

Science-for-Teaching Discourse in  
Science Teachers' Professional Learning Communities

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**Abstract**

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Professional learning communities (PLCs) provide an increasingly common structure for teachers' professional development. The effectiveness of PLCs depends on the content and quality of the participants' discourse. This dissertation was conducted to add to an understanding of the science content needed to prepare to teach science, and the discourse characteristics that create learning opportunities in teachers' PLCs. To this end, this study examined how middle school science teachers in three PLCs addressed science-for-teaching, and to what effect. Insight into discourse about content knowledge for teaching in PLCs has implications for the analysis, interpretation, and support of teachers' professional discourse, their collaborative learning, and consequently their improvement of practice. This dissertation looked closely at the hybrid space between teachers' knowledge of students, of teaching, and of science, and how this space was explored in the discourse among teachers, and between teachers and science experts. At the center of the study were observations of three 2-day PLC cycles in which participants worked together to improve the way they taught their curriculum. Two of the PLC cycles were supported, in part, by a science expert who helped the teachers explore the science

they needed for teaching. The third PLC worked without such support. The following overarching questions were explored in the three articles of this dissertation: (1) What kind of science knowledge did teachers discuss in preparation for teaching? (2) How did the teachers talk about content knowledge for science teaching, and to what effect for their teaching practice? (3) How did collaborating teachers' discursive accountabilities provide opportunities for furthering the teachers' content knowledge for science teaching? The teachers' discourse during the 2-day collaboration cycles was analyzed and interpreted based on a sociocultural framework that included concepts from the practice-based theory of content knowledge for teaching developed by D. L. Ball, Thames, and Phelps (2008) and the Accountable Talk framework by Michaels, O'Connor, & Resnick (2008). The study's findings could provide justification for and ideas on how to provide targeted support for PLCs to make teachers' work on science knowledge more applicable to lesson planning, teaching, and student learning.

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## **DEDICATION**

To Jörg

And to the great teachers in Germany and in the United States whom I had the privilege to work with and who taught me so much. They have strengthened my conviction that we can and should learn from and with each other. Because of them, I believe that if we continuously work together, we can grow our understanding of how to best teach and support students' learning. Because of them, I also believe that teachers should have the freedom to incorporate this understanding into their own unique way of teaching. No individual teacher is the perfect match for every student; it is only all teachers together who can provide the best teaching to all students.

## Prologue for My Colleagues in Germany and the United States

In the late 1990s, I lived in Seattle for a year. Having time on my hands, and with my never-ending interest in education, I visited schools and talked to teachers and educators. With every encounter, my own school system that I had grown up in and taken for granted appeared stranger. When I returned from Seattle to Munich, I started to notice, for example, when we talked among colleagues at the Gymnasium<sup>1</sup> about teaching and about science, how little our students' learning was part of these conversations. A few years earlier, I had asked a teacher visiting from the United States about the main difference between American and German schools. After I returned to Germany, I started to understand the answer he had given: In America, teachers are responsible for students' learning; in Germany (at least in the Gymnasium), learning is the students' own responsibility. While his response was overly simplified, it still highlighted the main difference between the approaches to teaching I observed in public secondary schools in the US Pacific Northwest and in Gymnasiums in Bavaria (I don't dare to generalize over wider geographical regions). And yet I encountered many great teachers in both countries.

In Germany, science teachers teach their subject for two or three periods a week per class; the result is that teachers teach different grade levels and two different subjects during the week. Preparing for so many different classes and science topics makes the teachers' understanding of core science ideas, ideas that run throughout the grade levels, a matter of survival. In my case, over the years, I taught biology from fifth grade to 13th grade and chemistry from ninth to 12th grade. On a Wednesday, for example, I would

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<sup>1</sup> Germany has three different types of secondary schools (fifth to 12th grade); the Gymnasium is the most academically oriented.

teach fifth-grade biology in first period, followed by a double period of 12th-grade advanced genetics, then have a preparation period, which was followed by 10th-grade chemistry and then some eighth-grade botany. And mostly I taught in the students' homerooms or in a science lab (teachers in Germany do not have their own classrooms). Today, that seems to me like another world. The marginal consideration given to individual students' learning, and the lack of opportunity for teachers to work together on improving their teaching, would have given me a theme to explore for a dissertation in Germany.

I returned to Seattle in 2004, and found my first job with the Institute for Systems Biology (ISB), a science research organization that has a small department of science educators who work dedicatedly with public schools in the region. The ISB education department is called the Center for Inquiry Science. There, I did an apprenticeship in the American public school system as it plays out in the Pacific Northwest. I also had the opportunity to join one of the Center for Inquiry Science's projects: Observing for Evidence of Learning (OEL), which provides secondary science teachers time and a process for collaboration, and was a close match with one of my main interests in education (call it serendipity). The teachers I worked with on the OEL program knew and cared a great deal about their students, their lives, and their struggles. However, over the last eight years, during which I have organized, observed, facilitated, and studied teachers' professional learning communities (PLCs), I noticed that often, teachers' conversations about teaching gave only marginal attention to subject matter. I could have an extended private conversation with a teacher about a science problem, yet during teachers' collaborative work, these types of conversations were strikingly missing. Even

in situations where one of the teachers would explicitly ask her<sup>2</sup> colleagues to explain a specific science concept she was uncertain about, the group would shy away from going deeper into the science itself.

Teachers in the United States have fewer students (overall, not per class), and they see their students every day. And many US teachers teach a limited range of grade levels; in middle schools, they often teach only one grade. Thus, the science needed for teaching can appear rather contained. This could be one of the reasons that US teachers' knowledge of their students seems to be more central than their knowledge of the subject they are teaching.

Having experienced these alternative approaches to teaching, I believed that if considerations about science and about students could become stronger and more interconnected when talking about and planning for teaching, then students could be better supported in learning science. Combining this belief with my interest in teacher collaboration, I decided that the focus of my dissertation should be about how teachers do or do not incorporate science-for-teaching knowledge in their discourse during collaborative work, and how such science-for-teaching discourse could be strengthened. Building on the work of many great scholars (as mentioned in Darling-Hammond & Richardson, 2009), I hoped that with more insight about how science is discussed during teacher collaboration, be it during common planning time or in formally organized professional development, teachers could be better supported, and in turn, better support their students' science learning.

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<sup>2</sup> Because the majority of the teachers I have worked with are women, I will throughout this dissertation use feminine pronouns for teachers, unless I address one of our male colleagues specifically.

# **Science-for-Teaching Discourse in Science Teacher Learning Communities**

## **Introduction to the Articles**

Increasingly high expectations for students' science learning, driven in part by the *Next Generation Science Standards* (NGSS Lead States, 2013), have created an ever-growing need for content-specific professional development (PD) for science teachers. While research has suggested that professional learning communities (PLCs) provide an effective structure for teacher learning (Darling-Hammond & Richardson, 2009; Stoll, Bolam, McMahon, Wallace, & Thomas, 2006), there is little agreement on the content knowledge to be learned during such collaborative time (D. L. Ball, Thames, & Phelps, 2008). This dissertation adds to an understanding of the content and the quality of discourse that could or should be part of collaborative deliberation specifically in science teachers' PLCs. To this end, this study examined how teachers in three PLCs addressed the science knowledge needed for teaching, and to what effect. This type of insight into discourse about content knowledge for teaching in PLCs has implications for the support of teachers' professional discourse and collaborative learning.

PLCs can bring together people with expertise from inside and outside of schools. Within schools, there is the deep knowledge teachers have about the context in which they are teaching: their students, their community, and the experience of "what works" within this context. Outside of schools, experts from school districts, universities, or PD organizations can provide specific knowledge about science and science teaching that could support teachers to make science more relevant and accessible for all students. Two

of the three PLCs observed for this dissertation were, in part, supported by outside science experts.

This dissertation comprises three articles that look closely at the hybrid space between knowledge of students, knowledge of teaching, and knowledge of science, and at how this space was explored in the discourse among teachers and between teachers and science experts in preparation of student-centered, inquiry-based teaching. This research focused on what kind of science knowledge teachers needed for teaching science; how teachers approached this science knowledge in their collaborative work and to what effect; and how the teachers' discourse created opportunities to enhance the group's science knowledge for teaching.

Several studies have shown that aspects of classroom teaching that are closely connected to subject matter content knowledge, such as guiding students' sense-making of science concepts, are often not performed at their full potential (Banilower, Heck, & Weiss, 2007; Gallagher, 2000; Weiss, Pasley, Smith, Banilower, & Heck, 2003). And while research shows that teacher collaboration is a promising form of PD that positively influences teachers' practice and students' learning (Vescio, Ross, & Adams, 2008), research also indicates that there are difficulties related to subject matter discourse and work in learning communities (Curry, 2008; Slavit, Kennedy, Lean, Nelson, & Deuel, 2011; Weaver & Lewis, 2010). This research has led to the hypothesis that improving how teachers discuss science knowledge during their collaborative work could have an additional positive impact on both teachers' practice and students' learning of science. Therefore, a focus on what role science knowledge for teaching played in the observed teacher PLCs seemed warranted.

This dissertation introduces three science teacher PLCs that were part of a PD project called Observing for Evidence of Learning (OEL). The OEL program provided all middle school science teachers in the Emerald School District<sup>3</sup> with support and time to meet several times a year. Participants in each of the three PLCs were observed while they worked together during a 2-day PLC cycle to improve the way they taught their curricula. All three PLCs were facilitated primarily by a participating teacher. Two of the PLC cycles were supported, in part, by a science expert who helped the teachers explore the science they needed for teaching a specific learning segment in their curriculum. The third PLC worked without the support of a science expert. The analysis focused on one of the many aspects of teacher collaboration by looking into teachers' discourse with a "science content lens." For this dissertation, the following questions were explored: (a) What kind of science knowledge did teachers discuss in preparation for teaching? (b) How did the teachers talk about content knowledge for science teaching, and how did this talk influence their collaborative lesson development and teaching practice? and (c) How did discursive accountabilities during teachers' collaboration provide opportunities for furthering their science knowledge for teaching?

Three lines of research informed the pursuit of the answers to these questions: First, literature on interactions and discourse during teacher collaboration, especially in the area of science and mathematics, supported the conceptual frameworks and the interpretation of findings (e.g., Feldman, 1996; Horn & Little, 2010; Slavit et al., 2011). Second, the characterization of the science knowledge needed for teaching was based on D. L. Ball and colleagues' framework of *content knowledge for teaching* (2008). Third,

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<sup>3</sup> Pseudonyms are used throughout this dissertation for the school district and for all participants in this study.

the Accountable Talk framework developed by Michaels, O'Connor, and Resnick (2008) for academically productive classroom discourse provided the basis for the *accountable teacher talk* framework developed for this study. A situative perspective on teachers' discourse and teachers' knowledge of science frames this qualitative research. This perspective places learning through discourse in a PLC in a social, cultural, and historical context.

I hope this academic endeavor, even with its limited scope, will inform the work of educators involved in brokering<sup>4</sup> (Wenger, 1998) between the academic and practical work of education. The study's findings could provide justification for and ideas on how to provide targeted support for PLCs to make teachers' work on science knowledge more useful to lesson planning, teaching, and student learning.

### **Synopsis**

This dissertation is divided into three main sections, each of which is structured as a stand-alone article. The dissertation as a whole tries to answer the overarching question of what role science knowledge for teaching plays in science teachers' collaborative work. The first article characterizes the dimensions of specialized science knowledge for teaching that were explored in two PLCs. The second article examines how content knowledge for science teaching was discussed in two PLCs and what effect this discourse had on the collaboratively developed lessons and teaching practice. The third article investigates learning opportunities for content knowledge for science teaching in one

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<sup>4</sup> "The job of brokering is complex. It involves processes of translation, coordination, and alignment between perspectives. It requires enough legitimacy to influence the development of a practice, mobilize attention, and address conflicting interest. It also requires the ability to link practices by facilitating transactions between them, and to cause learning by introducing into a practice elements of another" (Wenger, 1998, p. 109).

PLC, and how these learning opportunities were created through the accountabilities teachers assumed during discursive interactions.

To find suitable PLC cycles to investigate the research questions, 10 PLCs of high school and middle school science teachers in the Emerald School District were observed. Three of the middle school PLCs seemed best suited for this research with regard to group size, content focus, and uninterrupted flow of collaboration. Each of the three groups that were selected to be observed for the study worked collaboratively during a 2-day PLC cycle. Approximately 36 hours of the participants' discourse were recorded, and the participants' interactions were transcribed and analyzed (see Table 1).

Table 1  
*Overview of the Observed Professional Learning Communities (PLCs)*

PLC	Grade level	Content-study day prior to PLC cycle	PLC cycle (separate days)	# of teachers participating	Content support (PLC day 1)	# of teachers interviewed	Article in this thesis
1	8 <sup>th</sup>	yes	2 days	7	yes (1.5 hrs)	6	1 and 3
2	7 <sup>th</sup>	no	2 days	5	yes (2.5 hrs)	4	1 and 2
3	7 <sup>th</sup>	no	2 days	5	no	4	2

During the 2-day PLC cycle, the teachers collaboratively enhanced a learning segment that included science concepts from their curriculum that had been difficult for their students to understand. On the first day of the PLC cycle, prior to the lesson development, two of the observed PLCs were supported by an outside science expert; one PLC worked without science support. On Day 2 of the PLC cycle, the collaboratively developed lesson was taught and observed in a classroom. Then the teachers debriefed their observations and further adapted the lesson to better serve their students. One of the PLCs had an additional content study day prior to the PLC cycle.

The main data source for this research was the recordings of the teachers' discourse. Field notes, notes from classroom observations, curriculum documents, and semistructured interviews provided additional information about the context and supported the interpretation of the teachers' discourse. All data were surveyed for discourse episodes that contained science knowledge for teaching; these episodes were then analyzed from different perspectives and in different levels of detail for the three articles in this dissertation.

The first article, *Specialized Science Knowledge for Teaching in Science Teacher Learning Communities*, examines the science knowledge that teachers in two different PLCs explored in preparation for lesson planning. This article characterizes the different dimensions of specialized science knowledge for teaching that were discussed by the teachers along with a science expert. The article supports the utility of the concept of specialized science knowledge as predicted by the theory of content knowledge for teaching (D. L. Ball et al., 2008). It also provides insight into the complexity of the specialized science knowledge that teachers need for teaching and offers ideas of possible ways to support the development of such knowledge in teacher PLCs.

The second article, *Science-for-Teaching Discourse for Rigorous Lesson Development in Science Professional Learning Communities*, compares the discourse in two PLCs about content knowledge for science teaching, which included science knowledge for teaching and pedagogical content knowledge. A science expert from the local university assisted one of the PLCs for part of their collaborative work. The second PLC had no expert support. This article explores how the teachers in these two PLCs discussed science-for-teaching and how this influenced their lesson planning, teaching,

and debrief, especially with regard to their work with students' ideas. The findings suggest that examining the science knowledge for teaching needed for lesson planning might increase teachers' expectations for students' science learning and the rigor of the developed lessons.

The third article, *Every Voice Counts—Accountable Talk in Teacher Professional Learning Communities*, looks at the quality and content of teachers' discourse in one PLC. The analysis is based on a framework that combines the concept of content knowledge for teaching (D. L. Ball et al., 2008) and the Accountable Talk framework developed for academically productive discourse in classrooms (Michaels, O'Connor, & Rudnick 2008). The article explores the different accountabilities (to the community, to reasoning, and to knowledge) that teachers expressed during their discourse about content knowledge for science teaching, and how these affected their opportunities to learn and adapt their practice. The usability of an *accountable teacher talk* framework in teachers' PD, as analytical tool and as guide for facilitators and teachers, is discussed. Table II provides an overview of the research problems, hypotheses, frameworks, research questions, findings, and discussions in the three articles.

Research about teacher learning has struggled with the complexity of the situation where this learning takes place (Opfer & Pedder, 2011). I have limited the complexity of the subject by focusing on only one aspect of knowledge and learning (science knowledge for teaching) in only one kind of setting (teacher PLCs). This focus does not negate the importance of all other aspects of teacher learning. On the contrary, I believe that holding a magnifying glass over one particular point of teacher learning can add to the clarity of the whole picture.

The research presented here was not supported by a funding agency, so all teachers provided insight on their own terms. They were overly gracious with their time. However, as a researcher, I felt I had to honor their many obligations: I therefore remained a nonparticipant observer and tried to limit any distraction my involvement might have caused. Also, my own resources felt limited at times. Nevertheless, I tried what Opfer and Pedder (2011) suggested: “Ultimately, we need more studies that investigate how the generative mechanisms of teacher learning appear in different combinations and sequences, with different weights, in different but concrete situations” (p. 394). In this sense, this study may add important ideas to a theory of science teacher learning that is still in development.

Table 2  
*Science-for-Teaching Discourse in Science PLCs—Overview of Three Articles*

Structure \ Title	<b>Specialized Science Knowledge for Teaching in Science Teachers' Professional Learning Communities</b>	<b>Science-for-Teaching Discourse for Rigorous Lesson Development in Science Teachers' Professional Learning Communities</b>	<b>Every Voice Counts—Accountable Talk in Teachers' Professional Learning Communities</b>
Case	<p>PLCs 1 and 2:            Teachers and a science expert talk about science preparation (PLC 1) in the context of a collaborative teaching planning session (PLCs 1 and 2). This science support was considered by the teachers of both PLCs “as the best ones we had” (= relevance)</p>	<p>PLCs 2 and 3:            Comparison of two PLCs talking about science-for-teaching in a collaborative planning session for teaching. One of the PLCs had input from a science expert prior to the examined discourse; the other had no input from a science expert.</p>	<p>PLC 1:            Teachers talk in a collaborative planning session about teaching and learning science, thus creating opportunities to learn from and with each other.</p>
Research problem	<p>Pedagogical content knowledge is a widely used concept in science education. However, specialized (or pure) science knowledge needed for teaching, which is distinct, yet not independent, from knowledge about science &amp; students and science &amp; teaching, is not fully conceptualized, and empirical studies/practical examples in science are rare.</p>	<p>Research and the researcher’s own experience in schools show that there is often a lack of subject matter consideration in teacher-led PLCs. Consequently, teacher learning and teaching preparation is not optimal.</p>	<p>Cultural norms often put the responsibility for the functioning of a PLC mainly on the facilitator, negating the notion that PLCs depend on the contributions of all participants.</p>
Hypothesis	<p>Specialized content knowledge for teaching, as proposed by D. L. Ball, Thames, &amp; Phelps (2008), can be characterized as multidimensional in the area of science. This type of specialized content knowledge for teaching is valuable in preparation for lesson planning.</p>	<p>Short-term science interventions for PLCs can change how participants of a PLC talk about science-for-teaching in general.            Talk about science can influence how science lessons are planned.</p>	<p>During productive discourse in PLCs, all participants take on professional accountabilities, similar to the ones outlined in the Accountable Talk framework (Michaels, O’Connor, &amp; Resnick, 2008). If that is true, then moving from behavioral “norms of collaboration” to a framework built on professional accountabilities can improve academically productive discourse among teachers.</p>

Framework	D. L. Ball et al. (2008): Common content knowledge and specialized content knowledge for teaching	D. L. Ball et al. (2008): Content knowledge for teaching Deng (2007): School science	Michaels et al. (2008): Accountable Talk D. L. Ball et al. (2008): Content knowledge for teaching
Research questions	<ul style="list-style-type: none"> <li>• What dimensions of science did the teachers explore together with a science expert to prepare for collaborative lesson planning?</li> <li>• What characterizes the dimensions of science that teachers found relevant for teaching?</li> <li>• Why are these dimensions of science knowledge relevant for teaching certain topics?</li> </ul>	<ul style="list-style-type: none"> <li>• How do teachers in a PLC talk about content knowledge for science teaching when they are collaboratively planning their teaching?</li> <li>• What factors influence the features of this discourse about content knowledge for science teaching?</li> <li>• What is the effect of discourse about science knowledge for teaching on collaborative lesson development and teachers' practice?</li> </ul>	<ul style="list-style-type: none"> <li>• How are the different discursive accountabilities expressed during teachers' collaborative work in a PLC?</li> <li>• Do discursive accountabilities create learning opportunities for teachers? And if so, how?</li> <li>• Can a conceptualization of discursive accountabilities based on the accountable teacher talk framework support analysis and design of teachers' collaborative work?</li> </ul>
Main findings	Teachers approached the following dimensions of specialized science knowledge for teaching as relevant in preparing to teach: (a) foundational knowledge; (b) knowledge of representations; (c) knowledge of content boundaries; (d) knowledge of experiments and experiences; (e) knowledge of the nature of science; and (f) knowledge of the sociocultural and historic context of science ideas.	During lesson planning, the PLC without science intervention focused mainly on students' interest and on teaching strategies, without strongly connecting their ideas to the science inherent in the lesson. The comparison group, the PLC with science support, showed considerations of science & students and science & teaching in their discourse beyond the time of the science intervention. Also, they developed a learning segment that contained higher expectations for students' reasoning about the core scientific concepts, and a more targeted approach to students' science ideas, than the unsupported PLC did.	Participants in the observed PLC expressed accountabilities to the community, to reasoning, and to knowledge about science and students, science and teaching, and science content knowledge. During episodes that offered learning opportunities for the teachers, individual teachers took on a particular strong stand toward one of the accountabilities, thus disrupting the flow of agreeable talk and lengthening the time the PLC stayed with one problem of practice.

