenda, meeting days/times, scheduling the research lesson).
RES d	Teachers talking about following standards, frameworks, and/or pacing guides to support alignment to local and national standards.
RES e	Teachers talking about when they will be teaching certain topics or units during the school year.
RES f	Teachers talking about availability of resources (e.g., computer labs, sinks, vendors).

captured by the a priori codes was open-coded, resulting in the data driven or emergent codes (Glaser, 1992; Strauss, 1987). This accompanying inductive procedure of open coding allowed for new properties of studied phenomenon to appear (Charmaz, 2008; Glaser & Strauss, 1967). The final parent code categories were as follows. Regarding the first category of teachers' knowledge and beliefs: Science (SCI): Talk about science content knowledge (6 child codes), Pedagogy (PED): Talk about instruction or pedagogy (4 child codes), and Student (STU): Talk about students (5 child codes). For the second category of teachers' professional learning community: Professional Learning Community (PLC): Teachers collaboratively focused on enhancing their effectiveness as professionals to support student learning (6 child codes), and Evidence (EVI): Collecting, analyzing, and using evidence of student learning (4 child codes). Finally, for the third category of teaching and learning resources: Curriculum (CUR): Planning, evaluation, and revision of curriculum and/or instructional materials (4 child codes), and General Resources (GEN): General teaching and learning resources (6 child codes).

3. Results

3.1. Example cases: three middle school science lesson study teams

The analysis of teachers' professional discussions in three middle school science post-research lesson observation meetings served to illustrate the codes in use. The science topic of the research lesson for each team is presented in Table 3. First, we briefly present the quantitative frequencies of parent and child codes across all three coding categories for the purpose of demonstrating the utility of the codes in systematically documenting diverse aspects of teachers' professional learning and change. We then provide more detailed findings regarding teachers' knowledge and beliefs regarding science content (SCI), pedagogy (PED), and students (STU) in order to demonstrate similarities and differences in the substance of teachers' growth across cases. Analyses include both quantitative results regarding the frequency of the child codes within each of the focal category, as well as qualitative analyses of the nature of teacher learning and change within the excerpts. The frequencies of codes provide descriptive evidence regarding to what extent components of teacher professional learning and change were present. The qualitative analysis of

the excerpts demonstrates the substance of teachers' professional learning and the nature of the associated changes within and among teachers.

Fig. 3 shows the frequency of child codes across the seven parent codes of teacher learning and change for the three lesson study teams. These results indicate that overall, teachers' discourse focused primarily on students, followed by talk about evidence collected from the lesson observation. Moreover, certain child codes were clearly more apparent than others, depending on the overall category. In order to present these nuances in greater detail, in the following sections, the quantitative frequencies of child codes within the SCI, PED, and STU parent coding categories (related to teachers' knowledge and beliefs) are presented for three middle school science lesson study teams, along with qualitative analyses of the corresponding excerpts.

3.1.1. Talk about science content (SCI): the role of knowledgeable others

Deepened understanding of subject matter is a key element of teacher learning in lesson study (Lewis et al., 2009, 2006; Stigler & Hiebert, 2016). To capture teachers' learning around science content, SCI codes were applied to excerpts of teachers' dialogue in which teachers were discussing discipline-specific ideas. Talk about science content ranged from simple mention of scientific terms (SCI a) to more in-depth discussions and debates of scientific ideas and principles (e.g., SCI c and SCI d). Analysis of the code frequencies showed that in all three lesson study teams, there was a prevalence SCIa codes (Fig. 4); for the Liquid Density, Rivers, and Natural Selection teams, the SCI a code made up 72.22%, 76.67%, and 50.00% of the SCI codes, respectively. Deeper discussions of science content occurred infrequently, for example, SCI e and SCI f codes made up less than 20% of the codes in the SCI category in all three teams.

These results indicate that teachers' talk about science content was largely characterized by surface level mention of the target science ideas observed in the lesson, further supported by the qualitative analysis of excerpts corresponding to the SCI a codes. For instance, in the Liquid Density team, a teacher listed the academic vocabulary that she heard students using during the research lesson; "They used the word density and viscosity and there's a few other words ... mass and the volume to go along with it," but did not go into further discussion of how students understood these science ideas, such as discussing the context in which the science

Table 3
Research lesson topics and descriptions for the three lesson study teams.