<p>Conclusions and discussion</p>	<p>Specialized science knowledge as predicted by the theory of <i>content knowledge for teaching</i> (D. L. Ball et al., 2008) is multidimensional and complex, and not a transformation of academic knowledge, but a epistemic discipline in its own right (Deng, 2007).</p>	<p>Science content support in PLCs can strengthen talk about science-for-teaching. Keeping science knowledge needed for teaching in the forefront of teachers' collaborative work may increase the cognitive demand of the lessons developed as well as teachers' ability to work with students' emerging science ideas.</p>	<p>An accountable teacher talk framework may be useful for analyzing and supporting discourse in PLCs. Moving away from behavioral norms of collaboration toward professional accountabilities, for each participant in a PLC, could increase learning opportunities for the collaborating teachers and may increase the PLC's independence from outside facilitation.</p>
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*Note.* PLC = professional learning community.

## **Article 1**

### **Specialized Science Knowledge for Teaching in Science Teachers' Professional Learning Communities**

#### **Abstract**

The practice-based theory of content knowledge for teaching developed by D. L. Ball and colleagues in the realm of mathematics teaching predicts a specialized subject matter knowledge that is uniquely needed for teaching (2008). In the literature about pedagogical content knowledge for science teaching, the characteristics of specialized science knowledge are underresearched and only vaguely defined. This study was conducted to add an empirical base and further conceptualization of such science knowledge for teaching. At the center of the study were middle school science teachers who collaborated in two different professional learning communities to improve their teaching practice. Each learning community was in part supported by a science expert. The teachers' discourse allowed identification and analysis of the special nature of science knowledge that these teachers found relevant for their teaching. The study's findings suggest that teachers need specialized science knowledge for teaching that is extensive, detailed, and multidimensional. Five dimensions of specialized science knowledge for teaching were identified: (a) foundational knowledge, (b) knowledge of different representations, (c) knowledge of boundary content, (d) experiments and experiences, and (e) the nature of science and the sociocultural and historic context of science ideas. A clearer conceptual understanding of what kind of science knowledge teachers need could support development of better-targeted professional content education for secondary science teachers.

## Introduction

“Unbalanced forces will cause changes in speed.” This sentence is easy enough to repeat, even for middle school students. But what do science teachers need to know to make the science of Newton’s second law come to life and be accessible and understandable for all the students in their classes? This unique knowledge needed for teaching becomes—at least in part—apparent when teachers work collaboratively on their teaching practice in professional learning communities (PLCs).

Specialized subject matter knowledge uniquely necessary for teaching has been predicted by the practice-based theory of content knowledge for teaching developed by D. L. Ball, Thames, and Phelps (2008) in the realm of mathematics teaching. In the literature about pedagogical content knowledge for science teaching, the characteristics of specialized science knowledge are underresearched and only vaguely defined. This study was conducted to begin to fill this void and add an empirical base and further conceptualization of specialized science knowledge for teaching.

At the center of the study were middle school science teachers who collaborated in two different PLCs to improve their teaching practice. The science teachers’ talk about science offered the opportunity to inquire into the following questions: What dimensions of science did the teachers explore together with a science expert to prepare for collaborative lesson planning? What characterizes the dimensions of science that teachers found relevant for teaching? Why are these dimensions of science knowledge relevant for teaching certain topics? A clearer conceptual understanding of what kind of science knowledge teachers need can support the development of better-targeted professional content education for secondary science teachers.

While the K–12 science education framework (National Research Council, 2011) and *Next Generation Science Standards* (NGSS Lead States, 2013) provide detailed guidance about the science understanding students should develop from kindergarten to 12th grade, the information about what science knowledge teachers need to know in order to teach these standards can only be inferred. Similarly, the literature about science education reform provides a vision of what science teachers should be able to do (Duschl, Schweingruber, Shouse, & National Research Council, 2007; National Research Council, 1996, 2011), but no guideline on how this vision can be reached. Such reform documents, together with policies for accountability and evaluation (Ingersoll, 2012; MET Project, 2013), continuously increase the expectations for teachers' professional knowledge and skills.

Professional development (PD) is the major support system for teachers to reach and keep up with these increased expectations. Yet, while there seems to be consensus in the teacher education community that effective forms of PD should include both collaboration and a subject matter component (Desimone, 2011), there is no such consensus about what kind of subject matter knowledge should be developed during teachers' collaborations. Often, the PD that is designed for teachers addresses science at the level of student understanding (Weiss & Pasley, 2006), or presents science content that is irrelevant to the context in which teachers are working (M. Kennedy, 1998b; Zhang, Lundeberg, & Eberhardt, 2011). Or, teachers' PLCs may lack sufficient subject matter focus altogether (Slavit & Nelson, 2010).

This study explored the science that middle school science teachers discussed during a special form of PD that provided short-term subject matter support for ongoing PLCs. The study illustrates the kind of science knowledge that experienced teachers found relevant to collaborative lesson development. To date, research on teachers' professional subject matter

knowledge has either analyzed teaching practice (Hill, Rowan, & Ball, 2005), formally assessed knowledge for teaching (Akerson, Cullen, & Hanson, 2009), or explored teachers' understanding of teaching through interviews and self-reflection (Abd-El-Khalick & BouJaoude, 1997; Asikainen & Hirvonen, 2010; Drechsler & Van Driel, 2008; Hill, Blunk et al., 2008). Observing teachers as they engage collaboratively in content work brings a novel approach to this line of research.

In the two observed PLCs, dimensions of science knowledge that experienced teachers found relevant for teaching became explicit through teachers' discourse and interactions. This kind of knowledge would not necessarily have been visible in the teachers' practice or knowledge tests. Furthermore, with the added knowledge resources provided by a science expert, who was present during a part of the PLC time, these teachers could explore knowledge for teaching that did not exist within their group. To characterize the science knowledge for teaching that teachers explored in these two PLCs, the teachers' discourse and interactions were examined with a "science content lens." Examples of science knowledge that the teachers discussed were coded and categorized to characterize different dimensions of specialized science knowledge and to explore why these dimension may be relevant for the teaching of certain topics.

This study focuses on specialized science knowledge for teaching. It thus distinguishes itself from studies about pedagogical content knowledge that explore a wider range of teacher professional knowledge, including knowledge of students and knowledge of teaching. While the borders between these types of knowledge are blurred, a focus on subject matter may be especially helpful for providers of subject matter PD for science teachers. The findings may also inform researchers as well as practitioners who are working in the area of science teacher collaboration.

This article first places the study within research about teachers' subject matter knowledge and collaborative science professional development. Next, it introduces D. L. Ball's theory of content knowledge for teaching as the conceptual framework for this research (D. L. Ball et al., 2008). After the context and methodology of the study are provided, the dimensions of science knowledge for teaching that two science PLCs collaboratively explored are presented and interpreted. These findings were triangulated through interviews with science teachers and science experts. The article concludes with a discussion and recommendations for future support of subject matter work in PLCs.

### **Specialized Subject Matter Knowledge in the Literature**

Nearly 25 years ago, D.L. Ball and McDiarmid (1989) wrote: "Until a few years ago, the subject matter knowledge of teachers was largely taken for granted in teacher education as well as in research on teaching" (p. 20). Not much seems to have changed since then. While there is little doubt in the educational community that appropriate subject matter knowledge builds a teacher's basis for teaching a certain school subject (Borko, 2004; Darling-Hammond & Bransford, 2005; Saderholm & Tretter, 2008; Thompson, Windschitl, & Braaten, 2010; White & Frederiksen, 2005; Windschitl, 2009), there is still little research on the subject matter knowledge that teachers develop, or fail to develop, over the course of their career in order to optimize their teaching and their students' science learning.

There are at least five system-based reasons that teachers may not have optimal subject matter knowledge in science: (a) teachers' initial science education is not adequate for the science they are teaching (Davis, Petish, & Smithey, 2006); (b) teachers are required to teach out of their field of expertise (Ingersoll, 2007); (c) teachers' own development of knowledge of science for teaching over the course of their careers is inconsistent (Arzi & White, 2008) and

inadequately supported (Gray & Bryce, 2006); (d) teachers have little experience with “real science”—in other words, they lack insight into the work of research science or other science-intensive professions (Windschitl, 2004); and (e) scientific knowledge and related socio-scientific issues are changing rapidly (Ingersoll, 2007; Sadler, 2004).

In science, as in other subject areas, teachers’ knowledge needs to go beyond what they want to teach. This is central to teachers being able to interpret and assess students’ science ideas, to work with these ideas to further enhance all students’ science understanding, and to support students in becoming fluent in the different cognitive demands science entails (Darling-Hammond & Bransford, 2005; Little, Gearhart, Curry, & Kafka, 2003). Limited knowledge of a subject may require teachers to rely on textbooks and facts (Windschitl, Thompson, & Braaten, 2009) and lead them to teaching students what M. Kennedy (1998a) calls “recitational knowledge,” which is when students recite facts and schoolbook quotes instead of developing a conceptual understanding. However, there is no consensus among educators about the kind of subject matter knowledge teachers themselves should possess, and this is certainly true in science education. The science knowledge needed for teaching has not yet been sufficiently defined, despite the ubiquitous use of the term pedagogical content knowledge that Shulman coined in his seminal framework (1986).

Shulman asked, “Where did the subject matter go? What happened to the content?” (1986, p.5). He labeled the lack of subject matter issues in education research and policies as the missing paradigm, and offered a new perspective on teacher knowledge. This perspective suggests three categories of teachers’ content knowledge: (a) content knowledge in teaching, (b) pedagogical content knowledge, and (c) curricular knowledge. However, as over the years more and more areas of teacher professional knowledge have been merged into the one concept of

“pedagogical content knowledge,” the less important subject matter knowledge seems to have become. Toh and Tsoi (2008), for example, stated that it is important “for the master science teacher to have a well-developed pedagogical content knowledge rather than be an expert in content knowledge” (p. 620). One can argue differently: that master science teachers are experts in specialized science knowledge for teaching, which is different from the type of science that research scientists or scientists in other professions need.

Content knowledge in teaching, according to Shulman (1986), includes teachers’ knowledge of science concepts and facts, the various possibilities of their organization, and their relative importance compared to each other (substantive knowledge). It also includes the knowledge of what counts as science and how scientific ideas are warranted (syntactic knowledge). For Shulman (1986), the subject matter knowledge teachers gain at the college level undergoes a transformation to become content knowledge in and for teaching. Later researchers (Barnett & Hodson, 2001; Botha, 2012; Deng, 2007; Kind, 2009; Toh & Tsoi, 2008; Van Driel, Verloop, & de Vos, 1998) picked up the idea of transformation: “What skillful teachers do is transform subject matter into forms that are more accessible to their students” (Barnett, 2001, p. 432). Underlying this idea of transformation is the assumption that teachers have sufficient subject matter knowledge, and that it is possible for individual teachers to enact this transformation by integrating the initial subject matter knowledge with other knowledge for teaching gained through teaching experience.

There is only a vague correlation between teachers’ college science education and student learning (Bolyard & Moyer-Packenham, 2008). This indicates that the transformation of academic science knowledge into specialized science knowledge for teaching is mostly insufficient. Arzi and White (2008) show more specifically how and where this transformation is

weak. They followed 22 science teachers in Australia from their preservice training in 1985 until 2002, and found that indeed, over the years of practice, teachers' science knowledge improved and became more integrated (or transformed). But this improvement was neither optimal across teachers nor across science domains. All teachers in this study held a science degree in biology, chemistry, or physics, and over their years of practice, their subject knowledge for teaching improved—but mostly in the areas in which they already had a good foundation. Areas that were outside the teachers' initial knowledge base and interest often remained underdeveloped. This indicates the difficulty of the transformation from academic science into specialized science knowledge for teaching.

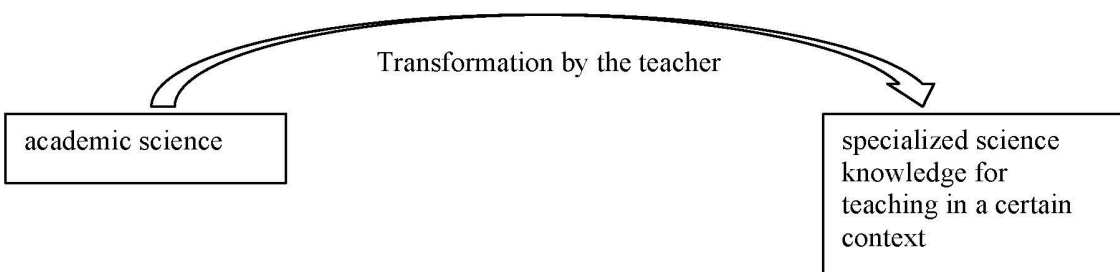
In contrast, Deng (2007) distinguished teachers' specialized science knowledge from their academic science knowledge. He pointed out that

their [researchers'] exclusive focus on the subject matter of an academic discipline and its transformation has set aside questions concerning the nature and character of the subject matter of a school subject which, one can argue, are important for a proper understanding of teachers' specialized subject-matter knowledge (p. 504)

and argues that the transformation should not have to be teachers' work, but should be part of their education. Deng (2007) proposed that school science be considered a disciplinary knowledge in its own right, separate from academic science. Both disciplines are concerned with the same science ideas, but serve different purposes. Based on research on two experienced physics teachers, Deng describes five dimensions of specialized subject matter knowledge for teachers (p. 521) in which school science distinguishes itself from academic science: (a) the logical dimension: knowing the relationships among concepts and principles (products of knowing); (b) the psychological dimension: knowing how such concepts and principles can be developed; (c) the pedagogical dimension: knowing big ideas and representations; (d) the epistemological dimension: knowing how scientists come to know; and (e) the sociocultural

dimension: knowing how the school science subject is situated in and shaped by a particular social and cultural context.

Using Deng’s idea, I hypothesize that if *science-for-teaching* (school science) were established as its own discipline with a defined body of knowledge, then the task of transforming science knowledge to be useful for teaching in a certain context would require less work, and teachers could be more successful in performing it.

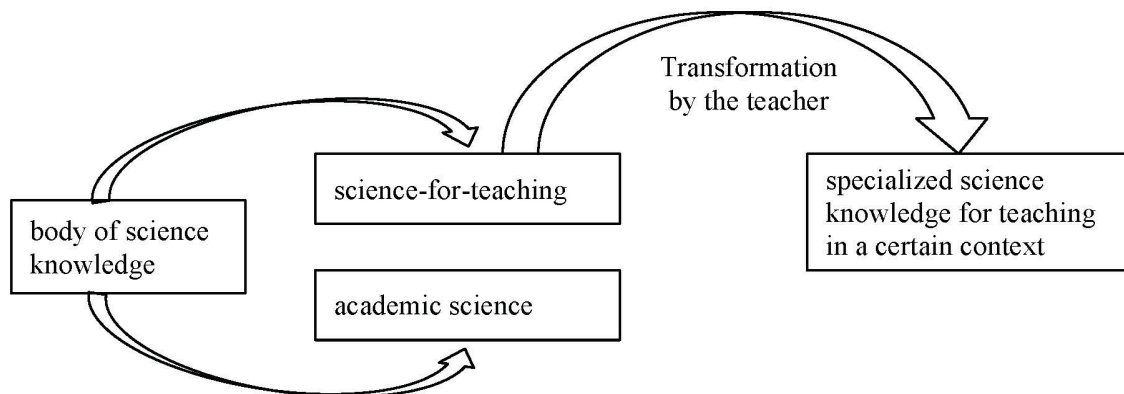


*Figure 1.1.* Transformation of academic science—traditional view. Academic science is transformed into specialized science knowledge for teaching by the individual teacher.

Figure 1.1 shows a common view of a teacher’s responsibility to transform academic science knowledge into specialized subject matter knowledge for teaching. This transformation requires extensive work. In this view, a student in an undergraduate biology course might, for example, cover the cell biology topic “Biomembranes: Compositions, Structure, and Dynamics” in one afternoon session. This session will allow for only one kind of abstract language and set of definitions, one kind of visualization, and a very limited view of how this knowledge had been developed by the science community. Later, this science knowledge that a teacher had acquired as a student has to be “transformed” into science knowledge for teaching. This work of transformation is entirely the responsibility of the teacher.

Figure 1.2 shows the adapted view of transformation as proposed by Deng (2007) with *science-for-teaching* (school science) as a distinct discipline equivalent to academic science.

Science-for-teaching draws from the body of science knowledge (which no discipline can grasp in its entirety) the parts that are useful for teaching. If teachers have access to science-for-teaching, then their work to transform this knowledge into specialized science knowledge for teaching in a certain context is reduced. Teachers can then invest more time and effort in preparing for teaching and supporting student learning.



*Figure 1.2.* Transformation of science—proposed view. Science-for-teaching (school science) reduces the necessary work of transformation into specialized science knowledge as needed in a certain teaching context.

A college science course for prospective science teachers could, for example, offer a more limited number of science topics than a course preparing research scientists would. In addition to learning the fundamentals of “Biomembranes: Compositions, Structure, and Dynamics,” a science-for-teaching course could ask prospective teachers to work together to interpret and construct various models of cell membranes, including models that may include logical but scientifically incorrect elements. Consequently, the students (prospective teachers) could capture the scientific thinking behind such models, their benefits and limitations for understanding the functions they represent, and their connections to other areas of science knowledge. Such education might enable teachers to know science in the way Driver, Newton, and Osborne (2000) described: “The claim ‘to know’ science is a statement that one knows not

only what a phenomenon is, but also how it relates to other events, why it is important, and how this particular view of the world came to be” (p. 297).

The practice-based theory of content knowledge for teaching, developed by D. L. Ball and colleagues (2008) in the area of mathematics also includes the notion of a specialized content knowledge for teaching and will further assist the conceptualization of science-for-teaching in this study.

### **Conceptual Framework: Content Knowledge for Teaching**

D. L. Ball and colleagues (2008) addressed the lack of a conceptualization of teachers’ subject matter knowledge in the realm of math teaching and developed a practice-based theory of content knowledge needed for teaching. This theory treats subject matter knowledge for teaching and pedagogical content knowledge as separate entities, similar to the discussion in Shulman (1986) but in contrast to the overarching use of pedagogical content knowledge in other publications. D. L. Ball and colleagues defined pedagogical content knowledge as “knowledge of content and students” and “knowledge of content and teaching.” pedagogical content knowledge is thus separate from the “pure” subject matter knowledge required for teaching (Figure 1.3). This section discusses how practice-based theory was adapted for science teaching with a focus on this “pure” subject matter knowledge.

D. L. Ball and colleagues (2008) established that subject matter knowledge for teaching contains two domains: (a) common content knowledge that builds the basis for both academic and school subjects, and (b) specialized science knowledge that is uniquely needed for the teaching profession. To use the example of knowledge regarding cell membranes again: Common content knowledge would include the parts and function of a cell membrane. Professionals in the life sciences share with biology teachers this common science knowledge. A

scientist who works in cell biology will acquire additional and specialized science knowledge about cell membranes. The biology teacher who teaches about cells will as well. Research scientists, for example, aim for the most parsimonious and appropriate explanation and representations of a scientific phenomenon, such as a cell membrane, when they investigate unknown areas and expand the scope of existing knowledge. Professionals in the applied sciences, like engineers, health care professionals, and conservationists, use science knowledge to find the best solution to a problem. These science professionals are using the basics of science fluently, efficiently, and tacitly (Bransford, Brown, & Cocking, 2000). Their specialized science knowledge for research would not be suitable for teaching middle school or high school students. Even if scientists and science teachers were to start their careers with the same university courses, over time their specialized science knowledge will become very different, but not necessarily in sophistication.

Science teachers will develop unique aspects of their subject matter that other science professionals will neither have nor need. Science teachers, who work with students for whom most of science is new, know the basics of science in an explicit and detailed fashion. (D. L. Ball and colleagues [2008] call this *decompressed knowledge*.) Science teachers have to be aware of the many possible ways their students may think about and understand scientific phenomena like the functioning of a cell membrane. This may include, besides the “sanctioned representations,” alternative ideas or new inventions (diSessa, 2004). And teachers not only need to be aware of the features and details of science phenomena that are essential to the scientific explanation, they must also be able to express these features in various ways. As science contains mathematics, some of the specialized content knowledge defined by D. L. Ball and colleagues (2008), concerning, for example, basic computations, is similar in both subject areas. In both subject

areas, a teacher needs to explicitly understand the various procedures that exist, and why these procedures can lead to a solution (or even a dead end). D. L. Ball and colleagues exemplify this “specialized form of pure subject matter knowledge” (2008, p. 396) with elementary mathematics tasks. An examination into this type of “pure” subject matter knowledge unique to teaching science has not, to my knowledge, so far been undertaken.

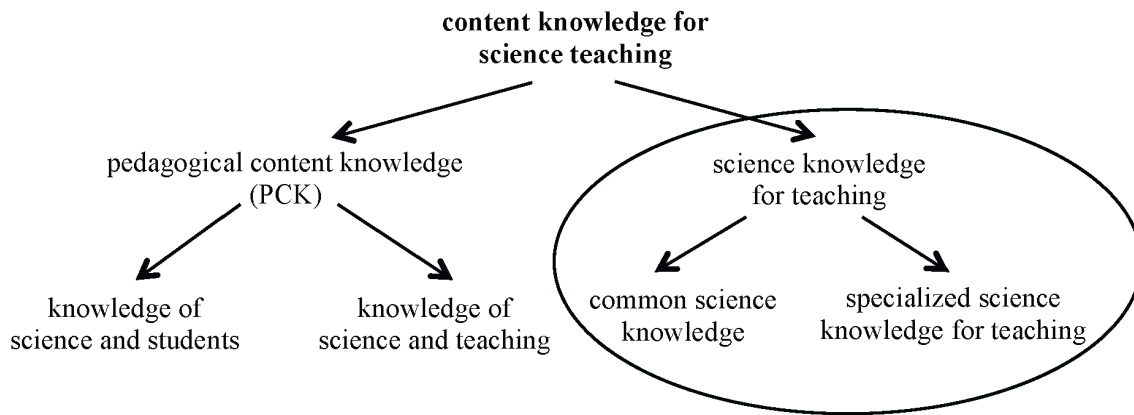


Figure 1.3. Domains of content knowledge for science teaching. Idea from “Content Knowledge for Teaching. What Makes It Special?” by D. L. Ball, M. Thames, and G. Phelps, 2008, *Journal of Teacher Education*, 59(5), pp. 389–407.

The three slightly different conceptualizations of specialized subject matter knowledge for teaching by Shulman (1986), Deng (2007), and D. L. Ball and colleagues (2008) will guide the identification and analysis of the science that was discussed between the teachers and science expert during the observed PLCs. This discourse about science allows for observation of the normally tacit specialized science knowledge for teaching, and can demonstrate some of the transformation and expansion needed for teachers to gain the science knowledge necessary to their specific teaching context.

### Professional Development Design Context

Collaborative work in form of PLCs has become more common in US schools over the last ten years. While some secondary science teachers nowadays have collaborative work time on a regular basis, the time is often limited to one or two class periods every other week or once a month (based on my personal experience of early release time in several schools in the Puget Sound region). Often the goals set for these PLCs are for teachers to implement state and local requirements (such as new state standards or teaching strategies the school district has decided to focus on). Many PLCs are led by *lead teachers* (based on my personal experience with PLCs and informal conversations with science teachers and science administrators from several school districts).

The two PLC cycles observed in this study were part of a PD model that differed from the description above in three main ways: (a) The PLC cycles took place only three times a year, but stretched over 2 days each. (b) The focus of the PLC work was to improve the commonly used curricula and teaching practices. The teachers could decide which curricular unit needed improvement and how to improve it. (c) Support for the PLCs varied according to need (and availability) and could include professional facilitators and science experts, both from partner organizations. Additional district-wide PD supported the teachers' collaborative work in the PLCs.

### **Observing for Evidence of Learning**

The school district in which this study took place began implementing the Observing for Evidence of Learning (OEL) model of PD in 2009 through a Washington State Mathematics and Science Partnerships grant. It was mandatory for all middle school science teachers to participate in this PD for three 2-day PLC cycles per year for 3 years.

During each 2-day PLC cycle (see Figure 1.4), a group of teachers works together to improve the curriculum they are currently teaching to better serve their unique student populations. At the same time, the OEL program aspires to encourage professional discourse in order to enhance the general teaching practice over time. Changes in the teaching practice are based on evidence of student learning gained during the enactment of the collaboratively developed lesson, when one of the teachers is teaching the lesson in her classroom while the other teachers observe the students.

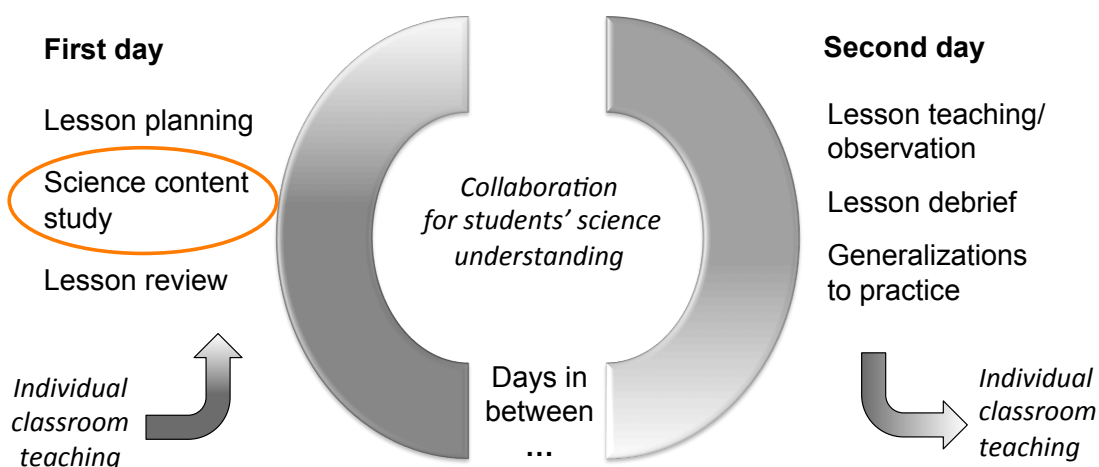


Figure 1.4. Two-day collaborative PLC cycle. The science content study phase (circled) was supported by a science expert.

In preparation for a PLC cycle, teachers choose from their common curriculum a learning segment that has proven difficult for students' conceptual understanding. During the 2 days of collaboration, a detailed protocol guides groups of teachers through six phases (Figure 1.4). On Day 1, teachers engage in (a) *lesson examination*, during which they have an opportunity to share past teaching experience; (b) *a science content study*, during which they are encouraged to discuss and solidify their understanding of the learning segment's scientific concepts; and (c) *lesson refinement*, during which they work on improving the learning segment. On Day 2,

teachers engage in (d) *classroom observation*, during which teachers have an opportunity to teach a lesson from the learning segment and observe students' interactions; after which they have (e) *individual reflection time*, and (f) *debrief* together the observed evidence of students' learning, which results in further improving the learning segment. Between each of the three PLC cycles, teachers (g) implement in their own classrooms the *generalizations to practice* that they had agreed on.

In other words, the teachers plan a lesson or improve a lesson from their curriculum together on Day 1 of the PLC cycle. A few days later, on Day 2 of the PLC cycle, one of the teachers teaches this lesson in her classroom while the other teachers observe and listen to students. (Most often the lesson is designed so that students work in groups over a period of time.) Then the teachers meet again and debrief what they saw and heard, and the student work they collected. Based on these observations and the conclusions drawn as a group during the PLC, the teachers most often enhance the lesson further or create a follow-up lesson. Between PLC cycles, the teachers try out strategies they experienced as successful in supporting students' learning.

At the time of the two PLC cycles that were observed for this study, the district was in the last cycle of its third and final year of its OEL program. So, it was the ninth time these teachers had participated in a PLC cycle. One PLC cycle was concerned with improving the teaching of adaptation and natural selection, and for the purposes of this study, it will be named the *Biology-PLC*. The other PLC aimed to improve the teaching of the concepts of force and motion and will be named the *Physics-PLC*.

On Day 1 of the PLC cycle, the Biology-PLC was co-facilitated by a PD provider and visited by a science expert for part of the day. The Physics-PLC had, in addition to and prior to

the PLC cycle, a science study day. This extra study day was requested by the teachers as preparation for lesson planning, to solidify their physics understanding for the chosen learning segment. A science expert collaborated with the teachers on this study day and also visited the Physics-PLC on Day 1 of the PLC cycle. For this study, the science-rich discourse during the Physics-PLC's additional content day and during the science experts' visits on Day 1 of both PLC cycles were the main sources of findings.

### **Setting and Participants**

The OEL PD model seemed especially apt for inquiring into teachers' specialized science knowledge because the collaboration of experienced teachers, an established PLC routine, and science content support together bore potential for substantive and extended discourse about specialized science-for-teaching. At the time the study was conducted, the school district was in the 3rd and final year of implementing the OEL PLC cycles as a mandatory PD model for all secondary science teachers. It was the ninth PLC cycle for the Biology-PLC and Physics-PLC teachers, therefore they knew each other well. They knew not just the colleagues in their own schools, but their colleagues across the school district. They were familiar with the demographics of the students at the different schools, and the resulting demands for teaching. They were also versed in using the OEL protocol and process.

#### **School District**

With about 19,000 students, Emerald School District (SD)<sup>5</sup> is a relatively large school district in the Pacific Northwest region of the United States. It serves a medium-sized city as well as suburban and rural areas. Emerald SD has a robust science program that supports science learning from elementary school onward, and it provides its teachers with a variety of PD

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<sup>5</sup> Pseudonyms are used for all names of individuals, schools, and school districts throughout this article.

opportunities. From 2003 to 2006, the school district adopted inquiry-based curricula for middle school science. Science teacher retention in Emerald SD has been high in recent years, so by the time this study took place in 2012, most of the middle school science teachers had been teaching the same curriculum for a few years and were quite familiar with its instructional approach and content. The science materials needed for the curricula are refurbished at the district's science resource center. For OEL implementation, the district collaborated with a small nonprofit organization that supports public school science education in the region. This organization works closely with local scientists and science educators.

### **Middle Schools and Middle School Teachers**

Emerald SD has five middle schools, each with five to seven science teachers for grades 6 through 8. The sizes of the middle schools range between 600 and 1,100 students. Emerald SD middle school students' ethnicities are comparable to the state's general student population: 60–65% of students are White, 10–19% are Hispanic, 5–20% are Asian, 11–21% are Asian/Pacific Islander, and 2.5–5.5% are Black. About 9% of students are Transitional Bilingual and 8–14% of students receive special education. Emerald SD's results in the state's eighth-grade science assessment in 2012 (78.6%) were considerably higher than the state average of 66.4%. The five middle schools serve a wide range of communities with regard to socioeconomic status. This diversity is reflected by the state science assessment test scores. For example, on average only 19% of Rosegarden Middle School's students are eligible for Free and Reduced Price Meals (FPM), and 91% of its students met the assessment's science standards for eighth grade in 2012. On the other side of the school district, 65% of Eastside Middle School students are eligible for FPM, and in 2012 only 60% of its eighth-grade students met science standards (Office of Superintendent of Public Instruction, 2012).

All 7 eighth-grade science teachers from the district participated in the Physics-PLC. Their experience as science teachers ranged from seven to 24 years. Four teachers had a master's degree in science education, three had a bachelor's degree. Half of the district's seventh-grade teachers participated in the Biology-PLC. The teaching experience of these five teachers ranged from four to 24 years. Three of them had a master's degree in science education, two had a bachelor's degree. These experienced teachers had over the course of their career attended numerous science PD trainings, including physics and biology PD offered by local universities and, most recently, three summer institutes addressing physical science that were arranged by the school district in cooperation with a local university and the PD provider of the observed PLCs. These teachers were all well aware of the disparities in their students' achievements on the state's yearly science assessment and were determined to do the best to leverage learning opportunities for all their students.

### **Science Experts**

The science expert who supported the Biology-PLC was a graduate student from the local university with two master's degrees, one in education and one in science. She had prior teaching experience and had previously supported several other PLCs in the region during their collaborative work on biology topics. The science expert who supported the Physics-PLC was a well-known physics education expert in the region and very experienced in working with science teachers on physics content. The experts' visits were organized by the PD providers. However, the teachers in the Physics-PLC had explicitly asked the school district's science administration for a science study day with the science expert prior to their collaboration on force and motion.

### **Professional Learning Communities**

To find suitable PLC cycles where the research questions could be investigated, 10 PLCs of high school and middle school teachers in the Emerald SD were observed. Purposeful sampling (Patton, 2002) of suitable cases that could provide insight into specialized science knowledge for teaching was based on four selection criteria: (a) A strong and extended discourse focused on science content; (b) an uninterrupted flow of collaboration; (c) a small group size that allowed the group to stay together for the entire PLC cycle (some other PLC cycles divided tasks between smaller groups); and (d) the participation of all teachers in the discourse about science. Only two of the observed PLCs, both supported during part of the PLC time by a science expert, fulfilled this criteria. One of these two PLCs had a content study day prior to their PLC cycle (see Table 1.1).

The content discussed during the PLC cycles was determined by the topic and lesson chosen by the teachers. While the science experts offered lots of science ideas, the choice of which ideas to discuss in depth, and how, was strongly influenced by the teachers. The dimensions of science knowledge that were important for teaching became observable through the interplay between the content needs expressed by the teachers and the science knowledge provided by the expert. The discourse about two different science disciplines, physics and biology, in two different PLCs made it possible to detect dimensions of specialized science knowledge across these disciplines.

Table 1.1.  
*Overview of the Observed Professional Learning Communities (PLCs)*

PLC	Grade Level	Content Study Day Prior to PLC Cycle	PLC Cycle	# of Teachers Participating	Visiting Science Expert (PLC Day 1)	# of Teachers Interviewed
Physics	8 <sup>th</sup>	yes	2 days	7 teachers	yes (1.5 hrs)	6
Biology	7 <sup>th</sup>	no	2 days	5 teachers	yes (2.5 hrs)	4

*Note.* The 2 days in each PLC cycle were non-consecutive.

**The Physics-PLC and Newton's second law.** The teachers in the Physics-PLC reported that only some of their students had come to a good and lasting understanding of Newton's second law by the end of their time in middle school. They worried that their students were not optimally prepared for physics in high school. The teachers' goal was to improve the learning opportunities for their students, and they chose for this PLC cycle the learning segment in their curriculum that included the concept of unbalanced forces and the resulting change of motion. In particular, they thought to substitute or complement the fan car activity in their *Energy, Machines, and Motion* curriculum (Toler & National Science Resources Center, 2000), because poorly functioning equipment caused, rather than dispelled, students' misconceptions. However, the teachers in the PLC did not feel well equipped to tackle this effort alone, since none of them had a college background in physics, and some had never taught any physics before. Therefore, they had asked the school science administration to have additional time with a science expert to work on the science content. This time was granted as a PD day prior to the PLC cycle.

The PLC cycle itself was facilitated by one of the teachers, Eric, who had taken on facilitation after he became convinced of the value of their collaboration during the second year of the OEL program. Donna was chosen to be the observation teacher for scheduling considerations: She was at the right place in the curriculum to make observing the collaboratively developed lesson feasible. Donna had previously taught the physics curriculum.

**The Biology-PLC and natural selection.** In the past, a PLC with all 10 seventh-grade science teachers in the district had proven too large to be productive, so for this PLC cycle, these teachers were divided into two groups of five. The district's science administration had suggested that both subgroups focus on the learning segment about adaptation and natural

selection. One of these subgroups was observed for this study. The suggested topics were part of the *Population and Ecosystems* curriculum (FOSS, Lawrence Hall of Science, & Delta Education, 2004) that was taught at the end of the school year, and that many teachers had rushed through, if they had time to teach it at all. Therefore, the teachers' expertise with these concepts was limited. Vanessa, a science expert, was invited to support the teachers' inquiry into the science needed to enhance the teaching of this learning segment. She stayed longer than the allocated 1.5 hours in order to run through the natural selection simulation provided by the curriculum with the teachers. An outside facilitator was present on the first day of the cycle, but did not participate much, as the teachers themselves were on task during the entire time.

### **Methods**

When teachers look for teaching content in private, by searching in printed or online publications, the interactions between the content resources and the teacher stay hidden. When content knowledge is handed to teachers in the form of conference presentations or similar forms of PD, the flow of information is in large part unidirectional. How teachers interact with the knowledge they receive is seldom observable. Even in PD with active participation, the learning objectives are often set by the provider in collaboration with school administration and may be relatively inflexible (personal conversations with numerous science teachers). In such cases, there is little opportunity for teachers to decide what content is important for them. On the contrary, a collaborative setting, like a PLC, allows for a unique window into the content work of teachers. This is especially true when teachers have extended conversations about the science they need for teaching with a science expert who can add necessary science knowledge that is missing in the group. Therefore, two teacher PLCs with a strong science content focus were chosen to answer the following research questions:

- What dimensions of science did the teachers explore together with a science expert to prepare for collaborative lesson planning?
- What characterizes the dimensions of science that teachers found relevant for teaching?
- Why are these dimensions of science knowledge relevant for teaching certain topics?

### **Data Sources**

The data for this study was gathered from two main sources: observations of the Physics-PLC's and Biology PLC's collaboration, and one-on-one semistructured interviews with participants (teachers, science experts, and a science administrator).

**Observations.** The discourse of the participants of the two PLC cycles was audio recorded in their entirety, and parts of the cycles were also video recorded. For the Physics-PLC, the content day preceding the PLC cycle was also recorded and included in the analysis. In addition, field notes were taken by the researcher in a “peripheral membership role” (Adler and Adler, 1998, as cited in Merriam, 2009, p. 124). The researcher, while known to some of the participants, did not interact with them during the observations. The recordings and field notes provided the basis for determining episodes that contained science knowledge for teaching (Erickson, 1986) that could be further analyzed for specialized science knowledge for teaching. The main data for the Biology-PLC came from the first day of the PLC cycle, before and during the science expert's visits. In the case of the Physics-PLC, the main data came from the science study day the teachers had with the science expert prior to the PLC cycle.

**Interviews.** The one-on-one semistructured interviews were conducted days or weeks after the observed PLC cycle. Lesson plans and student artifacts served as prompts for the teachers to recollect the events. During these interviews, the science teachers reflected on their

stance toward the science knowledge for teaching necessary for supporting science learning in their classrooms, on how they had experienced the science content negotiation during the observed PLC cycle, and on how the science discourse influenced their practice. The teachers' recounts of the influence the discourse about science had on their teaching practice was important for determining the relevance of the science content discussed during the teachers' collaborative work. The science experts were asked about their preparation for and reflection on the OEL content study phase they had supported. Interviews with the school administrators and the OEL program director rounded out the picture of the context in which the OEL PLC cycles took place. All interviews were audio recorded. Because emphasis in answering the questions differed for each individual, and the time available varied for each interview, the content discussed during the interviews varied widely.

**Documents.** In addition, the lessons in the *Energy, Machines, and Motion* curriculum (Toler & National Science Resources Center, 2000) and the *Population and Ecosystems* curriculum (FOSS, Lawrence Hall of Science, & Delta Education, 2004) were reviewed in order to compare the curriculum (teachers' guide and student book) as a science resource and the science knowledge that was discursively explored in the group both with and without the science expert.

### **Limitations**

The approach of collecting data by listening in on what is discussed between science experts and teachers in two PLCs can provide only a snapshot of the science knowledge teachers need. Using the interest shown and the input given by the teachers during the discourse as an indicator of how relevant the kind of science knowledge the teachers discussed was for their teaching is imprecise. Some domains of knowledge may have remained tacit and therefore

unobservable. Some domains of science knowledge may not have been accounted for, because they were not applicable to the topics discussed or in the given context. While the two PLCs presented in this article contained relatively outspoken teachers, some of the teachers may still have guarded their contributions. Teachers may have feared that arguing for more science knowledge might delay the task of producing an enhanced lesson; that adding more of their own knowledge might upset the social fabric of the teacher community; or that asking more questions might unfavorably influence their stand within the science community in their school district. Furthermore, there are always time constraints, in the PLC setting and when interviewing teachers. Not all domains of science knowledge could be explored during the PLC cycles or during the interviews. Consequently, the generalizability of the findings lies less with the presented examples and more with comparable experiences of the reader and findings from similar research. This study, acknowledging its limitations, was designed to contribute to a bigger picture of what kind of science knowledge provides the basis for science teaching. Since the idea of specialized subject matter knowledge has to date been researched mainly in the area of mathematics, this study fills a void in the research. In science, specialized science knowledge for teaching has to be inferred from research about science content requirements for students, science learning of students, and teaching requirements or suggestions for teachers.

### **Data Analysis: Finding the Science in Teachers' Collaborations**

The purpose of analyzing teachers' discourse in PLC sessions through a science content knowledge lens was to expose the science knowledge needed for teaching middle school students Newton's second law (Physics-PLC) and adaptation and natural selection (Biology-PLC). The science knowledge needed for teaching was further analyzed to detect patterns of different aspects of science knowledge that is unique to teaching—called *specialized science knowledge*,

in contrast to common science knowledge that is needed by all science professionals (D. L. Ball, Thames, & Phelps, 2008)—and to characterize the dimensions of such knowledge. This analysis provided the basis for a subsequent conceptualization of why these aspects of knowledge were relevant for teaching the science concepts of the teachers’ curricula. While the relevance of *specialized science knowledge* is closely related to the *knowledge of science and students*, and *knowledge of science and teaching*, for the purpose of this study, these latter two domains of pedagogical content knowledge were kept in the background.

### **Relevance of the Science Discussed**

The relevance of the knowledge discussed was determined by the teachers’ interactions, discourse moves, and comments.<sup>6</sup> During the PLC cycle, all teachers asked questions to clarify and expand the science content. They expressed their own understanding and struggles with science concepts as well as with teaching these concepts. All of the teachers took notes and made comments of agreement and praise, like “This is good!” One of the teachers commented in the interview that notes taken during this PLC cycle would be the only notes from that school year’s various PDs that she would keep, and that she would revise her teaching materials accordingly. Later, one of the teachers stated that she “wished she [the scientist] could have stayed longer.” Other teachers stated that this was the best science support they’d had in their three years of the OEL program. This unexpectedly positive evaluation of both science interventions led to the researcher’s decision to study the discourse, with the goal to determine what made the science discussion so useful to the teachers and their practice.

### **Unit of Analysis**

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<sup>6</sup> “All discourse analysts can do to deal with the frame problem is offer arguments that the aspects of context they have considered, in a particular piece of research, are the important and relevant ones for the people whose language is being studied and for the analytic purpose of the researcher” (Gee, 2004, p. 32).

To analyze and characterize the science knowledge for teaching that was explored in the two PLC cycles, discourse and interactions were examined with a science content knowledge lens. Episodes of talk that included the exploration of science concepts were extracted from the discourse during the science study day for the Physics-PLC, from discourse during the entire 2-day cycle for both PLCs, and from interviews with participants. The episodes relating to specific concepts were then connected to understand the development of these science ideas during the PLC cycles. The episodes of talk about science knowledge were then coded and categorized.

### **Coding**

The researcher's reflection on the conceptual importance and analytical value of discursive episodes and their meaning in the given context led to the development of preliminary categories of science knowledge for teaching: (a) core ("pure") science ideas; (b) various approaches for one core idea; (c) relationship of experiences to core science ideas (e.g., experiments or life experiences); (d) teacher knowledge beyond student knowledge (exceptions, limitations, extensions); (e) networked science knowledge for teaching (how core ideas relate to each other); and (f) nature of science (how science is done). Once these six categories were established, the recorded episodes were coded accordingly. After coding, episodes from the Physics-PLC and the Biology-PLC discourses and interviews were compared and further analyzed. In combination with the conceptual framework, this led to adaptation of the dimensions of science knowledge for teaching as outlined in the following sections. The characterization of the dimensions also supported inferences regarding why these dimensions of science knowledge were relevant for teaching.