LS team	Topic of the unit	Description of research lesson
Liquid Density	The density of different liquids including the relationships among mass and volume.	Students combine different liquids and make qualitative observations regarding the properties of the liquids. They use data recorded from their experiments to make evidence-based predictions about the order in which four different liquids will layer.
Rivers	How rivers modify and shape Earth's surfaces through erosion and deposition.	Students create a model of a river system to observe how the sedimentary materials are removed, transported, and deposited during the process of river erosion, which result in different landforms.
Natural Selection	The process of adaptation by natural selection on populations due to changes in the environment.	Students model how the environment (e.g., food source) affects the genetic fitness of individuals in a population by determining which crabs (mini versus medium claw) in the population survive to reproduce and pass on their traits to the next generation.

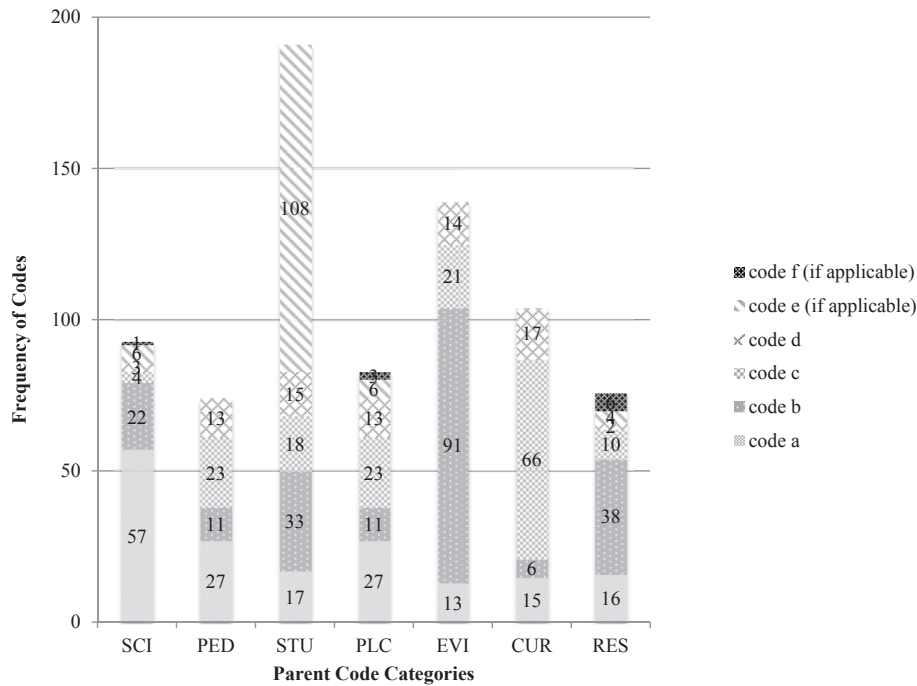


Fig. 3. Frequency of child and parent codes across three categories of teacher learning and change applied to transcripts of teachers' discussions in middle school science lesson study.

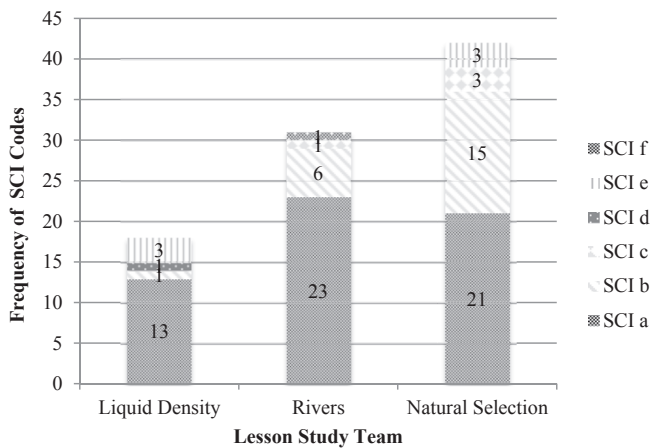


Fig. 4. Frequency of science content (SCI) codes across three lesson study teams.

vocabulary was expressed or how students' conversations revealed information about their understanding of concepts related to the target vocabulary. In another example, a teacher in the Rivers team made a general statement about students' understanding of river erosion, "they understood that water was a key factor in erosion", which also lacked a more detailed analysis of how students used or understood the target science content ideas.