### **Dimensions of Science Knowledge in Teachers' Collaborations**

Considering teachers' time constraints, and the fast flow of the topics they are required to teach, a deep foray into the science content needed for teaching is often not feasible during a PLC cycle. In other teacher PLCs observed by the researcher over the course of 8 years, the science content resources most commonly used were the curriculum materials and the state standards. Especially for middle school teachers, these materials express core science ideas in a rather contained and concisely formulated way, if at all. The Internet, which was also used in teacher PLCs, can offer a vast array of teaching materials and common science knowledge, but isn't targeted toward a special curriculum or context. It can therefore be quite difficult and time-consuming for teachers to find the science knowledge they need for teaching a certain concept on the Internet, if applicable sources are available at all. Therefore, the presence of a science expert offered the teachers an easily accessible science resource, which they could use to get the information they needed for the lesson plans being developed during the PLC cycle, and more generally for the learning segments they were currently teaching.

In the following section, the common science knowledge and different dimensions of specialized science knowledge that were found in the discourse of the two observed PLCs are presented and interpreted. These findings are then used to discuss why these dimensions are important for teaching.

### **Common Science Knowledge in Teaching Materials**

The science knowledge presented in curriculum materials, such as the teachers' guide, and in state standards is targeted yet minimal. It cannot include many of the contextual circumstances in which the content is taught, such as students' strengths and needs; resources and equipment available in classrooms, schools, and school districts; or specifics of the natural environment. In addition, curricula designed as modules (kits) that can be combined in various

ways often assume that teachers' and students' knowledge has been built through previous modules. This cannot be guaranteed. Thus, the curriculum materials available to the Physics-PLC and Biology-PLC outlined common science, but were limited in respect to the science knowledge provided to support content teaching.

**Physics: Force and motion.** The *Washington State K–12 Science Learning Standards* (Office of Superintendent of Public Instruction, 2009) require a simplified version of Newton's second law for middle school science students (see Appendix A). Besides the core science ideas of balanced and unbalanced forces, speed and acceleration, and friction, teachers have to attend to the notion of systems, inquiry, and application. (The *Next Generation Science Standards* [NGSS Lead States, 2013] suggest Newton's third law for middle school, and the second law in elementary grades 3–5. Still, Newton's first and second laws are the basis for the third law.) In the teachers' guide for *Energy, Machines, and Motion* (Toler & National Science Resources Center, 2000) the common science knowledge about unbalanced forces is expressed in the following way:

#### Forces and Motion

When an unbalanced force acts on an object, the object will accelerate, or change its speed. The change in motion produced by the unbalanced force is seen in the acceleration of the object. The acceleration can be a change in speed or a change in the direction of the motion of the cars. The greater the unbalanced force acting on the cars, the greater the acceleration. This relationship is summarized in Newton's Second Law of Motion:  $F = ma$  (force equals mass times acceleration).

When an unbalanced force acts parallel to the motion of an object, the resulting acceleration changes only the speed of the object. Forces acting in the direction of the motion increase the speed of the object; those acting opposite the motion decrease the speed. If a constant unbalanced force acts on an object, the object will have a constant acceleration, which means there will be a steady change in the speed of the object. In these inquiries, students will measure changes in speed only at various points in the motion of the cars and gather evidence that, with the fan running, the speed of the fan car increases as the car moves farther along the path. (p. 218)

“The change in motion produced by the unbalanced force is seen in the acceleration of the object.” This concept seems simple and clear, easy to teach, and easy to test. Why is it not easy to understand? As Hestenes, Wells, and Swackhamer note in their article “Force Concept Inventory” (1992), in regard to introductory level college physics: “Every student begins physics with a well-established system of commonsense beliefs about how the physical world works derived from years of personal experience. Over the last decade, physics education research has established that these beliefs play a dominant role in introductory physics” (p. 141). They add that “commonsense beliefs about motion and force are incompatible with Newtonian concepts in most respects” (p. 141). If college students struggle with Newton’s laws, then the same will certainly be true for middle school students. So to understand and, even more so, to teach Newton’s second law, there is more science knowledge needed than indicated in the teachers’ guide.

Furthermore, the science experts and teachers who participated in the observed PLCs stated that the teaching materials were insufficient for supporting the teaching toward a scientifically correct science understanding of core concepts. When Denise (science expert) was interviewed, she stated: “It [the kit] is okay because it gives students experiences, but it doesn’t do anything to getting kids to these four big ideas [balanced forces, unbalanced forces, motion, and friction].” During the content day, she argued that the kit introduced the concepts, but gave no guidance to the teachers on how to develop with their students an understanding of these concepts and the connections between the concepts. It was therefore likely that students would hold on to their “commonsense beliefs about motion and force,” and that some of their current misconceptions may actually be reinforced through the experiences provided by their teachers.

One of the science concepts of this lesson as outlined in the teachers' guide is that "an object changes its speed (accelerates) when an unbalanced force acts on it." The correlating learning objective for the students reads: "Determine the effect of a constant force on the speed of a fan car." The common content knowledge about unbalanced forces causing acceleration is outlined in the teachers' guide (see Appendix B). However, the way the lesson is designed, the apparently easy approach can become problematic in the real world of classroom teaching. In the PLC, the teachers brought up an equipment problem with the fan car that was closely correlated with a conceptual problem: Because five periods of classes with over 30 students each were wearing out the batteries, the fan cars were often not visibly accelerating anymore, and sometimes they were even slowing down over the distance they traveled for the experiments. The teachers feared that this could cause or cement students' misconceptions of "a constant force (battery) causes constant speed." A further cognitive problem was introduced by Denise: Students might think the battery is exerting the force that pushes the car. But the force that is actually acting on the car is the air: An object cannot exert force on itself. Therefore, this setup could introduce or reinforce the misconception that an "internal force" (battery) is moving the object. In the teachers' guide, this specialized science knowledge for teaching, necessary for this experiment, is not clearly outlined. The guide states: "The constant unbalanced force is the result of the constant force produced by the fan and the opposing frictional forces in the cars. The car moves across the surface with increasing speed" (Toler & National Science Resources Center, 2000, p. 219). However, and only with sufficient science knowledge for teaching, the teachers can decide (a) if they should still include the fan car experiments, consciously guiding students toward the correct interpretation, or (b) if they should substitute the fan car experiment with a setting that is less ambiguous. The teachers in the Physics-PLC chose to do the latter.

The gap between the information provided by the curricular materials and the knowledge needed to support students' learning the physics concepts related to Newton's second law indicates the cognitive work teachers have to do not only to transform common science knowledge but to add new knowledge that is not available or very difficult to find in publicized form.

**Biology: Adaptation and natural selection.** The *Washington State K–12 Science Learning Standards* (Office of Superintendent of Public Instruction, 2009) have determined that variation and adaptation are the big ideas in science for grades 6–8. (The *Next Generation Science Standards* [NGSS Lead States, 2013] include inheritance and variation of traits, natural selection, and adaptation as disciplinary core ideas for middle school as well.) For adaptation, the state standards outline that “adaptations are physical or behavioral changes that are inherited and enhance the ability of an organism to survive and reproduce in a particular environment” (Office of Superintendent of Public Instruction, 2009, p.78) (see Appendix C). Natural selection has not been included in the state science standards for middle school. However the curriculum provides the following definition in the glossary:

Natural selection: The process by which heritable traits that are favored by environmental conditions become more common in successive generations, and heritable traits that are less favored by environmental conditions become less common. Over time, this process may result in the emergence of new species. (FOSS, Lawrence Hall of Science, & Delta Education, 2004, p. 120).

This definition summarizes the common content knowledge needed for this topic. While the teachers' guide for *Populations and Ecosystems* (FOSS, Lawrence Hall of Science, & Delta Education, 2004) gives ample background information, the lessons themselves provide a simplistic introduction of the science that is supposed to be taught. For example, to make the concept of inheritance and adaptation easier for students to grasp, the curriculum reduces the

chromosome number for the imaginary “larkeys” (foxlike creatures of unknown origin) to four. For the natural selection simulation, which was at the center of the learning segment the PLC was focusing on, the curriculum works with four clearly distinguishable features of the larkey. Each animal has two or three different traits (qualities): solid, striped, or spotted fur; short or long legs; bare or bushy tails; and red or grey eyes (neither tails nor eyes are regarded as an adaptation, and frequency of these traits does not change in the simulation). A teacher could easily teach the lessons as outlined in the curriculum, and the students would be engaged and have fun. However, in this case students could develop limited black-and-white (dichotomous) ideas about inheritance, variation, adaptation, and natural selection.

**Common science knowledge in the PLCs.** In most cases, the curriculum, state standards, and state assessments determine the core science concepts that a student should understand, indicate at what level of complexity these concepts should be taught, and thus also declare what does not need to be covered. These science objectives are similar to what D. L. Ball and colleagues (2008) refers to as common content knowledge, the knowledge science teachers and members of other science professions have at the basis of their work. What teachers need to know beyond this common science is not clearly defined anywhere (Saderholm & Tretter, 2008).

For the Physics-PLC teachers, Denise defined the common science for their learning segment in the following way:

But for middle school, the tricky part is knowing that you are not trying to go to this full-blown mathematical representation of one of Newton’s laws. You are just trying to understand that with balanced force your motion is constant, that the speed doesn’t change. Could be zero speed or constant speed. And with unbalanced forces on an object, you either are speeding up or slowing down.

This depicts what students get to understand (despite the “you” in this quote). The question is, what do teachers need to know to have students truly understand this concept of

balanced and unbalanced forces. The notion of “zero speed” alone is hard to fathom for some, and students easily end up only parroting a definition or explanation provided by the teacher or the curriculum, without a true understanding that can be transferred to other situations and rekindled in later years.

The Biology-PLC teachers met for an hour before the science expert joined them. During this time, they talked about the lesson they wanted to develop further, and what science concepts they had to convey with this lesson. During this conversation, they aligned the lesson target (learning goal for the lesson) and the common science definitions provided by the state standards and the curriculum.

Emily (Reading lesson objectives from curriculum): “Natural selection is the process by which individuals best adapted to their environment tend to survive and pass their traits to subsequent generations.”

Facilitator: You can turn that into a learning target...

Ann: Like, “I can describe that natural selection is the process by which the individuals best adapted to their environment tend to survive and pass their traits to subsequent generations.”

Carol: So the key part of that is that individuals best adapted—so adaptation—survive and reproduce. I mean that is the main thing they have to understand.

Similar to the Physics-PLC, the common science is expressed through basic definitions that stand in for the science students should understand. The parameters set by standards and the common curriculum provided the teachers of the Physics-PLC and Biology-PLC with common expectations and a joint interest, and enabled a focused conversation. Furthermore, the curriculum lessons the PLCs were focusing on established the common science knowledge necessary for the teachers to teach the lesson. “In short, they [the teachers] must to be able to do the work that they assign their students” (D. L. Ball et al., 2008). However, the teachers needed

additional science knowledge to plan and improve their teaching of the learning segments they were working on.

### **Discourse About Specialized Science Knowledge**

The science expert at each PLC provided and discussed with the teachers specialized science knowledge that went beyond the knowledge expectations for students. This domain of teacher knowledge was important for designing lesson plans with learning opportunities that went beyond gaining recitational knowledge (M. Kennedy, 1998a). It was also important for teachers to create and expand learning opportunities in the moment of teaching (see Article 2 in this dissertation). Most of the specialized science knowledge discussed did not explicitly end up in the lesson plans, but was considered valuable for teaching the entire learning segment or related concepts to students. The specialized science knowledge that was part of the teachers' discourse comprised several dimensions: (a) foundational knowledge, (b) knowledge of different representations of science, (c) knowledge of content boundaries, (d) knowledge of experiments and experiences, (e) knowledge of the nature of science, and (f) knowledge of the sociocultural and historic context of science ideas. These dimensions are outlined below. Due to the specifics of the lessons and science topics, there may have been certain dimensions of specialized science knowledge, important in different contexts, that were not discussed.

**Foundational knowledge.** Before the Physics-PLC teachers discussed the concepts of Newton's second law, they explored with the science expert all of the forces that potentially act on an object. They perceived this exploration as a useful foundation for approaching their lesson planning. The teachers discussed questions about gravity, normal forces, and air pressure, as well as the role of friction when an object is and is not moving. The lively discussion with all teachers asking questions and making comments indicated that this understanding, while not found in

their grade-level curriculum or standards, was relevant for their teaching. Eric, an experienced science teacher who hadn't taught this physics unit before, reasoned about what he had learned from discussion and from clarifications by the science expert:

I feel like it solidified my understanding and helped me to demystify a couple of the questions I had as far as forces in two directions at once and what do we count when we are adding up forces on an object—are we counting everything like air pressure and that kind of stuff? That was good for me, because I have the same questions some of the kids have when we are talking about that.

Without knowing all the forces that are acting on an object, there is no understanding of why some forces and not others are important for the movement of the object. Professionals in the field of physics will have this knowledge, but implicitly. However, teachers' knowledge has to be explicit and detailed so it can be easily accessed when needed for teaching. Even if teachers are not planning to introduce their students to all the forces, they should be able to listen for students' confusion about forces, or answer questions, for example about the role air pressure plays in acceleration.

Before the Biology-PLC teachers discussed the concepts of adaptation and natural selection, they spent considerable time with the science expert discussing the implications of variation. Variations within species are prerequisite to adaptation and natural selection. In the curriculum, variations were portrayed as distinct traits: the larkeys' having three possible fur colors or two leg lengths, or humans having the ability to roll one's tongue (or not) or having straight versus bent pinky fingers. However, small variations between individuals of a species are much more prevalent in nature: slight differences in leaves between different maple trees, the shades of color in a fish population, or the skin color of humans. Such minute variations within species together with the variations of the environment are the basic factors that drive natural selection and adaptation over time. With the PLC's discussion about variations, the science

expert and teachers developed and expanded knowledge foundational to the main concepts of the lesson. The teachers' expanded understanding of the importance and the various aspects of variation still permeated their discourse after the science expert had left.

In general, teachers' knowledge of the significance of variation and awareness of numerous examples of the interplay between variation and environment should enable them not only to introduce variation to their students in a more scientifically accurate way than that suggested by the curriculum, but also to recognize when it would be appropriate to reinforce this concept over the course of the school year. This, in turn, would give students multiple access points for understanding and applying this foundational science idea. This constant reiteration of "variation" also appeared in the teaching of the collaboratively developed lesson. The observation teacher's prompts and her students' answers regarding variation indicated that prior to this lesson, variation had not just been introduced but had been a recurring theme.

**Representations of science.** Teachers in both PLCs spent considerable time contemplating verbal representations of the science concepts they were planning to teach. When the Physics-PLC teachers talked about forces, they spent a fair amount of time thinking about how to wordsmith sentences that expressed the concepts of force and motion. While this type of discussion requires teachers to have knowledge of the students they will teach, such as what their students will be able to understand, teachers also need a solid understanding of science, as simplifications can lead to expressing the concept incorrectly or in a way that can be misleading. During the interviews, several teachers expressed how important a simple word change was to the way they taught how forces act. For example, stating that "forces act *on* an object" became important for the teachers, while the curriculum read "forces acting *in the direction of* the motion" (Toler & National Science Resources Center, 2000, p. 16). The verbal representation of

forces acting *on* an object was supported during the PLC by the visual representation of force arrows always directing away from the object (see Figure 1.5). Thus, consistency across both verbal and visual representations was ensured.

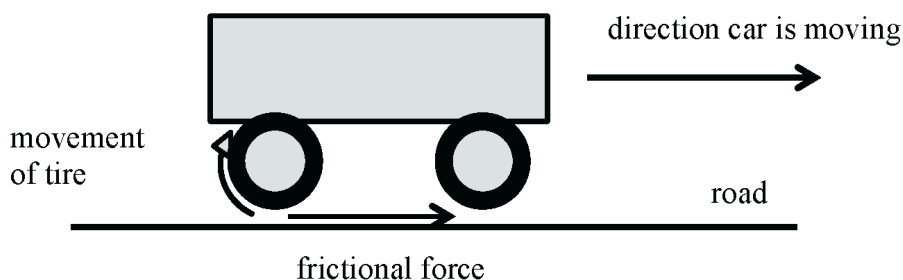


*Figure 1.5.* Force arrow on an object.

For example, Barbara, a more senior teacher, said she had made changes because of the discussion: “But in one of the first sessions when we talked about forces on objects —[now I am] being very intentional about the language and forces acting *on* this thing.” This consistency also made it into the poster depicting the “gravity-assisted car” experiment (see Figure 1.7).

For the members of the Biology-PLC, verbal representations were equally important. The teachers repeatedly made sure that they each expressed the idea of adaptation correctly, so as not to convey the idea that adaptation is an active process. Vanessa (the science expert) brought up the example of resistance against a disease, where sloppy language could misrepresent an idea or cause an incorrect understanding: “The other variant of that is that the adaptation, the genetic change occurs after the change in environment. So a disease pops up and then resistance happens. Rather than resistance was there all along, you just couldn’t tell until the disease came along.” Later in the cycle the teachers continued to remind each other to stay with precise formulations. Emily, for example, reminded the group that “it’s not a change that is occurring; adaptation is something that already exists, it is desirable, so it gets passed on.” The teachers thought about the adaptation simulation that was central to the lesson from their students’ point of view. However, the verbal representation of “adaptation” was something the teachers had to work on themselves, before they felt they could communicate it adequately to their students.

**Content boundaries.** In the Physics-PLC, an example of knowledge needed by the teachers but not by their middle school students arose when one of the teachers mentioned the forces that act on the tires of a car. In this example, the direction of the movement in relation to the direction of friction is not obvious, as the object the force is acting on is the tire, not the car (Figure 1.6). A similar, but more intuitive example of this concept, which students would encounter in middle school science, is a block sliding across a surface, where movement and friction point in opposing directions. To the contrary, in the case of a car, movement and friction are pointing in the same direction.



*Figure 1.6.* Friction and movement on car tires.

During the interview, Donna remembered:

For example she [the science expert] talked about friction slowing [the car] down, but that the friction with the tires going [miming the direction of the friction]. So I'll make a more conscious decision. I'm not going there with my students, because that would completely confuse them. So that was helpful for me. I will pretend that doesn't exist right now—in the classroom, because it would just confuse.

Other examples of ideas that teachers decided not to pursue with their middle school students after their PLC discussion were air pressure as a potential force on objects, and the limits of speed (speed of light). Ideas that might be too complex or confusing for students are nevertheless important for teachers to know, either to consciously avoid them in class, to be

prepared to deal with them when brought up by students, or to incorporate them in a pedagogically sensitive way, such as for differentiation.

In the Biology-PLC, the teachers and science expert discussed the boundaries of the natural selection simulation. In this simulation, the population is regarded as isolated, and therefore the population dynamic is simplified. In real life, there would be “continual immigration and emigration, so the gene pool is going to be in flux,” according to Vanessa, the science expert. In middle school, the teachers may not explicitly include this concept in their teaching. This kind of knowledge would not necessarily enhance or even constrain students’ understanding, but might on the other hand be part of some students’ ideas. Should students bring up similar ideas during discussion, and the teacher be aware of the dynamics in real populations, she could guide the discussion in a way that would be most beneficial for the class. For teachers to do this, knowledge of science ideas adjacent to the concepts being taught is useful. The teachers in the PLCs found that knowing the boundaries of the central and the adjacent science ideas was useful for setting up the lessons, and for reacting to students’ ideas while teaching.

**Experiments and experiences.** Conducting experiments and providing students with various experiences that could build a basis for understanding science is an integral part of science teaching. However, when hands-on activities are not closely related to the science concepts they should convey, their potential to support the learning of science is not tapped. The above-mentioned fan car experiment could even create or cement misconceptions if the conceptualization of the scientific ideas were not carefully guided by the teacher.

With support of the science expert, the Physics-PLC teachers came to the realization that a gravity-assisted car would exemplify the science concepts of force and motion in a much more

unambiguous way than the fan car. In this experiment, a string connects washers, over pulleys, with the car. When the washers fall down, the car speeds up (see Figure 1.7). By substituting the fan that is part of the car with washers that are clearly outside the car, the misconception of an inside force moving the car can be avoided. In addition, students can easily understand that gravity is a constant force and will not change no matter how often the experiment is repeated (unlike batteries running out of power). The teachers worked through all the parts of the experiment and the connections to the scientific concept, first with the science expert and then on their own. This discussion was especially intense when the teachers were making plans to videotape the experiment. The video was created so that students could watch repeatedly for the different aspects of the experiment. For example, in the beginning of the video, the car speeds up, and as soon as the washers hit the ground, the car slows down. There is time and distance to be measured, and friction to be considered. While making the video, the teachers felt they had to understand every detail of the equipment and how, as well as why, it would influence the results. Only then could they extract the essentials and create a clear model for the work with their students (Figure 1.7).

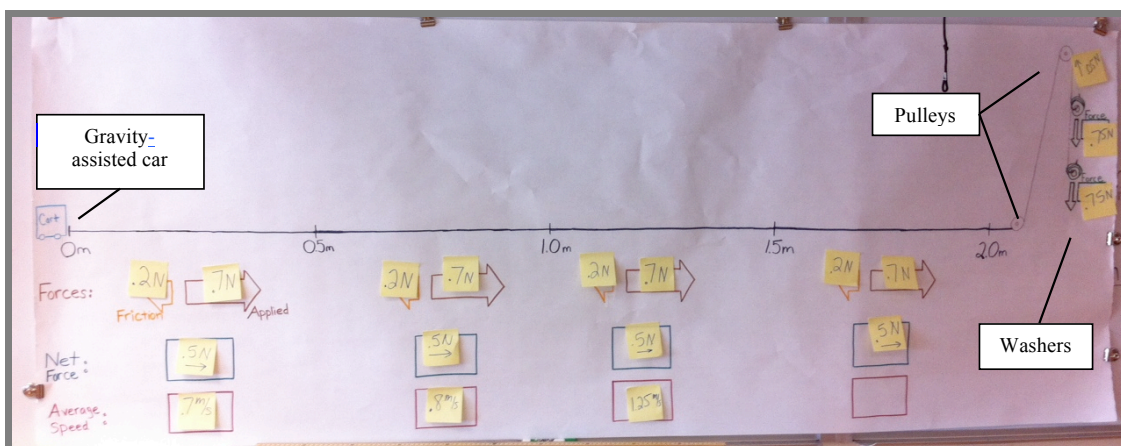


Figure 1.7. Gravity-assisted car poster. Sticky notes were applied according to students' input during the observation lesson of the PLC cycle.

In addition, on the Physics-PLC content day prior to the PLC cycle, the science expert went through a plethora of simple science experiments with the teachers, as well as offering other options to demonstrate the way forces work. One example is the human arm holding a book to exemplify the normal force on a book that is pushing up (represented by the arm) when a book lies on a table and gravity is pulling down. These types of small-scale experiments are part of a science teacher's toolbox, so the teacher can decide when to use them or not use them in context. These experiments are developed for purely didactic reasons and are found dispersed in various publications, yet are seldom part of science teachers' education. The knowledge of these experiments coupled with the scientific understanding these experiments can convey is specialized knowledge solely for teaching. When teachers know the science that each part of an experiment conveys, and know small experiments for each part of a concept, then they have a toolbox that enables them to adapt their teaching according to different contexts and needs.

**The nature of science.** Much has been written about the nature of science and how important it is for teachers to teach not only facts and concepts but also how these facts and concepts came to be known. When the school district adopted an inquiry-based curriculum, it was thought that the nature of science would become an integral part of teaching. However, the nature of science is often reduced to one "scientific method" of doing controlled experiments. The discussion the Physics-PLC teachers had with the science expert gave them the opportunity to expand their knowledge about the nature of science in a way that was relevant to the unit they were teaching.

An interesting example of the nature of science came about when teachers were struggling with ways to demonstrate constant speed (other than zero speed) and to prove that it is caused by balanced forces on an object. A teacher had found a video about constant speed on the

Internet. However, it did not deliver the required data: The time per distance differed considerably from section to section when a toy car moved. So the teachers were desperate to find a way to make this very difficult-to-grasp concept of balanced forces and constant speed more accessible to their middle school students. During the discussion, Denise (the science expert) added the idea that science cannot always prove a concept. Consequently, scientists have to prove that models which could potentially explain a concept such as constant speed (like a constantly increasing force, or unbalanced forces), are resulting in changing speed instead. The model that cannot be shown to result in changing speed is most likely the best-fitting model for the concept of constant speed. In the case of constant speed, that would be balanced forces. Supporting a hypothesis by ruling out alternative hypotheses is a theme throughout scientific discoveries and can be employed in many classroom situations.

I would argue, as many others have (from Schulman, 1986, to Osborne et al., 2003), that the way teachers need to know the nature of science should be considered specialized science knowledge, because for people in other science professions, the knowledge about how they are doing science is implicit. It is seldom talked about explicitly, and professionals in certain science disciplines see only their own way of doing things, and are quite often oblivious of different approaches in other disciplines (O'Rourke & Crowley, 2013). A teacher, in contrast, comes across a variety of epistemological and practical approaches that are tacitly embedded in the topics they are teaching. Specialized science knowledge is this type of understanding made explicit and usable.

**Sociocultural and historic context.** In the Biology-PLC, the nature of science was interwoven with historic and sociocultural ideas. Many science ideas are associated with values, beliefs, politics, and regulations, and appear as news topics. Classrooms cannot be shielded from

what Gee (2011) calls the Big “C” Conversation.<sup>7</sup> So science teachers are often required to deal with politically and emotionally charged issues. To know the accurate science behind such Big “C” Conversations gives the science teacher a necessary (although not sufficient) tool to distinguish fact from fiction, in a way that is socially responsible, as the following example shows.

The idea of the “survival of the fittest,” discussed in the Biology-PLC, exemplifies this point. Before the science expert arrived, the teachers were already stressed about how the word “fittest” is misleading.

Carol:           And as I was reading, I was guessing that the “survival of the fittest” is a misconception for students.

[...]

Ann:            Right, the person with the biggest muscles, and the tallest, and the strongest. And everything “survival of the fittest” means is a bit fight, like people.

Carol:           This is the misconception, fitness is really the number of offspring you have.

Ann:            But really, it is about small adaptations that occur, like maybe a whole bunch of...

Carol:           ...and you have to fit the ecosystem.

Later, the science expert further relativized the notion of the fittest: “But what is the ‘fittest’ is going to change every day, every season, every year. Who is the fittest during a really wet summer is different than who is going to be the fittest during a really dry summer.” The group then discussed how “fit” is determined not by a single trait but by a combination of traits, and that changing environmental pressure, like weather, climate, predators, competition, and illness, influences the fitness of an individual. Furthermore, these changes occur on different time scales, from daily fluctuations to seasons, years, decades, centuries, and beyond. The group

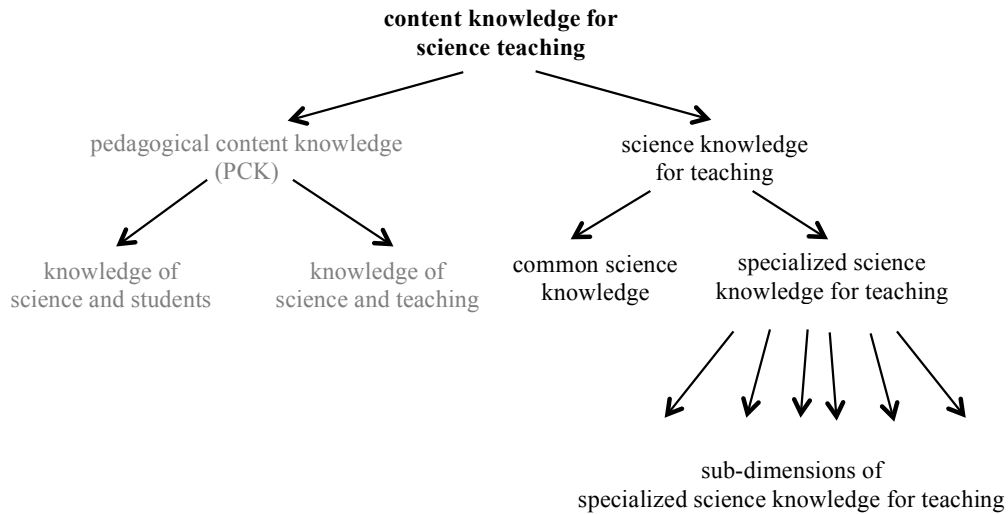
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<sup>7</sup> “Debates in society or within specific social groups ... that large numbers of people recognize, both in terms of what ‘sides’ there are to take in such debates and what sorts of people tend to be on each side” (Gee, 2011, p. 201).

agreed with the idea that “fit,” in contrast to “fittest,” and together with the idea of variations being necessary, implied a different scientific and social message than the idea of having “one form that is the fittest.” Even if the middle school science curriculum does not discuss aspects of the historical distortion of science ideas and the political and historical atrocities justified by the ideas of social Darwinism, influences from and influencing the conversation cannot be avoided, and an awareness of such elements enables teachers to make conscious choices in planning and teaching.

### **Discussion and Conclusions**

The previous section described examples that support D. L. Ball, Thames, & Phelps’ theory of *content knowledge for teaching* (2008). These examples suggest that there is indeed science knowledge for teaching that can be differentiated as common science knowledge and specialized science knowledge, and that this science knowledge for teaching is distinct from but not independent of the domains of pedagogical content knowledge. The further analysis of specialized science knowledge implies that there are several dimensions, and that six dimensions were found in the discourse between teachers and science experts in the studied contexts. These dimensions are necessary to prepare for teaching. Normally, this kind of knowledge is difficult to research because it stays tacit when teachers work individually (Eraut, 2000). However, this knowledge can be revealed when teachers collaboratively prepare for teaching, at which point the knowledge becomes prompted and available not only for the teachers themselves, but also for the researcher.



*Figure 1.8.* The subdimensions of specialized science knowledge for teaching in relation to overall content knowledge for science teaching.

### **Characteristics of Science Knowledge for Teaching**

All professions have their own specialized knowledge. Specialized science knowledge for teaching is knowledge that other science professions do not need to have to fulfill the tasks of their work or their research. Because teachers deal with students who are just beginning to understand how science and nature work, the common science knowledge taught in middle school is limited. This can create the illusion that learning the science necessary to teach these concepts is easy. However, the complexity lies not in the amount of different facts and concepts, but in the fine-grained or “decompressed” (D. L. Ball et al., p. 400) and multidimensional nature of this knowledge. In short, a teacher has more knowledge about less content than other science professionals do. If common science knowledge is the skeleton, specialized science knowledge is the body that connects the dry facts and concepts with nature, with science as the human endeavor, and with the experiences of individuals and society. To continue with this analogy, pedagogical content knowledge would bring this body to life.

The way science knowledge for teaching presented itself in the teachers' discourse in the PLCs leads to the conclusion that it is not, as Shulman (1986) and others (Barnett & Hodson, 2001; Botha, 2012; Kind, 2009; Toh & Tsoi, 2008; Van Driel et al., 1998) have claimed, "transformed" academic science knowledge. Common content knowledge that is shared in both academic science and science for teaching is incorporated rather than transformed. Specialized science knowledge, on the other hand, is specific and unique and exists beside academic science knowledge. This is in accordance to Deng (2007), who suggested that what he calls "school science" is an epistemic discipline in its own right. This supposition would also explain the weak correlation between the science college courses teachers had taken in preparation for their teacher education and the subsequent learning success of their students (Wayne & Youngs, 2003).

However, the boundaries of specialized science knowledge remain obscure. There are naturally close connections between knowledge about students, learning, and teaching, and it is not always easy to distinguish specialized science knowledge from other knowledge needed for teaching. Yet, within the obscure boundaries, there is a core of pure yet specialized science knowledge for teaching. For example, students may have the misconception that motion requires force. A teacher's knowledge that this is a misconception (that is, knowledge of science and students) does not on its own support teaching Newton's second law. Science knowledge for teaching, such as understanding both the scientific truth within a naive misconception and the connection between experiences in the real world and scientific concepts,<sup>8</sup> is necessary. Such science knowledge is the prerequisite for creating learning opportunities that can guide students to expand their scientific understanding of force and motion. A question remains: To gain

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<sup>8</sup> For example, that force and motion are closely connected, and we normally need force to move an object, due to the omnipresent friction on earth.

specialized science knowledge, do teachers need to know their students, or to know about teaching? Or can specialized science knowledge be learned by education students before they start teaching (pre-service). The answer is likely that specialized science could be part of pre-service teacher education. However, knowledge about students and teaching may be necessary in order to understand why specialized science knowledge is important and how to use it for and in teaching. This suggests that content knowledge for teaching should be learned in tandem with the development of teaching practice, beginning during pre-service and continuing through in-service education.

### **Science Knowledge for Teaching**

To fulfill the requirements of teaching certain science concepts within a given time frame, teachers need a good explanatory model that represents the common content knowledge. Such a model helps limit the teaching to the ideas that are central to understanding the core concepts (Windschitl, Thompson, & Braaten, 2008). Different dimensions of specialized science knowledge would further support teacher preparation: (a) Foundational knowledge embedded in the concepts to be taught enables teachers to assess whether students have this foundation and if not, to prepare the necessary support. (b) Knowledge of different representations for a single concept can provide different access points for students, and a more complete and contextual “picture” of the concept. (c) Knowledge of content boundaries allows for or prevent detours into adjacent science ideas. (d) Awareness of experiments and experiences that are closely connected to the science concept being taught allows for lesson planning that is adaptive to the context in which teaching takes place. (e) Knowledge of the nature of science and (f) knowledge of its sociocultural and historic context provide ideas for how to convey a more realistic view of science, and prepare students for a life that takes on responsibility in regard to science in society.

Specialized science knowledge is therefore a prerequisite for teachers to capitalize on their knowledge of students and knowledge of teaching to make science learning happen.

### **Science Knowledge in Teaching**

Teachers who engage all their students and support them in learning science provide these students opportunities to work with their own ideas toward a scientifically correct explanation of natural phenomena. These teachers encourage students to express their understanding and to publicly reason about science ideas (Thompson, Windschitl, & Braaten, 2013). But students' reasoning and questioning brings uncertainty into the classroom. Right ideas can be expressed in various forms, and what sounds wrong may be a correct understanding presented in a clumsy way. On the other hand, students may air opinions or naive conceptions. So for the teacher, a specific, detailed, and multidimensional understanding of the science will be necessary (among all the other various skills and understandings a teacher needs) to acknowledge and work with students' input and at the same time guide and coach them toward a scientifically correct and developmentally appropriate understanding. As discussed in the fan car example in the findings section, a student may say, "The battery is moving the car." In this moment, the teacher realizes that the student is expressing a scientifically incorrect idea. With her knowledge of science and teaching and science and students, this teacher will be able to elicit more of this particular student's thinking. But how does a teacher then move forward with such a student's scientific understanding? To evaluate what parts of a student's understanding are useful for the scientifically correct idea, and what parts need to be redirected, specialized science knowledge is necessary. To know how to redirect, pedagogical content knowledge comes to play.

## Prospects

This study's attempt to add a practice-based conceptualization of specialized science knowledge that is needed for teaching, based on the theory of content knowledge for teaching (D. L. Ball et al., 2008), is not meant to diminish the importance of all the other knowledge and skills involved in teaching. It is also not intended as a normative act to define what teachers should or need to do or to know and to put even more pressure on them. It is meant to add to the argument that teaching is a profession with highly specialized knowledge and skills that requires adequate preparation and PD, including content-specific support (Ingersoll & Perda, 2007).

Whenever we ask teachers to change grade level, science discipline, or subject, we ask them to start again with the work of building their specialized science knowledge in this new area and new context. These changes may be neither avoidable nor undesirable. However, an awareness of the complexity of science knowledge for teaching advocates support for such changes. The complexity of science knowledge for teaching may also warrant support for experienced science teachers (for example through extra planning time) to cultivate their content knowledge for teaching in a way that can be used to coach and support their colleagues.

Teachers' specialized science knowledge develops over time, and teachers benefit when they can work on this development together. This type of knowledge also needs targeted support by experts in science teaching, such as experienced teachers, instructional coaches, science educators, and scientists with a background or special interest in education. To create a cadre of such "science-for-teaching specialists," the education community may be well served to give these specialists the means and opportunity to collaboratively expand and improve their own understanding, and to develop tools to support their own and other teachers' specialized science

knowledge. These science-for-teaching specialists could then provide the necessary content input for teachers' collaborative PD and serve as mentors and coaches on a more individual basis.

## Article 2

### Science-for-Teaching Discourse for Rigorous Lesson Development in Science Teachers' Professional Learning Communities

#### Abstract

More and more, professional learning communities (PLCs) for teachers have become the means for teachers to advance their teaching practice and promote student learning. However, there is a trend for science teachers in PLCs to privilege talk about students and teaching over talk about science (Weaver & Lewis, 2010). This trend suggests that teaching practice, but not necessarily the teaching of science, is likely to improve. Two groups of experienced middle school science teachers were observed working collaboratively to improve their common curriculum during a 2-day PLC cycle. One of the two PLC cycles included 2 hours of support by a science expert, who worked with the teachers on science knowledge related to their curriculum. Based on D. L. Ball, Thames, and Phelps' (2008) conceptual framework, the teachers' discourse in both PLCs was analyzed for three aspects of content knowledge for science teaching: (a) talk about science and students, (b) talk about science and teaching, and (c) talk about science knowledge for teaching (*science-for-teaching*). The teachers in the PLC without expert science support focused mainly on students' interests and on teaching strategies, without strongly connecting these ideas to the science inherent in the lesson. The teachers in the PLC with the science support focused on all three aspects of content knowledge for science teaching in their discourse, even beyond the time of the science expert's visit. The teachers in this PLC, compared to the unsupported PLC, developed lesson plans that contained higher expectations for students' reasoning about scientific concepts. The findings suggest that a brief science support included in

teachers' collaborative work can strengthen the role science plays in teaching. The findings also suggest that teachers' discourse about science knowledge for teaching influences the academic rigor of collaboratively developed lessons. With these findings, this comparative case study adds practical evidence to the concept of content knowledge for teaching and demonstrates the value of research on and in support of science knowledge for teaching in professional development for teachers.

## **Introduction**

The *Next Generation Science Standards* (NGSS Lead States, 2013) call for a more in-depth and integrated understanding of disciplinary core ideas, scientific and engineering practices, and crosscutting concepts. This will likely spur a considerable professional development (PD) effort to support teachers with the science content they need to teach to these new standards. The PD effort may come in two different modes: confined content PD, and professional learning communities (PLCs). Each has its advantages and drawbacks. Confined content PD, provided separately from teachers' work contexts, can offer teachers an opportunity for deep inquiry into the science the standards require. However, it can be difficult for teachers to transfer this knowledge into their teaching practice. Teachers' PLCs allow teachers to make a close connection between their collaborative work and their teaching practice. However, the science knowledge teachers are required to know for the standards may not always be sufficiently present in or accessible to a PLC for teachers to improve the way they teach scientific concepts.

Science content support that is incorporated in teachers' collaborative work may combine the benefits of both forms of PD. This article introduces such a PD format. The study followed the collaborative work of two PLCs: one PLC that included a brief phase of science content

support incorporated in the 2-day PLC cycle, and one PLC that had no such support. Although this study took place before the *Next Generation Science Standards* were fully developed, the findings could provide input for PD that aims to provide science content support for teachers adopting the new standards.

Evaluative research of PLCs similar to the ones introduced in this study has found that in general, teachers tend to privilege talk about students and teaching over talk about science (Weaver & Lewis, 2010). The purpose of this study was to compare the discourse about content knowledge for science teaching in two PLCs and to examine the influence of this type of discourse on lesson development and on teachers' practice. The research hypothesis of the study is that strengthening talk about and deliberation of the science needed for teaching during teachers' collaborative work would also strengthen the teaching of science in the classroom. The teachers in both PLCs had comparable experience and education in science and in teaching—the question was how and why they engaged with science content during their PLC cycles and with what consequences.

This article presents an analysis of the discourse among two groups of experienced seventh-grade teachers. Each group participated in a 2-day PLC cycle that focused on topics of inheritance and adaptation taught in the district's common curriculum. Both groups worked to collaboratively improve lessons to better fit the needs of their students in their particular contexts. Based on the theory developed by D. L. Ball, Thames, and Phelps (2008), the teachers' discourse in both PLCs was analyzed for three aspects of content knowledge for science teaching: (a) talk about science and students, (b) talk about science and teaching, and (c) talk about science knowledge for teaching. The relationship between the discourse about content knowledge for science teaching, the development of lessons, and the debriefs after the lessons

had been taught and observed were examined and the findings outlined. In the conclusion, the role of the science expert is discussed, and connections between science discourse, resulting lessons, and teachers' practice are suggested.

In the literature, research findings about teachers' collaborative work imply that teachers' discourse often stays superficial unless supported by expert facilitators, and therefore that potential learning and improvement of practice in PLCs may be limited (Nelson, Deuel, Slavit, & Kennedy, 2010). However, very few publications focus specifically on the content knowledge for science teaching discussed in PLCs. This research study adds to this emerging field by examining the following questions:

- How do teachers in a PLC talk about content knowledge for science teaching when they are collaboratively planning their teaching?
- What factors influence the features of this discourse about content knowledge for science teaching?
- What is the effect of discourse about science knowledge for teaching on collaborative lesson development and teachers' practice?

Understanding the relationship between the discourse about content knowledge for science teaching in collaborative settings and teachers' practice, as well as having empirical examples of how this kind of discourse can be supported, is valuable for the necessary evolution of ongoing and contextualized content-based PD for teachers.

### **Literature Review**

Providing PD for teachers is one of the most influential interventions for supporting change within classrooms, schools, and school districts (Borko, 2004). There is a large body of research on the effectiveness of PD interventions, and Desimone (2009) has identified five

critical features of effective PD on which the majority of the research community agrees. Collaborative PD in the form of PLCs can exhibit all of these features: PLCs (a) are ongoing (as opposed to one-time interventions), (b) are collaborative, and (c) provide opportunities for active learning. Furthermore, collaborative work in PLCs should be (d) concerned with the subject matter the participants teach, and (e) aligned with other initiatives and policies within the school district (coherence). In addition, PLCs are closely connected with teachers' practice.<sup>9</sup> As McLaughlin and Talbert (2006) summarize: "Teachers work collaboratively to reflect on their practice, examine evidence about the relationship between practice and student outcomes, and make changes that improve teaching and learning for the particular students in their classes" (p. 4). This strong focus on teaching practice makes PLCs a form of PD that can positively affect teaching and learning in the participating teachers' classrooms (Vescio, Ross, & Adams, 2008).

Despite the current research literature's strong support for formal teacher collaboration as the most promising form of teacher PD, a clear correlation between teacher collaboration and improved teaching practice and student learning remains elusive. As Opfer and Pedder (2011) point out in their review of literature on teachers' PD practices, teacher learning is too strongly contextualized and complex to draw simple conclusions.