On the other hand, analysis of the instances in which teachers were engaged in deeper discussions around the science content, such as explaining science content to one another (SCIb), grappling with science content (SCIc), and referring to disciplinary resources (SCIf), showed that the presence of 'knowledgeable others' (Perry & Lewis, 2009; Takahashi, 2014) played a significant facilitative role. For example, a science faculty member participating in the Rivers team prompted teachers to take a deeper look at students' thinking around the process of river erosion. Specifically, he noticed that students were focused primarily on the landforms that resulted

from the stream table, and were not attending to the critical process of erosion:

"One of the things I noticed while students were doing the experiments is that they were really busy writing down and drawing while the water was flowing, and not really taking the time to observe. I'm wondering if there's some way that we could change the worksheet or the instructions so that they're doing more active observation while the water is flowing through the stream table. It's actually the process of the sediment eroding down and the development of the channel that we want them to focus on."

The science faculty's explanation of the science content ideas, in relation to his observation of students' lack of attention to the process of river erosion, prompted teachers to revisit the key science ideas related to the lab, and critically discuss how the lesson could be improved to guide students' attention the process of erosion in the lab:

Teacher 1, Rivers: It looks like they see the 'before' and they see the 'after' but I guess it takes one or two more steps for how to get from point A to point B. Anything that will [guide] their thinking on the moving water and the moving sand. Not just sand static before, and sand now after. They missed that part, the moving part.

Teacher 2, Rivers: The process-the erosion part (laughs).

Similarly, in the Natural Selection team, a science coach who attended the meetings also played a significant role in facilitating deeper discussions around the science content. Following the lab activity, in which students engaged in a simulated 'environmental challenge' to test and document the survival of mini versus medium sized crabs, the team analyzed students' written scientific explanations on a Claim-Evidence-Reasoning graphic organizer (McNeill

& Krajcik, 2008). The coach noticed that in their written explanations, students frequently reasoned that the first generation of medium crabs survived because they were better adapted to gather food. Although teachers initially considered this statement appropriate to support the claim that medium clawed crabs were better adapted to the environment, the coach raised the following point:

“The fact of the matter is that in the first generation, we said it was well adapted, but actually, the reason was that there were only medium claws [that survived] is because that’s what we started with ... Because there was no competition ... in the parent generation, right? There was only medium [crabs].”

This led the team towards a deeper discussion regarding evidence and reasoning statements from students’ written work that indicated scientific understanding of natural selection, as well as an analysis of common student misconceptions that emerged from students’ written explanations.

3.1.2. Talk about pedagogy (PED): opportunities to develop students’ science literacy

Talk about pedagogy was conceptualized as teachers’ discussion of knowledge regarding teaching, such as instructional strategies and tools (Shulman, 1986). Findings showed that there was a high frequency of pedagogy codes that captured deep discussions of teaching, specifically in terms of teachers debating about or grappling with pedagogical ideas (PED b) (40%–62.07% of all PED codes) and teachers describing their rationale or justification for selecting a particular pedagogical approach (PED d) (26.32%–34.78% of all PED codes) (Fig. 5).

A major theme that emerged from the analyses of PED excerpts related to shifts in science teaching towards more inquiry-based, student-centered approaches (and later NGSS practices) (Abd-El-Khalick et al., 2004; Anderson, 2002; NRC, 1996). One way teachers tackled this pedagogical shift was in exploring strategies to support student engagement in the practices and language of science, in service of developing their students’ scientific literacy (Pearson, Moje, & Greenleaf, 2010; Snow, 2010).