### **Teacher Learning Through Discourse**

From a sociocultural perspective, discourse can be seen as the most prevalent and important means of learning in PLCs. Through discourse, individual and cultural meanings are negotiated, revised, and created (Rogoff, 2003; Wenger, 1998). A positive effect of discourse during collaborative work on student learning can be expected when teachers engage "in

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<sup>9</sup> I define *practice* in this article according to Gee (2011, p. 17), as a "socially recognized and institutionally or culturally supported endeavor that usually involves sequencing or combining actions in certain specified ways."

conversations that are less about sharing activities, information, and student anecdotes and more about raising and pursuing questions of learning goals, instructional practices, and all students' attainment of agreed-upon goals" (Nelson et al., 2010, p. 176). This type of effective discourse often ensues when teacher collaboration is facilitated (Little, Gearhart, Curry, & Kafka, 2003). Slavit and Nelson (2010) observed that when no outside facilitator was present in PLC sessions, the discourse among teachers became less probing, and the researchers lamented the fact that they could not provide all their PLC sessions with trained facilitators. Weaver and Lewis (2010) engaged in evaluative research on the pilot implementation of the PD model that the PLCs presented in this article followed, and stated that the discourse about science knowledge needed for teaching was especially challenging for the collaborating teachers when not facilitated. In most other research studies on science PLCs and math PLCs, collaboration was supported by researchers or by experienced educators, who either actively participated in the PLCs or explicitly facilitated the collaboration of teachers (Ackerson, Cullen, & Hanso, 2009; Doppler et al., 2009; Horn & Little, 2010). This presence of outside expertise strongly influenced the PLC participants' accomplishments. However, in most school districts, PLCs are most often facilitated by the teachers themselves, because funding for or availability of knowledgeable external facilitators is limited.

PD that complements the work in PLCs has also been noted as important for supporting productive discourse. Slavit, Kennedy, Lean, Nelson, and Deuel (2011) stated that school district initiatives and content PD provided additional knowledge that was accessible to all teachers and thus informed changes in individual teachers' practice as well as subsequent discussion about these changes in PLCs. "The variety of resources ... that engaged the work of SVMath [a PD project] were fundamental to the formation and success of this work" (p. 126).

Outside expertise in the form of facilitators or supplementary PD influences teachers' work in PLCs. It supports focused discourse and increases the knowledge base available to the participating teachers, and can thus foster the development of knowledge for teaching. The research presented in this article extended this notion by asking whether combining collaborative work in PLCs with traditional content PD could also support teachers' learning. Such limited support during a 2-day PLC session could focus the teachers' discourse on science knowledge for teaching, even if the PLC is facilitated by the teachers themselves.

The prevailing norm of privacy and the "culture of niceness" (Nelson, 2009; see also Grossman, Wineburg, & Woolworth, 2001) and of noninterference (Little, 1990) in schools can prevent discourse about important and productive issues, often out of fear that uncovering differences in beliefs, values, and capabilities may lead to unproductive tension. Taken-for-granted understanding and assumed concepts (Eraut, 2000), and the urgency of tomorrow's task (Horn & Little, 2010), can also hinder discussion of different knowledge and beliefs. Kazemi and Hubbard (2008) also noted the importance of and the difficulties in supporting content work in PLCs that coevolves with teachers' classroom practices.

### **Development of Knowledge for Teaching**

Teachers' professional learning is inherently complex (Opfer & Pedder, 2011). First, knowledge lies not only within an individual, it is also distributed across individuals, and carried by practices, concepts, and materials. What knowledge is available, what gets accessed, and how this knowledge is dealt with determines the learning opportunities for the individual as well as for the group. Every PLC establishes, in part explicitly and in part implicitly, "what counts as knowledge in the group's domain, including use and interpretation of its terminology, meanings of its concepts and principles, and applications of its methods" (Greeno, 2006, p. 89). In other

words, how and what participants in a learning community are able to contribute and to learn, what knowledge they are collaboratively able to create, and what a community is willing to apply to its practice is fundamentally dependent on and situated in a specific context (Eraut, 2000) and is therefore different for each PLC cycle.

**Tacit knowledge.** An additional feature that complicates the development of usable knowledge for teaching is that a significant part of teaching knowledge is tacit. Teachers, in the same way as other professionals, learn most of what they know in a informal and implicit way through their practice (Eraut, 2000). In PLCs, this creates the problem of “awareness and representation” (p. 118). If teachers are not aware of their own knowledge, or if they do not present their knowledge to make it accessible to others, it will stay hidden from their colleagues (and from researchers), even if this knowledge is used and useful for teaching. Professional collaboration has not been part of the enculturation of most teachers, and when they start collaborating in PLCs, they often lack the vocabulary to verbalize their expertise. Furthermore, teachers often have to first develop a conceptualized understanding of their practice, and of the premises and beliefs underlying their work, before they can share what they actually know. This study examines whether a phase where science knowledge for teaching is *explicitly* discussed can activate teachers’ tacit knowledge, make it available to others, so that it can be deliberated, developed, and distributed, and learning can occur.

**Transferability and transposability of knowledge.** In addition to the transferability of knowledge from one person to another, the aspect of *transposability* from one context to another (Melville & Wallace, 2007) also has to be considered in connection with knowledge development for teaching. If knowledge developed in a PLC cannot influence the teaching in the classroom, the PD has not fulfilled its purpose. However, the intertwining of knowledge

(possessed), knowing (deployed in action) (Kazemi & Hubbard, 2008), and context makes the transposition of knowledge an uncertain event.

McLaughlin and Talbert (2006) speak of “situated generalizations” (p. 6), when teachers can modify knowledge for teaching so that it applies to their own students and classroom settings. Unlike a cognitive perspective that depicts cognitive knowledge structures as something that can be accessed in different environments if a task requires these knowledge structures, a situative perspective assumes that transfer relies on “overlapping aspects of activities in practice” (Greeno, 2006, p. 80). Knowledge might be “stored with characteristic features of the classrooms and activities” (Putnam & Borko, 2000, p. 13) and thus be retrievable through similar situations but less so through similar cognitive requirements. This view implies that transposition from the learning context (PLC) to the application context (classroom) requires additional learning (Deng, 2007; Eraut, 2000). Boundary objects (Wenger, 1998), such as student worksheets or lesson plans, might assist the transposability of knowledge from a PLC into the classroom.

Transferability and transposability are complex yet important and underresearched characteristics of collaboratively developed knowledge. Therefore, this study included the question of how discourse about science knowledge for teaching influences (a) collaborative lesson development, as an important first step toward setting the cognitive demands of teaching; and (b) lesson teaching and debriefing, which were also part of the PLC cycle. This study also examined how this collaborative work could, as a consequence, influence teachers’ practice in their classrooms.

### **Conceptual Framework**

There is little doubt in the educational community that appropriate content knowledge builds a teacher’s basis for teaching a certain school subject (Borko, 2004; Darling-Hammond &

Bransford, 2005; Saderholm & Tretter, 2008; Thompson, Windschitl, & Braaten, 2010; White & Frederiksen, 2005; Windschitl, 2009). In science as in other subject areas, knowledge that goes beyond what the teacher wants to teach is necessary for teachers to interpret and assess students' ideas, and to work with these ideas to further enhance all students' understanding and support them to become fluent in the different cognitive demands science entails (Darling-Hammond & Bransford, 2005; Little et al., 2003). Limited knowledge of a subject may require teachers to rely on textbooks and facts (Windschitl, Thompson, & Braaten, 2009) and lead to what M. Kennedy (1998a) calls *recitational* knowledge (when students recite facts and textbook quotes) as opposed to *conceptual* understanding. However, there is no consensus among educators about what content knowledge for teaching comprises, and this is certainly true for science, despite the extensive use in education of the term *pedagogical content knowledge* (Shulman, 1986).

### **Content Knowledge and Pedagogical Content Knowledge**

The knowledge teachers need in the classroom has often been portrayed as a didactic triangle, with teachers, students, and content at the corners. This triangle depicts important relationships. However, traditionally the focus has been on the relationship between the teacher and the students, while the interrelatedness of the content was assumed as a given. This led Shulman (1986) to address content knowledge and pedagogical content knowledge, to refocus the educational community on the importance of subject matter understanding. He urged the education community to further conceptualize this thesis and support it with empirical evidence. Over 10 years later, Stigler and Hiebert (1999) noted that “in the U.S. lessons, there are the students and there is the teacher. I have trouble finding the mathematics; I just see interactions between students and teachers” (pp. 25–26). It can be assumed that the same could be said about science lessons. A more recent study (Weiss, Pasley, Smith, Banilower, & Heck, 2003) noted,

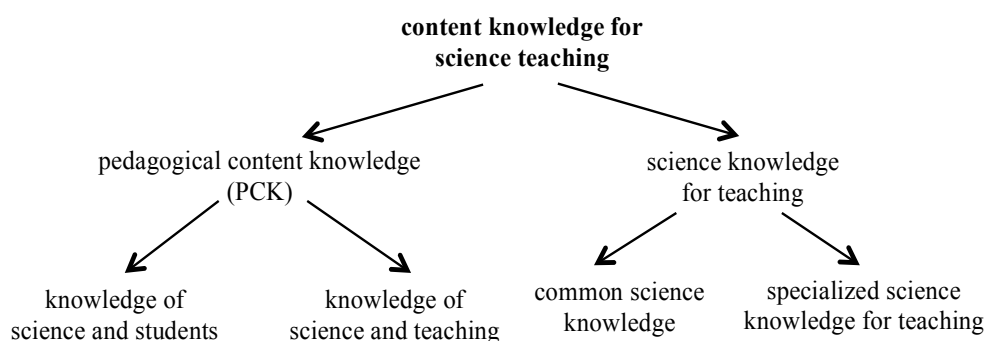
for example, that science content and students' sense-making of science are still less prevalent in US classrooms than in classrooms in countries whose students show higher science proficiency on international tests such as TIMSS (Trends in International Mathematics and Science Study) or PISA (Program for International Student Assessment).

### **Content Knowledge for Science Teaching (Science-for-Teaching)**

D. L. Ball and colleagues (2008) further conceptualized content knowledge for teaching by developing a practice-based model based on their extensive expertise in mathematics education. This conceptual model distinguishes two domains of pedagogical content knowledge: “knowledge of content and students” and “knowledge of content and teaching.” In addition to pedagogical content knowledge, content knowledge for teaching is proposed to also include “pure” subject matter knowledge, also with two domains: “common content knowledge” and “specialized content knowledge” (see Figure 2.1). This model established that specialized content knowledge for teaching contains unique aspects of the subject matter that other professions would neither have nor need. While, for example, most professionals working in the area of mathematics (or science) aim for the most parsimonious and elegant solution of a mathematical (or scientific) problem, math teachers need to know all possible ways of resolving a mathematical (or scientific) problem, including the approaches that ultimately lead to a dead end. As science includes mathematics (e.g., basic computations), some of the specialized content knowledge defined by D. L. Ball and colleagues is similar in both subject areas.

A more science-specific example might be the knowledge of different scientific visual representations and models. While most science-educated individuals know one or two of the typical visual representations (e.g., of a cell membrane) found in textbooks, science teachers need to know many different ways to model a cell membrane (e.g., from using soap bubbles to

computer animation to student drawings); need to know the various scientific benefits and drawbacks of different kinds of conventions and symbols; should be able to uncover misleading or incorrect features; and need to develop scientifically correct models of various sophistication. Other science professionals would not normally spend so much intellectual work on modeling one part of a concept. But it is this kind of specialized science knowledge for teaching that is developed by teachers over time.



*Figure 2.1.* Domains of content knowledge for science teaching. Adapted for science teaching from the more general concept of “Content Knowledge for Teaching—What Makes It Special?” (D. L. Ball, Thames, & Phelps, 2008)

### **Science-for-Teaching Discourse**

In general, the development of content knowledge for science teaching is driven by teachers’ own backgrounds and interests, by the students the teachers are teaching, and by curricula, mandatory assessments, and standards. Content knowledge is influenced by teachers’ assumptions and beliefs, and is supported by PD (Arzi & White, 2008; Pasley, Weiss, Shimkus, & Smith, 2004). In PLCs, teachers can potentially develop their science knowledge for teaching further through discourse with their colleagues. How productive this type of discourse is for teachers’ learning is determined through the quality and substance of this discourse. In other

words, it is determined by how the different domains of the science knowledge for teaching are discursively explored. Applying the conceptual model of content knowledge for teaching in a study about teachers' discourse in science PLCs will help to illustrate how teachers' discourse during their collaborative work incorporates these different dimensions, and to analyze how this discourse influences teachers' practice.

### **Science Content Discussed in the Two PLCs**

The two PLCs in this study focused on aspects of the theory of evolution. There is much discussion in the education and science community about the implications of teaching inheritance, variation, adaptation, and natural selection as the foundation for students' understanding of the theory<sup>10</sup> of evolution in high school and college. The *Framework for K–12 Science Education Practices, Crosscutting Concepts, and Core Ideas* (National Research Council, 2011) and the *Next Generation Science Standards* (NGSS Lead States, 2013) explicitly state that evolution is a central theme in biology: “Biological evolution explains both the unity and the diversity of species and provides a unifying principle for the history and diversity of life on Earth” (National Research Council, 2011, p. 161).

**Teaching for understanding the theory of evolution.** The *Next Generation Science Standards* (NGSS Lead States, 2013) suggest that the core concepts that are foundational to understanding evolution should be taught throughout a student's K–12 school career, so that in higher grades and college, students can actually grasp the complex and broad theory of evolution (McVaugh, Birchfield, Lucero, & Petrosino, 2011; Olson & Labov, 2012). In addition, “far from being an uncertain science, evolution is science done right. ... As such, it is one of the best

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<sup>10</sup> Throughout this article, the term “theory” is used in the scientific sense: “Scientific theories are constructs based on significant bodies of knowledge and evidence, are revised in light of new evidence, and must withstand significant scrutiny by the scientific community before they are widely accepted and applied” (National Research Council, 2011, p. 67).

examples available to illustrate the nature of science” (Olson & Labov, p. 16). Yet building an understanding of evolution is likely to be a rocky road for both teachers and students. Too many alternative conceptions prevail, not only with students, but also in textbooks and curricula, and taught, sometimes explicitly but more often implicitly, by teachers (Gregory, 2009; Nehm & Schonfeld, 2007). Often, the best outcome is that “students may have a lot of knowledge about evolution but not be able to use that knowledge to create a functional explanation” (Olson & Labov, 2012, p. 27). In addition, correlated with these scientific concepts are teachers’ and students’ worldviews and beliefs that enter discussions in the classroom. This is an additional reason for teachers to have a strong understanding of science: so they can discern facts from myth (Nadelson & Nadelson, 2010; Rutledge & Mitchell, 2002). For the purpose of this article, I will touch briefly on the concepts the teachers discussed in the two studied PLCs—variation, inheritance, adaptation, and natural selection—to support readers who are not inherently familiar with these concepts.

**Variation.** The concept of variation is essential for understanding inheritance, adaptation, and natural selection. Also, it is probably the most approachable of the four concepts (Zabel & Gropengiesser, 2011), since variation is universal and observable. Students can easily detect the subtle differences that exist between all individuals of a species, such as between maple trees, cats, or humans.<sup>11</sup> This variation exemplifies the concept that, contrary to our inclination to define a prototype for each species, there is no such thing as one ideal version. All possible variations together constitute a population, or a species. This idea counteracts the tendency to see individual differences as not normal or of lesser value.

Variation between individuals is caused by two processes: Sexual reproduction distributes the genes from both parents in new ways, and mutation changes the genes themselves.

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<sup>11</sup> Variations can be also caused by environmental influences such as level of nutrition.

Both processes are random (undirected). Generally, the concepts of random occurrence, probability, and chance are hard for students to conceptualize and accept. As a result, one of the most persistent misconceptions about adaptation is the teleological idea that organisms acquire special traits because they are needed, wanted, or deserved<sup>12</sup> (Gregory, 2009; Shtulman, 2006).

**Inheritance, dominance, and Punnett squares.** Many people may remember from their days in school that traits/genes/alleles are either dominant or recessive, and that a monk with the name of Gregor Mendel (1822–1884) discovered the “rules” of inheritance through sexual reproduction. These “rules” are found as the introduction to genetics in most textbooks and science standards, and prevail in science assessments. The ways dominant and recessive traits are inherited through generations can be visualized with Punnett squares (see Figure 2.2). This concept is relatively straightforward to teach and, most importantly, easy to test. However, while this simple rule is not wrong, it is the exception and not the norm.<sup>13</sup> And it is an example of how simplification can have adverse consequences for students’ understanding of core science ideas.

	W	W
w	Ww	Ww
w	Ww	Ww

Cats:

WW = complete white hair (very rare)

Ww = complete white hair (very rare)

ww = some white hair

W: uppercase indicates dominant allele

w: lowercase indicates recessive allele

*Figure 2.2.* Example of a Punnett square. In this example, the gene for white hair is dominant; the trait is nevertheless very rare. Idea from *Myths of Human Genetics*, by J. H. McDonald, 2011, Retrieved from <http://udel.edu/~mcdonald/mythintro.html>.

<sup>12</sup> Epigenetics, the most recent strand of genetics, suggests that the teleological idea may actually be possible (Pennisi, 2013).

<sup>13</sup> See <http://udel.edu/~mcdonald/mythintro.html> for more information.

A focus on dominance can support some of the following ideas: That there are normally two alleles of the same gene that determine a trait; that one of these alleles is stronger, better, fitter, and more prevalent; that a dominant trait will “suppress” the recessive trait; and that “dominance” is the norm, and therefore recessive traits are somewhat not normal (Allchin, 2002; Redfield, 2012). These ideas are not entirely accurate. In fact, most traits (e.g., hair color) are determined by more than one gene and more than two alleles per gene. Normally, both inherited alleles of a gene (from mother and father) are expressed, but only one of the traits may be recognized as the phenotype. Further, this understanding of dominance implies a nonexistent causality and intentionality, while dominance is relative to the partner gene only. That is, in some pairings, a trait may be more “dominating,” while in others it will not (e.g., blood groups).

Also, a trait can have several characteristics, some of which are considered “dominant” and some “recessive” (e.g, sickle cell anemia causes both limited oxygen transport in the blood [recessive under normal circumstances] and malaria resistance [dominant]). Moreover, some genes have different levels of activity over the course of a life (e.g., there is decreasing activity of the gene for lactose tolerance towards adulthood for the majority of people).

Dominance also evokes the image of competition and therefore influences students’ interpretations of the concepts of inheritance, adaptation, and natural selection. For example, people find it easy to believe that red hair (a recessive trait) will disappear over time (while in fact, if there is no selective pressure on a gene, a recessive gene may “hide,” but will not change its overall proportion in the population), and that “normal” traits are always dominant (in fact, the allele for polydactyly, having more than five fingers, is dominant over the five-finger allele, but is extremely rare).

Dominance thinking therefore leads to the interpretation of the well-known expression “survival of the fittest” as “stronger is better,” or the “strongest” are here to “survive.” The scientific meaning of *fit*, on the other hand, means only to survive long enough to reproduce. Dominance thinking also tends to focus students on individual organisms rather than populations as the unit for natural selection and adaptation, and makes it harder for students to fathom that the time of genetic mechanisms spans countless generations.

This type of thinking about dominance is extremely sticky: It comes naturally to students, as it fits with their experience of what the word *dominant* means in their own lives. Therefore, the problem is not that the rule of dominant-recessive inheritance is taught at all, but that it has such prominent status by being the first genetic rule that students encounter. Its prominent position and the stickiness of dominance thinking together create obstacles for students’ learning a more complex picture later on. However, even middle school teachers who want to convey a nuanced approach to variance and inheritance find that time pressure, limited curriculum resources, standards and assessments requirements, and lack of science content support (an online search will take hours or days—as determined by the author’s attempt—and yield little) make it hard to go beyond simple Punnett squares in the classroom.

**Natural selection and adaptation.** As mentioned, populations are the unit on which natural selection and adaptation occur. Individual organisms do not adapt, but rather they pass on certain traits to the next generation in changing proportions. In other words, some traits get passed on more frequently than others due to environmental pressure, such as predators, illness, or availability of food. These traits accumulate over time in a population, hence, the characteristic of the overall population changes. Adaptation, therefore, is a repeated two-step process of mutation (change in the individual) followed by natural selection (change in the

population) (Gregory, 2009). One problem with these concepts is that nature as we experience it is rather static. The processes of adaptation can seldom be observed in daily life, and few people are aware of them. Therefore, students' experiences and the concepts they are taught do not match. Different meanings of terms like *adapt* and *select* in the vernacular and in scientific language further complicate the matter (Shtulman, 2006). As with most seemingly simple concepts in science, neither their teaching nor their learning is straightforward.

**Science-for-teaching.** The science content presented in the preceding sections illustrates common science knowledge as it is taught in biology courses and found in biology textbooks in a very abbreviated form. However, it also includes the knowledge necessary for the reader to understand the teaching of the content, and therefore depicts some aspects of content knowledge for science teaching. Specialized science knowledge includes the different examples of dominant genes that encode traits that are very rare (e.g., white fur color in cats, or polydactyly in humans), and various forms of nondominant inheritance. Knowledge of science and students includes all the potential examples that would be interesting or important for students. And knowledge about science and teaching includes how to choose the examples that are most productive for students' learning of the concepts, and what methods to choose to guide this learning.

Most teachers have to develop this content knowledge for science teaching in isolation. This requires extensive work and time for each teacher who teaches the topic. Teachers with a good academic science foundation from college or related work experience may find their efforts to expand their common content knowledge successful. But without foundational knowledge—such as when middle school science teachers are asked to teach three science domains (life, physical, and earth science) in one year—and without adequate professional development, teachers will rarely be able to accomplish it. Collaborative work in PLCs at least enables teachers

to share this type of knowledge. Making such knowledge available during teachers' collaborative work can greatly reduce teachers' individual work and enable them to further contextualize content knowledge for science teaching and to focus on student learning and their teaching practice.

### **Professional Development Design Context**

The PLCs observed for this study were part of a district-wide mandatory science PD initiative that began several years ago and included science teachers' work in PLCs.

The PD model was Observing for Evidence of Learning (OEL), a model for collaborative work among science teachers that had been implemented by school districts in the Pacific Northwest region of the United States since 2005. The school district in which this study took place began implementing the OEL program in 2009 through a Washington State Mathematics and Science Partnerships grant. Middle school science teachers participated in this mandatory PD for approximately three 2-day PLC cycles per year for 3 years. This study took place during the last (ninth) OEL cycle in the school district.

In the OEL program, during each 2-day PLC cycle (see Figure 2.3), a group of teachers work together to improve the curriculum they are currently teaching to better serve their unique student populations. At the same time, the OEL program aspires to encourage professional discourse in order to enhance the general teaching practice over time. Changes in teaching practices are based on evidence of student learning gained during the enactment of the collaboratively developed lesson, when one of the teachers teaches the lesson in her classroom while the other teachers observe the students.

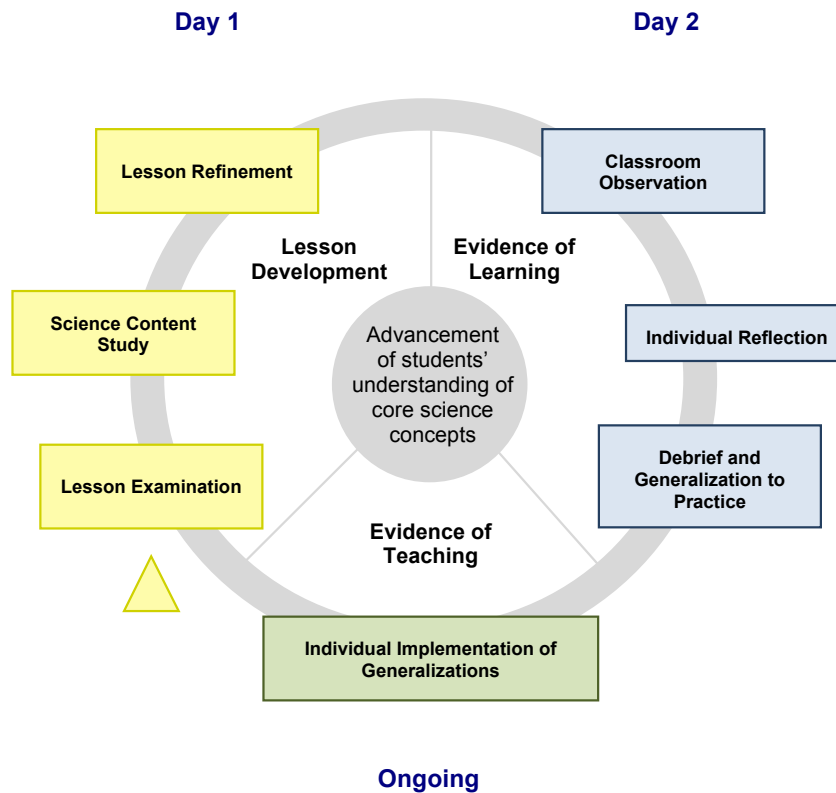


Figure 2.3. Two-day collaborative PLC cycle. The six phases of the protocol span 2 days; the implementation of generalizations for teaching is the work of individual teachers between cycles.

To prepare for the PLC cycle, the teachers choose a learning segment (several lessons that lead to the learning of a science concept) from their common curriculum that includes concepts their students have had difficulty understanding. During the 2 days of collaboration, a detailed protocol guides groups of teachers through the following phases. On Day 1, teachers engage in (a) *lesson examination*, during which they have an opportunity to share past teaching experience; (b) a *science content study*, during which the teachers are encouraged to discuss and solidify their understanding of the learning segment's scientific concepts; and (c) *lesson refinement*, during which the teachers work on improving the learning segment. On Day 2, teachers engage in (d) *classroom observation*, during which teachers have an opportunity to teach a lesson from the learning segment and observe students' interactions; after which they

have (e) *individual reflection* time; and (f) *debrief* together the observed evidence of students' learning, which results in further improving the learning segment. Between the PLC cycles, teachers (g) implement in their own classrooms the *generalizations to practice* that they as a group had agreed on.

The science content study phase on Day 1 can be supported by outside science experts who have specific knowledge about the concepts required by the curriculum. These science experts explore the science informally and collaboratively with the teachers. In this way, they can be responsive to the teachers' interests and needs and incorporate teachers' experiences. However, scheduling science experts who work outside the school district, often in research positions, can be difficult, and not all PLC cycles are structured in this way.

### **Setting and Participants**

The study took place in a school district with a diverse student population in the Pacific Northwest. The district had high science teacher retention, in part because of a science administration that was perceived by the teachers as very supportive. The science administration itself had a long-standing relationship with the PD providers who supported the implementation of the observed science teacher PLCs.

#### **School District**

With about 19,000 students, Emerald School District (SD)<sup>14</sup> is a relatively large school district in the Pacific Northwest region of the United States. It serves a medium-sized city as well as suburban and rural areas. Emerald SD has a robust science program that supports science learning from elementary school onward, and it provides its teachers with a variety of PD opportunities. From 2003 to 2006, the school district adopted inquiry-based curricula for middle

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<sup>14</sup> Pseudonyms are used for all names of individuals, schools, and school districts throughout this article.

school science. Science teacher retention in Emerald SD has been high in recent years, so by the time this study took place in 2012, most of the middle school science teachers had been teaching the same curriculum for a few years and were quite familiar with its instructional approach and content. The science materials needed for the curricula are refurbished at the district's science resource center. For OEL implementation, the district collaborated with a small nonprofit organization that supports public school science education in the region. This organization works closely with local scientists and science educators.

For three years, from 2009 to 2012, the middle school science teachers participated in approximately three 2-day OEL cycles per year. This collaborative work was complemented by summer PD focusing mainly on physical sciences content, but also on issues of collaboration and the OEL process. Participation in each of the OEL cycles was mandatory. The observed cycles were grade-level based, with half of the seventh-grade science teachers from across the district participating in one cycle, and the other half part of the other cycle observed for this study.

## **Middle Schools**

Emerald SD has five middle schools, each with five to seven science teachers for grades 6 through 8. The sizes of the middle schools range between 600 and 1,100 students. Emerald SD middle school students' ethnicities are comparable to the state's general student population: 60–65% of students are White, 10–19% are Hispanic, 5–20% are Asian, 11–21% are Asian/Pacific Islander, and 2.5–5.5% are Black. About 9% of students are Transitional Bilingual and 8–14% of students receive special education. Emerald SD's results in the state's eighth-grade science assessment in 2012 (78.6%) were considerably higher than the state average of 66.4%. The five middle schools serve a wide range of communities with regard to socioeconomic status. This diversity is reflected by the state science assessment test scores. For example, on average only

19% of Rosegarden Middle School's students are eligible for Free and Reduced Price Meals (FPM), and 91% of its students met the assessment's science standards for eighth grade in 2012. On the other side of the school district, 65% of Eastside Middle School students are eligible for FPM, and in 2012 only 60% of its eighth-grade students met science standards (Office of Superintendent of Public Instruction, 2012). The teachers are well aware of this disparity and are working to improve learning opportunities for all their students.

### **Middle School Science PLCs and Participating Teachers**

The ninth PLC cycle for Emerald SD's seventh-grade science teachers was observed for this study. Because a PLC with all 10 seventh-grade science teachers had proven too large to be productive, they were divided into two groups: in one PLC, five teachers represented all five middle schools in the district; in the other PLC, four of the five middle schools were represented. Both PLCs worked on parts of their *Populations and Ecosystems* curriculum (FOSS, Lawrence Hall of Science, & Delta Education, 2004). The district's science administration had suggested using the learning segment about inheritance, adaptation, and natural selection as the focus for the PLCs' collaborative work. These particular topics were scheduled at the end of the school year and many teachers rushed through the concepts, if they had time to teach them at all. Therefore, the teachers' expertise with the concepts was limited. One of the PLC cycles, which focused on inheritance and the human karyogram, is referred to here as the Inheritance-PLC. The other PLC cycle focused on adaptation and natural selection and is referred to as the Adaptation-PLC.

The teaching experience of the seventh-grade teachers participating in the observed PLCs was comparable in both groups and ranged from 4 to 24 years. In the Inheritance-PLC, the master's in science education degrees were on average more recent, and three of the teachers had

previously worked in a science-related profession. However, the data shows no evident difference in science knowledge between the two PLCs (Table 2.1).

Table 2.1  
*Science Teachers in the Adaptation-PLC and Inheritance-PLC*

Adaptation-PLC				Inheritance-PLC			
Pseudonym	Age	Teaching Experience	Degree	Pseudonym	Age	Teaching Experience	Degree
<b>Emily</b>		4	MEd 2007	<b>Sarah</b>	40–50	6	MEd 2009
<b>Ann</b>	30–40	12	MEd 1999	<b>Kimberley</b>	30–40	7	MEd 2004
<b>Carol</b>	30–40	15	MEd 1999	<b>Grace</b>	> 50	8	MEd 2003
<b>Lydia</b>	40–50	16	BA	<b>Ashley</b>	40-50	12	MEd 2003
<b>Joe</b>	50–60	24	BA	<b>Elizabeth</b>	40-50	20	B
<b>Average</b>	42	14		<b>Average</b>	47	11	

Note. BA = Bachelor of Arts degree; MEd = Master of Education degree

### Science Experts

A science expert worked with the Adaptation-PLC for part of Day 1 of the PLC cycle. She was a graduate student at the local university with master’s degrees in education and in science, and had already supported several PLCs in this PD program. The Inheritance-PLC was not supported by a science expert.

### Facilitators

On Day 1 of the PLC cycle, the Adaptation-PLC also had one of the external PD providers present as a designated co-facilitator. However, she spoke only sporadically to summarize statements or to turn the group’s attention back to a statement a teacher had made previously. On Day 2, the Adaptation-PLC was teacher-led. The Inheritance-PLC was teacher-led on both days of the PLC cycle.

## Methods and Data Analysis

This study uses a qualitative comparative case study approach with a strong discourse analysis component.

### Sampling

The two seventh-grade PLCs were chosen for this comparative case study (Yin, 2006) because they worked within a similar context but differed in one main aspect: One PLC was supported for part of the first day by a science expert, while the other PLC had no such support. In all other ways, these PLCs were comparable. The participants in both PLCs were experienced science teachers (average years of teaching was 11 and 14 years). As it was these teachers' ninth PLC cycle in 3 years, they were used to collaborative work and knew each other well, even if they had worked together in different configurations in the past. The teachers used the same curriculum and worked on related topics—variation, inheritance, adaptation, and natural selection—which most of them had taught either in broad strokes or not at all in previous years. Both PLCs fulfilled the task of designing a lesson plan, which was then taught by one teacher and observed by the others. Both PLCs also created a follow-up lesson plan based on what they learned during the teaching of their lesson. In general, the teachers in both groups expressed satisfaction with the lessons they had developed.

### Data Collection

Data sources for this study included observations, audio and video recordings, field notes, semistructured interviews, and documents from the curriculum.

**Observations and field notes.** The main data source for this study were the observations and audio recordings of both 2-day PLC cycles. Parts of the Adaptation-PLC cycle were also video recorded. In addition, field notes were taken throughout the PLC cycles by the researcher

acting in a “peripheral membership role” (Adler and Adler, 1998, as cited in Merriam, 2009, p. 124). The researcher did not interact with the teachers during the PLC cycles. Field notes were the main data source for the lesson observations; audio and video taping were not permitted. The recordings were transcribed, and together with the field notes enabled an understanding of the science and the problems of practice that were discussed. This understanding provided the basis for determining which discourse episodes were relevant for answering the research questions about content knowledge for science teaching (Erickson, 1986).

**Interviews:** One-on-one semistructured interviews were conducted with four of the five teachers from each PLC. The interviews took place several days after the relevant PLC cycle. Each interview lasted between 20 and 60 minutes. In these interviews, the science teachers reflected on their stance on what science knowledge was necessary for supporting science learning in their classrooms, on how they had experienced the science content negotiation during the observed PLC cycle, and on how the science discourse had influenced their practice. Lesson plans and student learning artifacts served as prompts for teachers to recollect the proceedings of the PLC cycle. Which interview questions were answered, in what length and detail, as well as the overall length of the interviews depended mainly on the teachers’ interest and availability.

The science expert was asked about her preparation for and reflection on the PLC content study phase she had supported.

These interviews supported an understanding of the science discussed in the PLCs. Interviews with a school administrator and the OEL program director, as well as many informal side conversations, added context. Thus, the interviews helped to build an understanding of the context and history of teachers’ work in PLCs and to triangulate some of the findings. All interviews were audio recorded and transcribed.

**Documents:** The curriculum, in the form of a teachers' guide and student textbook, was consulted to analyze the science knowledge available to the teachers. Lesson plans, student worksheets, and other materials developed by the teachers gave additional insight into their practice and further triangulated observations about the teachers' practice. Publicly available school and teacher data, such as test results for the state's science assessments, teachers' years of teaching, and teachers' highest education degree were also used to understand context and to determine the level of comparability of the two cases.

### **Discourse Analysis**

The discourse of the two PLCs was compared to determine how the discourse that developed differed due to the different support received, and consequently, what different knowledge resources the teachers were able to access. There were three research questions:

- How do teachers in a PLC talk about content knowledge for science teaching when they are collaboratively planning their teaching?
- What factors influence the features of this discourse about content knowledge for science teaching?
- What is the effect of discourse about science knowledge for teaching on teachers' collaborative lesson development and teaching practice?

**Discourse analysis within a case study approach.** The teachers' discourse observed in this study took place within the bounded system of a 2-day OEL cycle; each cycle was considered a "case" (Merriam, 2009). Both cases were similar in the composition of teachers, setting, and topic chosen, but differed in that one case had the support of a science expert and one did not. The unique data from both cases were analyzed individually and then compared to analyze the influence of the expert science support on teachers' discourse about content

knowledge for science teaching. The analysis and interpretation of the presented data concludes with an evaluation of limitations.

**Data sources and analysis.** Primary data sources included the audio recordings of the two observed PLC cycles and field notes taken by the researcher. For the first case study, the Inheritance-PLC, 5 hours of recorded discourse was transcribed and analyzed, and field notes were taken during 90 minutes of classroom interaction during the observation of the collaboratively developed lesson. For the second case study, the Adaptation-PLC, more than 8 hours of recorded discourse was transcribed and analyzed, and two periods in the classroom were observed. One period was the lesson taught for observation as part of the PLC cycle; the other was the follow-up lesson that the PLC had developed after debriefing the lesson observation. The follow-up lesson was taught by the same teacher as the observed lesson, but was observed only by the researcher and not by the other teachers in the PLC.

The analysis of the teachers' discourse went through different rounds:

1. The first review of the transcripts was to discern talk related to content knowledge for science teaching from talk that did not include any science ideas.
2. The first round of analysis established *discourse strands* that followed the talk about specific topics (e.g., “chromosomal aberrations,” “variation”) and were sustained over a longer period, or dropped and taken up again.
3. These discourse strands were then coded for “knowledge of science and students,” “knowledge of science and teaching,” and “science content knowledge.”
4. The way that content knowledge for science teaching was approached during discourse strands was compared across the two cases, with regard to content (what was talked

about) and participation (who participated, and what did this participation entail with regard to access, use, and development of knowledge).

5. Episodes that were exemplary for how teachers talked about content knowledge for science teaching were selected to answer the first research question: “How do teachers in a PLC talk about content knowledge for science teaching when they are collaboratively planning their teaching?”
6. Further analysis aimed to establish correlations between discourse about content knowledge for science teaching and approaches to teaching practice, as indicated by (a) the collaboratively developed lesson plan, (b) the lesson taught for observation as part of the PLC cycle, and (c) teachers’ work with students’ ideas during the lesson debrief (and, for one for the cases, during a consecutive lesson that was not part of the PLC cycle). This part of the analysis approached the question “What is the effect of discourse about science knowledge for teaching on teachers’ collaborative lesson development and teaching practice?”
7. Throughout this analytical process, the following question was contemplated: “What factors influence the features of this discourse about content knowledge for science teaching?”

Secondary data provided context for the interpretation of the discourse data. The sources of secondary data were interviews with participating teachers, an administrator, and the PD provider; informal conversations with individuals involved in the OEL program; publicly available school and teacher data; and documents such as curriculum materials, lesson plans, and related materials.

## **Limitations**

The two PLC-cycles observed for this study possessed comparable features and were within the normal range of the many teacher PLC cycles previously observed by the researcher. However, as is often the case in qualitative research, the match was far from perfect. The approach of observing how two PLCs treated knowledge for science teaching during their collaborative work can only suggest correlations between discourse, development of teaching materials, and teachers' practice. Each case was unique, and it isn't possible to know with certainty what influence the science expert had on the discourse or the products. "A major limitation in fieldwork is the partialness of the view of any single event" (Erickson, 1986, p. 144). The researcher—not part of the school district, and previously but no longer involved with the PD providers—was a relatively, but certainly not fully, objective observer.

## **Findings**

The two middle school science PLCs in this study were comparable with regard to participants, science content focus, and task framing. Each PLC comprised five experienced science teachers with 4 to 24 years of teaching experience. The teachers in each PLC represented all five of the five middle schools in the district (Inheritance-PLC) or four of the five schools (Adaptation-PLC). Interviews indicated that the teachers in both PLCs had strong and diverse science knowledge and interest. Three of the Inheritance-PLC teachers, for example, had past experience working in other science professions. One of the Adaptation-PLC teachers had a research science background. All 10 teachers had already attended eight similar PLC cycles over the previous 3 years; the cycle observed in this study was the ninth and last of the OEL program. The teachers knew each other and worked well together. Both PLCs used the same inquiry-based

curriculum, *Populations and Ecosystems* (FOSS, Lawrence Hall of Science, & Delta Education, 2004), as the basis for their lesson development.

For both PLCs, the district's science coach had recommended the focus of the collaboration. Due to the sequence of the seventh-grade science modules/kits, the *Populations and Ecosystems* curriculum was the third and last one to be taught during the school year; teachers often didn't have enough time to fully develop all the concepts of this curriculum with their students, and sometimes a few concepts were not taught at all. However, inheritance, genetic variation, adaptation, and natural selection are core ideas in science and are necessary to understanding overarching concepts such as evolution in high school. With evolution an important concept throughout the grade levels in the *Next Generation Science Standards* (NGSS Lead States, 2013), the district had decided that in the following year, the *Populations and Ecosystems* curriculum would be taught earlier in the school year and that the PLC sessions would be a good opportunity to bring the teachers up to par. The district's science coach suggested that the Inheritance-PLC fill a void in the curriculum by adding a lesson about the human aspects of genetic variation. Without this type of lesson, students would not be introduced to human genetics until high school. For the Adaptation-PLC, the science coach suggested that the teachers work on the adaptation and natural selection part of the same curriculum.

The teachers in both PLCs worked to improve how they taught existing lessons. In the Inheritance-PLC, a teacher provided a lesson sequence she had learned in a PD session years before as the basis for their collaborative work. The Adaptation-PLC used the original lesson from their common curriculum. Both original lessons had a strong student engagement component (e.g., sorting chromosomes into a karyogram according to their patterns, a natural selection simulation). Both teams created a detailed lesson plan and student worksheets for the

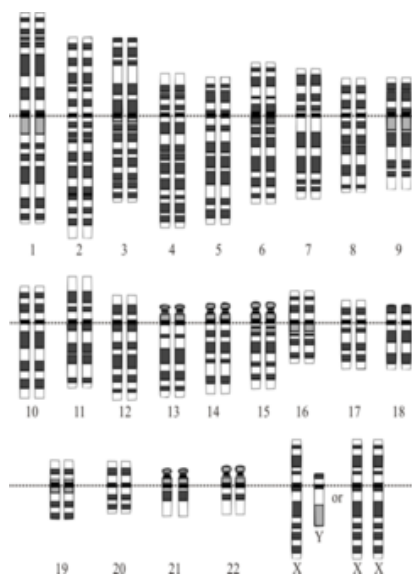
observation lesson, including extra advice for current and future seventh-grade teachers who were not participating in the PLC cycle. Both teams expanded their lesson plans to include a follow-up period, based on the insights gained during the observation lesson and debrief. The teachers in both PLCs expressed their satisfaction with the lesson they had created. All materials from the two lessons were submitted to the district's intranet to be made accessible to all teachers in the district. Thus, the teams fulfilled one of the goals of the OEL program: enhancing the teaching of certain lessons that were traditionally unsatisfactory in helping students learn science concepts. The one important difference between the two PLCs was their science content support. The Adaptation-PLC was visited by a science expert for about 2 hours during the first day of the PLC cycle; the Inheritance-PLC had no such support.

While each PLC cycle is inherently unique, the contextual similarities enabled a comparison that could show the influence of discourse about content knowledge for science teaching that was supported by a science expert who brought science knowledge to the forefront of the conversation. In the following two case studies, three themes in the teachers' discourse are contrasted: (a) framing a science idea as simple versus complex, (b) positioning science knowledge that seemed marginal to the lesson as unnecessary versus useful, and (c) having different levels of expectation for students' science understanding. The discursive interactions of the two PLCs are first presented individually and then compared.