In the Rivers team, teacher talk about science literacy was conceptualized as increased use of scientific vocabulary (Pearson et al., 2010) related to key concepts explored in the river erosion lab. Teachers noticed unique vocabulary-based challenges ELL students faced as they engaged in the science activities, particularly

in regards to lack of fluency in utilizing appropriate terminology to describe their observations. As teachers carefully analyzed students’ learning, they drew evidence from the research lesson to identify and address students’ need for more concrete, or ‘hard’, paper-based scaffolds (Belland, Glazewski, & Richardson, 2008). Specifically, teachers decided to add a word bank to the observation worksheet that created explicit instruction and opportunities for students to apply science vocabulary in writing.

In other teams, science literacy was conceptualized as developing students’ ability to orally communicate scientific information through discourse (Pearson et al., 2010). Teachers in the Natural Selection team discussed several discourse strategies, including the use of ‘talking sticks’ to support equity of voice as well as the ‘think-pair-share’ technique to increase peer-to-peer discourse. The Liquid Density teachers also discussed discourse strategies, specifically targeted at creating structured time for students to share with one another the results from their experiments. The following excerpt shows an example in which the teachers are discussing an activity for students in different groups to compare and contrast data collected from their two-liquid combinations:

Teacher 1, Liquid Density: I think it would be a good idea for them to have a class discussion and see why they got different results.

Teacher 2, Liquid Density: In my class, I saw that once they had finished one of them, they said, ‘Oh, we didn’t get to try ...’ So they were disappointed that they only had four tries. So I also thought that discussing, comparing and contrasting results as a class, would be a good idea.

Teacher 3, Liquid Density: I would like that the group to share their results, and then we can look at it and if we’ve got some conflict then we can ... [engage in a] scientific community conversation ... how powerful that is—sharing our data—‘why is this different?’ ... that’s a really critical thing because you’re making these observations and you know we can have that whole discussion about what scientists observe.

This activity set the stage for class discussions related to converging and unexpected or contradicting results across groups. Such opportunities for scientific discourse not only facilitated students’ understanding of disciplinary ideas, but of the nature of science more broadly in regards to epistemic frameworks that mirror how knowledge is shared and develops in a scientific community.

3.1.3. Talk about students (STU): mixed ability grouping and student reasoning

The student (STU) codes were related to how teachers talked about their students. Based on the frequencies of STU codes, results showed that teachers’ talk about students centered on unpacking what and how students were learning (STU e code accounted for 44.30%–67.27% of STU codes), followed by discussions of their view of the learning process (STU b codes accounted for 12.28% to 22.78% of STU codes) (Fig. 6). The qualitative analyses of excerpts related to the STU codes afforded a rich picture of the various ways teachers were developing a collective understanding of their students’ thinking and learning processes.

In particular, teachers discussed unique patterns of interactions in student groups, such as the use of dual languages (Spanish and English), leadership dynamics, and gender differences. These observations provided teachers with information about how classroom structures, such as different student group configurations, may influence the ways in which students engage in learning. As an

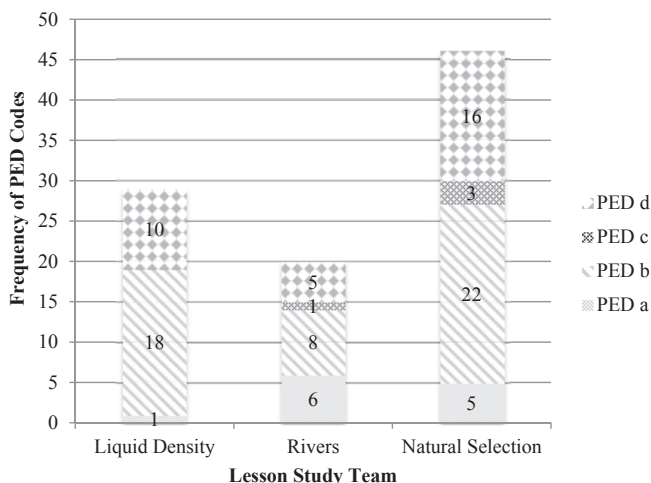


Fig. 5. Frequency of pedagogy (PED) codes across three lesson study teams.

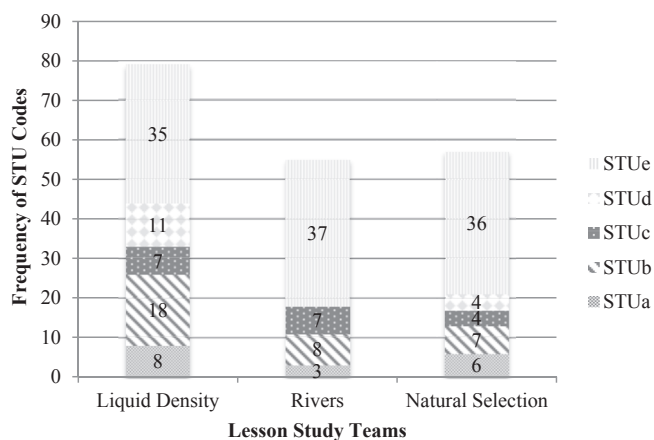


Fig. 6. Frequency of student (STU) codes across the three lesson study teams.

example, based on their observations of students' discussions, teachers discussed the possible benefits of intentionally creating mixed ability groups to foster peer-to-peer learning. A teacher in the Natural Selection team shared his observation of student-led, cooperative learning in an activity that asked students to graph the relationship between the number of survived crabs by species for each of the generations:

"I think [student 1] was getting a lot of help from Student 2. So that came up more during group work, during the graphing. Student 2 sat next to him, did a really great job of really helping him and giving him directions on what data to graph. Because I think that was one of the questions that came up from his side, is like what am I graphing?"

Similarly, a teacher in the Liquid Density team noted that although one of the students she was observing initially demonstrated leadership and confidence in conducting the experiment, the student later received help from his group mates to complete the data worksheet:

"There was a student who was delegating, but when it was time to fill in the worksheets, he got stuck and he had doubts- he kept asking others for help. So what I learned today was that there are so many different types of learners, and so many different types of students- and the fact they worked together was so nice to see."

Teachers' talk about their students also included analyses of the different ways in which students were reasoning about scientific phenomena. For example, in the Liquid Density team, teachers noticed that as students were testing combinations of two different liquids, they began to form theories about why the liquids were forming the layers. One of the teachers noted that many students spontaneously attributed different properties to the liquids by drawing on their prior knowledge: "They were saying that the liquid sinks because it's thick ... or the stickiness of the liquid." In response to this observation, another teacher in the team suggested challenging students' alternative conceptions of 'liquid thickness' by pointing out evidence from the experiments in which 'thick' liquids (e.g., oil) sometimes layered on top of 'thin' liquids (e.g., water, rubbing alcohol), and in other cases, settled to the bottom layer (e.g., corn syrup). The detailed evidence teachers gathered

around students' idiosyncratic sense-making processes allowed them to identify ways to build upon students' prior knowledge, as well as to target students' scientifically inaccurate conceptions. This in turn allowed them to identify moments in the classroom for creating cognitive dissonance (e.g., pointing out contradictions between students' personal theories and evidence from the experiment) to drive conceptual change (Festinger, 1962; Linenberger & Bretz, 2012).

Similarly, in the Natural Selection team, teachers noticed that students were experiencing high cognitive load due to the presence of multiple elements (e.g., two species of crabs, multiple generations) that needed to be attended to simultaneously in the graphing activity (Sweller, 1994). For example, teachers noted that many students did not know how to label the axes, and/or failed to realize that they needed to represent data from two distinct groups (mini versus the medium sized crab species) in the graph. As teachers noted specific areas of challenge, they developed scaffolds by adding a key on the graph worksheet, aimed to guide students' towards recognizing that both phenotypes needed to be represented, and putting the labels on the x and y axes to draw clearer links between the students' data tables and the axes on the graph.

In summary, evidence from the analysis of excerpts related the STU codes showed that the opportunities for teachers' to carefully observe students' learning in the classroom unearthed detailed, context-specific information about their students' characteristics, learning processes, and how students reasoned around science ideas. As one teacher from the Natural Selection team stated, "It's so amazing how many things you think of when you watch kids, like I never would have thought of that without watching kids."

4. Discussion

This study is predicated on the notion that ongoing collaborative professional learning for teachers is one of the most powerful agents of teacher learning and change. Lesson study is increasingly being adopted as a professional learning model, but much remains to be understood regarding the substance of teacher learning and change across contexts (Lewis, 2015; Saito, 2012; Stigler & Hiebert, 2016). A review of the literature indicates that there is a lack of available methodologies and tools to conduct systematic and comparative case study analyses examining the nature and quality of professional learning in lesson study. The code scheme presented here provides a tool for systematically documenting the extent and depth of teacher learning and change within aspects of interrelated personal, practice, external, and consequential domains (Clarke & Hollingsworth, 2002; Perry & Lewis, 2009).

Related to the first research question, we developed codes of teacher learning and change in regards to teachers' knowledge and beliefs, professional learning community, and instructional resources. The subcodes within each category include qualitative indicators that allow for a systematic documentation of the mechanisms underlying teachers' micro-exchanges as teachers' engage in professional discussions in lesson study (Dudley, 2013). Of note, the codes capture not only different aspects of teacher and learning and change (e.g., content knowledge, pedagogy, professional learning community) but also the quality of growth within each of these aspects. For example, the codes related to subject matter document teachers' discussions on a continuum from superficial mention of content topics to more substantive dialogue in which teachers are debating discipline-specific ideas and deepening their content knowledge. When studied over time and across multiple cases, the application of the codes can serve to build evidence that demonstrates significant shifts in teachers' personal

and collective learning.

Related to the second research question, we present findings from analysis of three middle school science lesson study teams to illustrate the codes in use for systematically documenting, both quantitatively and qualitatively, the aspects of professional learning that drive changes in teachers' knowledge and beliefs. For example, the SCI codes serve an important purpose of investigating teacher learning as they engage in interactive decision-making with careful attention to the role of disciplinary knowledge. In the example cases presented, we demonstrate how an application of these codes revealed that the presence of science and instructional experts (knowledgeable others) in the lesson study teams facilitated teachers in moving beyond simple mentioning of scientific terms, towards deeper disciplinary discussions of the scientific terms in use (e.g., how students are making sense of science ideas). Past research has shown that members with different backgrounds and expertise bring different discourses to a professional learning setting, and establishing shared meanings among these discourses is part of the work for the professional community (Fujii, 2016; Takahashi, 2014). Particularly in lesson study, knowledgeable others provide a third party perspective on the work and can infuse additional information about content, standards, and other related topics (Fernandez et al., 2003; Takahashi, 2014). Our findings regarding the discipline-specific supports from science faculty and coaches may be particularly critical given the advent of the NGSS, which proposes a shift towards integrating earth, life, and physical science content areas across all grade levels—a shift that would require science teachers to learn and teach new content in ways that may be unfamiliar to them.

Similarly, the codes related to pedagogy documented how teachers developed greater awareness of the unique challenges of student subgroups (e.g., ELLs) that allowed them to develop differentiated pedagogical strategies (Gersten & Baker, 2000; Moje, Collazo, Carrillo, & Marx, 2001; Watts-Taffe & Truscott, 2000) and capitalize on diverse student abilities through mixed ability groupings (Gamoran & Mare, 1989; Linchevski & Kutscher, 1998; Slavin, 1990). Finally, through the use of STU codes presented in this study, we present evidence that documents how lesson study provides opportunities for teachers to know what their students know. Whether teachers were discussing alternate (and scientifically inaccurate) student conceptions, observing benefits of mixed ability grouping, or documenting student challenges with scientific practices, the instructional decisions made around these complex topics were based upon evidence of actual student learning behaviors collected during the research lesson observations.

5. Conclusion

Altogether, this study presents a theoretically grounded set of codes with detailed indices to systematically uncover the substance of teachers' professional learning and change, with example cases in the context of middle school science lesson study. The codes capture critical domains of teacher learning and change that used across multiple, comparative, and longitudinal studies, can serve to build a coherent body of evidence towards better understanding how lesson study can lead to improved instruction. The detailed case examples highlight the range of insights that teachers gain regarding subject matter, pedagogy, and students' learning as they engage in lesson study.

Acknowledgment

This research is supported by the National Science Foundation

Grant # 09628.

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