### **Case I: Inheritance-PLC's Discourse About Teaching, Students, and Curriculum**

The Inheritance-PLC's participants were experienced teachers whose 2-day PLC cycle was facilitated by Sarah, one of the participating teachers. They had no extra science support for this PLC cycle. The teachers worked on the beginning part of their seventh-grade unit on genetic variation. The objectives of this unit included ideas about variation, heredity, chromosomes,

genes, alleles, and dominant and recessive inheritance. Because the curriculum investigated these ideas through imaginary organisms (the larkeys, foxlike creatures with only four chromosomes) and animals, the group decided to introduce the human karyogram to illustrate how the unit's science ideas apply to humans. One of the teachers, Elizabeth, had brought a lesson plan, a karyogram template, and individual hand-sized cardboard chromosomes that could be attached to the huge template that hung at the back of the classroom. The result of the sorting activity would look like a karyogram found in textbooks (see Figure 2.4).



*Figure 2.4.* Human karyogram. This image is similar to the one used for the sorting activity. Reprinted from *Genetics of Down Syndrome*, by Snustad, D.P., Simmons, M.J.(2006). Principles of Genetics (4th ed.). Hoboken: John Wiley & Sons, Inc Retrieved from URL <http://prescottgeneticss10.wikispaces.com/Genetics+of+Down+Syndrome>. Reprinted with permission.

The group decided to use these materials as the basis to design a lesson for their students. During the 2-day PLC cycle, this group of teachers expressed detailed knowledge about their students' contexts, such as their family circumstances, their standing within the school community, the countries they were originally from, and for

some, their journey of immigration. Throughout the PLC cycle, the teachers showed deep concern for their students' well-being. These aspects of teacher talk are not represented here, as the analysis focuses on the discursive exchanges related to teaching science.

**Inheritance-PLC's framing of variation as difference.** When the teachers talked about genetic variation, they indicated that they were well aware of the science, their students' interests and needs, and effective teaching strategies. However, these domains of knowledge for teaching were often only hinted at and not made explicit. Consequently, connections between science and students and science and teaching were not explored, and the tacit knowledge present in the group was not used to develop a more scientifically productive view of genetic variation.

The group began a discussion about variation in terms of the similarities and differences that their students could notice among each other and what could exemplify the idea that most variations between individuals of one species, such as humans, are incremental. However, the teachers' discourse quickly moved to syndromes that are caused by changes in number of chromosomes and manifest as severe changes in an individual's appearance. Thus, the teachers moved the focus of the lesson from variations caused by sexual reproduction (mixing of genes) to variations caused by mutations (changes in the genetic code or in the number of chromosomes). This move was driven less by the science they were supposed to teach and more by the teachers' and students' interests.

At the beginning of their collaborative work, the teachers created the objective of the lesson and based on the focus question on the *Washington State K–12 Science Learning Standards* (Office of Superintendent of Public Instruction, 2009) and the original lesson they were using. They posed the following direction in the lesson plan: “On your whiteboards, explain why you are probably similar to your biological mom and dad?” With this question, the

Inheritance-PLC asked their students to think about the similarities among their relatives. The focus on similarities was to aid the idea that traits are passed down from parents to offspring. Sentences like “similar but not identical to their parents” were also included in the lesson plan. Subsequently, the teachers’ discourse around developing the idea of genetic variation moved from “similarities” as a frame for variation toward “differences.”

Kim: So for the engage ... I always like to do that thing where I say, “Look around the room and see how different we are from each other. And so today we want to know why that is.”

Ashley: Some might want to argue that “I’m the same, I am not different ...”

Kim: So why not “similarities and differences from other people”?

This brief episode shows that the teachers were considering their middle school students’ desire to blend in rather than be different. So they changed the students’ entry task at the beginning of the lesson slightly to include similarities by suggesting in the lesson plan that the teacher could ask: “Look around the room and notice the similarities and differences in your traits to the other students in the room. Let’s find out why.” Here, the teachers’ knowledge of their students actually encouraged them to stress similarities over differences.

However, the teachers decided to move away from the concept of similarities, and they focused on Trisomy 21 (Down syndrome) as the first example of the influence of chromosomes on the inheritance of traits. During their discourse about how to talk about Trisomy 21, the teachers were concerned that students would regard the differences caused by a third 21st chromosome as “not normal.” Therefore, they agreed to use the expression “atypical features.” The teachers also talked about the importance of students knowing what causes Down syndrome and understanding that having this syndrome is no one’s “fault.” The teachers even considered inviting the mother of a child with Down syndrome to talk about living with this syndrome. To

help their students think about the causes of Trisomy 21, the teachers included the following question in the lesson plan, referring to the karyogram of a girl without and a girl with Trisomy 21: “How are the chromosomes of this second person different from the first person we looked at? Do you think this changes the traits of the second person, why or why not?” This question directs the students toward the idea that a difference in number of chromosomes causes differences in traits.

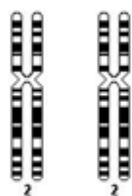
The discourse about Trisomy 21 revealed that knowledge of science, of students, and of teaching was present in this group of teachers. Indeed, because they frequently mentioned additional knowledge about cell division, chromosomes, sexual reproduction, and mutations the teachers seemed to possess more knowledge about science than was expressed during the PLC cycle. The teachers displayed knowledge about students and their context and were concerned about relationships and how to employ community resources. And, the teachers demonstrated knowledge about teaching when, for example, they carefully crafted their questions. However, these teachers did not discuss the *connection* between the science ideas they wanted to teach and their knowledge about their students and about teaching. Therefore, these connections could not have been further explored, and the productiveness of teaching for students’ science learning was not considered.

The teachers in the Inheritance-PLC discussed, in addition to Trisomy 21, other examples of genetic mutations they could introduce to their students. However, they didn’t want to convey to their students that all mutations had a negative impact on the individual, so they included in the teachers’ notes for the lesson plan that teachers should also include mutations that have a more positive impact on the individual. They included the examples of lactose tolerance that enables adults to digest milk, and sickle cell anemia that lessens the impact of malaria. Including

these more positive examples showed an implicit understanding of the problems with framing variation of traits as a dichotomy, especially when skewed toward the negative. However, this problem was not made explicit during lesson planning, and the framing of variation in black-and-white rather than gradual terms was reflected throughout the lesson plan and its extension.

When the observation lesson was taught, the students expressed curiosity about more subtle differences and similarities that they had experienced. They asked, for example, “Why does a younger sibling normally look more like the mom?” and similar questions about siblings and twins. The teachers were excited about the questions that the lesson generated, but again, during their PLC time they neglected to discuss the connections between their students’ interest and the science. While Trisomy 21 is an interesting topic that illustrates the fact that the right number of chromosomes is important to be healthy, it does not prepare students for the concepts of adaptation and natural selection. And with students more interested in the ubiquitous genetic variations they experience in their daily life than in the extremes, the work of connecting this knowledge of students with knowledge of science was left to the individual teacher.

**Moving away from science knowledge.** In the following episode, the teachers discussed chromosome banding, typically seen in karyograms. One use of karyograms is to determine whether the cells of a fetus contain the correct number of chromosomes. For this purpose, chromosomes are extracted from cells and dyed. The dye darkens some areas more than others, depending on the chemical characteristics of the DNA, leaving dark bands that are typical for each chromosome and the same for each chromosome pair (Figure 2.5). This technique makes it easy to match, order, and count chromosomes under the microscope. However, dark bands and location of genes are not correlated.

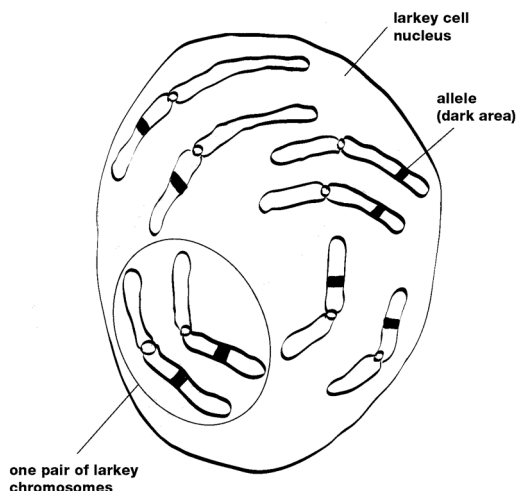


*Figure 2.5.* Chromosome banding of the second human chromosome pair

The topic of chromosome banding is not part of the knowledge students need to gain in middle school and is not required by either curriculum or standards. This example is chosen because it shows that even teaching “simple” middle school science, teachers come across issues that will go beyond what one would expect in middle school, and that are not or are only incompletely explained by the resources available to the teachers (e.g., the curriculum’s teachers’ guide). Furthermore, knowledge about chromosome banding seems at first glance to be unnecessary for students’ understanding of the lesson objectives. So the team had to decide in the moment whether the limited time they had would be well spent figuring this issue out, or whether it would be better to gloss over it and move on.

To complicate the matter, the common curriculum the teachers were using actually supported the (wrong) idea that a chromosome band caused by dyeing represents a gene. A sketch (figure 2.6) of a simplified karyogram showed the location of a gene marked by a black mark on the chromosome, similar to the banding of chromosomes in a karyogram. In the teachers’ guide and student book, the comment for this picture reads “Look now at these dark areas. Both chromosomes in a pair have dark areas in exactly the same location. The dark areas are called **alleles**.” (FOSS, Lawrence Hall of Science, & Delta Education, 2004, p. 270; bold word in original). This sketch should demonstrate that alleles of one gene have the same location

in a chromosome pair. However, this depiction and the chromosome banding in a karyogram could be easily understood as being the same.



*Figure 2.6.* Larkey karyogram. The black mark is meant to indicate that alleles occupy the same location in a chromosome pair (FOSS, Lawrence Hall of Science, & Delta Education. (2004). *Populations and ecosystems: Teacher guide.* Nashua, NH: Delta Education, p. 270).

The following episode about chromosome banding shows how science that is implicitly embedded in a lesson, such as chromosome banding, can play an important role in how a lesson plays out in the classroom. In this example, the knowledge about chromosome banding was, at least in part, available within the PLC, and specifics could have been relatively easily to access via the Internet. However, the group moved away from a clarifying discourse about chromosome banding, perhaps for these two reasons: (a) limited time, and the pressure of the task; and (b) the norms of collaboration.

During the planning phase of the PLC cycle, the teachers discussed which patterns (e.g., form, size, pairs) the students would discover, as a class, when they organized the chromosome models into a karyogram. In addition to the fact that chromosomes come in pairs, and have

different sizes, the students would also recognize that each chromosome pair showed the same “stripes.”

1 Elizabeth: And they [students] will probably tell you, too, that they have all stripes on  
2 them.

3 Sarah: As they all have stripes on them, so there are five different things [patterns]  
4 they could record. And they could record [draw] the stripes on one  
5 chromosome only.

6 Elizabeth: And notice that they match.

7 Grace: Yes, that is good.

8 [...]

9 Ashley: We want to write [as potential student answers for the teacher notes  
10 of the lesson plan], “There are stripes on the chromosome.”

11 Elizabeth: So, just write “Note [to the teacher], these represent alleles on chromosomes.”

12 Ashley: Actually, they represent just the banding patterns, when they [the  
13 chromosomes] condense. They do not actually have to represent any alleles or  
14 genes. They don’t actually represent the alleles. So...

15 Grace: What do they represent?

16 Ashley: When the chromosomes condense, it’s a specific banding pattern, and the  
17 genes can actually be, they don’t actually have to be, like, a gene may not  
18 actually sit completely next to each other on a chromosome. It’s...part can be  
19 here and part can be here. The banding patterns is a way to recognize the  
20 chromosomes, it is not necessarily about the alleles and the genes. So when a  
21 gene is turned on, you can have different pieces that end up being brought  
22 together, from different sections. [silence...]

23 Elizabeth (reading from the original lesson description): So “Specific DNA sequences for  
24 certain products and traits, called genes, are known to  
25 be present in specific bands.”

26 Ashley: They may be present in specific bands, but they might be spread out  
27 throughout...

28 Elizabeth: But, yeah, you know [doubtful], for kids, just to say those bands may contain  
29 genes, we could say that.

30 Ashley: Yeah. And that there are huge sections of the chromosome that do not contain  
31 genes. They just contain...

32 Grace: So do you want me to write the bands contain genes? Is that what  
33 you, or just...  
34 Ashley: Some genes are contained within the bands. Not all genes are...  
35 Elizabeth (dictating for the lesson plan): Next, we would have them “record the various  
36 patterns seen by the class on your diagram below.” So, “on your worksheet...  
37 Sarah: ...use scientific words...  
38 [...]  
39 Sarah: And you could stop at each pattern and have them recorded, as  
40 opposed at the end, you record them all

At the beginning of this episode, the teachers’ discourse focused on observational patterns that students could detect while sorting chromosomes into a karyogram. In line 11, Elizabeth expressed the scientifically incorrect inference that the bands of chromosomes show the location of alleles. This is a common misconception among students that was supported by some of the illustrations found in the curriculum (Figure 2.6). Ashley tried to straighten out the scientific facts, and Grace supported this by asking for further explanation (line 16). However, Ashley was not prepared to explain this part of science, and she struggled to express her thoughts in a concise way. So Elizabeth turned to the teachers’ notes for the original lesson as a reference (line 24); the notes are quite ambiguous. Lines 29 to 36 show how the teachers’ discourse moved from scientific explanation to what students need to know. And for the lesson plan, Elizabeth suggested, “You know, for kids, just to say those bands may contain genes, we could say that” (line 29), suggesting that further exploration of the banding issue would not be necessary. With this comment, the group moved away from the science needed for teaching toward the task of completing the lesson plan and student worksheet.

This episode shows how one teacher (Ashley) tried to clarify the facts but had a hard time doing so; the teachers appeared to be reluctant to be taught by a colleague. This is a tension that

the researcher had often observed in previous PLC cycles, and which was also confirmed during the interviews with the teachers. The teachers expressed that they were very reluctant to be in situations that would show that they “don’t know the science.” And at the beginning of this PLC cycle, the group had expressed that they were anxious about not completing a lesson plan and not having materials ready for teaching. This very real time constraint may also have convinced the group to move away from the science toward the task of lesson planning.

The episode shows that the PLC did not make the connection of how this science fact could influence students’ learning. However, a few days later, when Sarah taught the collaboratively developed lesson in her classroom, it became clear that the banding patterns of the chromosomes caused students to struggle with the science concepts of inheritance through sexual reproduction. Two students were overheard talking while drawing chromosomes on their worksheet:

Student 1: If they have the same lanes, does that means that mum and dad had the same genes?

Student 2: Maybe the difference is in 23? [23rd = sex chromosomes]

The students saw the identical banding of the chromosome pair as an indication that these chromosomes were passing on identical traits. While debriefing the lesson, the teachers brought up this dialogue.

Elizabeth: But then when you put up the pictures, there were a lot of misconceptions, because they [the chromosomes] matched, so they assumed it was the same DNA. From mom and dad, you get the same DNA. [...]  
But then they made the misconception that only the X and Y chromosome, because they were different, was where the difference came from...

Sarah: So they were wrestling with some ideas...

While Elizabeth and Sarah acknowledged students' potential misconceptions, no one in the group brought up the problem of *science and students*. Despite the teachers' knowledge about students' difficulties with the science, and the knowledge about science facts that was present in the group, the teachers did not take the opportunity during their remaining PLC time to connect the two domains of content knowledge for science teaching and to change the lesson plan in a way that would prevent obstacles for students' science learning.

**High expectations for student engagement.** The debrief, which was held after Sarah had taught the collaboratively developed lesson and the others had observed students in the classroom, showed that the teachers' main focus was on improving their teaching by ensuring the students' engagement and interest. And they noticed that they were successful in this regard. However, they did not discuss the strong interest in science that the students had shown with their questions, which in turn could have been the basis for an extended science-for-teaching conversation that could have benefited students' science understanding during the course of this learning segment.

The engaging lesson plan piqued students' curiosity during the observation lesson, and they came up with many questions. During the debrief of the lesson, the teachers acknowledged these questions:

Sarah: [...] There were questions about twins, questions like how you get the extra 21st chromosome. Is the difference in the X and Y chromosome between people, is it the sex chromosomes that make people different, or is there something else in the DNA? Why do the chromosomes look the same and yet there is differences, but why do they look identical [the chromosomes] when there are differences [in people]?

However, there was no further discussion about the science the students were asking about. Subsequently, the teachers did not focus on the connection between science and students,

but rather on the teaching. The teachers then discussed adding leading questions in the lesson plan:

Elizabeth: You could just say, “Are the chromosomes of the second person different from the first person we looked at.” Or “Do you think the traits will be the same?”

[...]

Sarah: Is it necessarily wrong in a lesson like this to have a leading question?

The teachers then reflected on their lesson with regard to students’ interest and engagement, when they thought about what their *generalizations to practice* could be:

Sarah: Should be there something in there [in a lesson], that students expected it was the same and they were surprised when there was something different? [such as doing the same activity again, but with an additional chromosome]

Elizabeth: They were totally engaged, that’s what I loved, that’s evidence of learning. Totally engaged when they realized it was not the same.

Kim: Yes, that just this one chromosome difference would give someone Down syndrome, I think that was something really fascinating.

The discourse strand outlined here illustrates how the teachers’ discourse about students and about teaching stayed focused on students’ interest and teaching strategies, yet was disconnected from the science they were teaching.

**Simplification of science.** In general, the teachers’ discourse in the Inheritance-PLC was mainly about the corners of the didactic triangle: teacher/teaching, students, and curriculum. The science knowledge embedded in the topic they were teaching—the human karyogram and its relation to the variation of traits—remained unproblematized during the 2-day PLC cycle, and thus the connections between science and students and science and teaching often remained unexplored.

The teachers discussed how students were interested in science that related to them individually, and how they should be sensitive when talking with students about chromosomal disorders, such as Down syndrome. They were also pleased with the questions the students asked during the observed lesson, and they planned to engage with some of the questions during the course of their teaching. Their discourse about teaching reflected their knowledge of a certain type of learning cycle, of questioning strategies, and of how to match different tasks effectively with different modes of teaching. Their experience enabled them to easily envision how their planning could play out in the classroom. However, during their collaborative work, they did not connect their knowledge about students and about teaching with their knowledge about science. They wanted their students to understand that traits are inherited from parents, and that changes in the karyogram cause changes in appearance. Therefore, the changes they presented were changes in number of chromosomes, which cause severe disabilities. The teachers also talked about other mutations that cause distinctive differences in the individual carrier. The kinds of variations students noticed at the beginning of the lesson—genetic variance caused by sexual reproduction—were not addressed. And even as students' science questions were directed toward genetic variance, this science concept still remained absent in the discourse.

That does not mean that there was not sufficient science about inheritance and sexual reproduction present within this group. Sarah, when introducing the lesson, hinted about various science concepts that the learning sequence about inheritance implies, and the interviews, especially with Sarah and Elizabeth, indicated much more knowledge and interest in science than the teachers had expressed during the PLC cycle. But the science idea of variations and differences was never problematized, and therefore there was no need to access more of the teachers' science knowledge. Consequently, the teachers developed a lesson that greatly engaged

their students through a hands-on activity, small group work, and whole class discussions. The students were kept on task through directive questions, presented both verbally and on the student worksheet. However, the cognitive demand of the lesson stayed low, and the teachers' simplification of science, determined to be appropriate for their middle school students' understanding, resulted in the dichotomous framing of variation of traits—which caused confusion rather than understanding.

Experienced teachers such as these will over time guide their students toward a better science understanding, by answering students' questions and reacting to their confusion. But this example shows that as a group, they did not fully access their science knowledge during their collaborative work. Thus their tacit knowledge neither benefited lesson development nor opened up opportunities for the teachers to learn from each other.

## **Case II: Adaptation-PLC's Discourse About Science-for-Teaching**

The Adaptation-PLC's participants were experienced teachers, and their 2-day PLC cycle was facilitated by one of the teacher-participants, Emily. A PD provider was present during the first day of the PLC cycle, but she mostly stayed out of the conversations. From time to time, she would summarize the teachers' contributions, or bring a previous contribution back into the conversation. At the start of the first day of the cycle, a visiting science expert spent 2 hours with the teachers, focusing the discourse on science and on the connection between science, students, and teaching. From a starting point based on the curriculum and Washington State standards (Office of Superintendent of Public Instruction, 2009), which represented science ideas in a simplified form, and with the guidance of the science expert, the teachers moved the discussion toward a more complex idea of variation and natural selection. After the science expert left, the teachers continued to keep the science topics at the forefront of their discourse as they developed

the lesson. This resulted in two enhanced lessons that were not only engaging, but encouraged students to reason about the scientific concepts of natural selection and adaptation. The discursive deliberation of the content knowledge needed for science teaching during the PLC also prepared the teachers to work productively with their students' emergent understanding.

The teachers who participated in the Adaptation-PLC were working on a lesson in the unit on genetic variation that was further along in their *Populations and Ecosystems* curriculum (FOSS, Lawrence Hall of Science, & Delta Education, 2004) than the lesson the Inheritance-PLC worked on. In the original lessons leading up to the concept of natural selection, the topic of variation was described as distinct characteristics that someone does or does not have, such as the ability of tongue rolling, or having straight versus bent pinky fingers. The prominent place of Punnett squares in this lesson progression further reinforced the idea of distinct traits. The imaginary larkeys (foxlike creatures of unknown origin who have only four chromosomes) introduced as a means of simplifying concepts of inheritance, adaptation, and natural selection, also show only distinct traits, like having striped, solid, or dotted fur, or long or short legs.

**The curriculum and framing of variation as difference.** At the center of the lesson from the curriculum was a simulation of natural selection. Carol, a younger but experienced teacher, had managed to teach natural selection in previous years, while for most of her colleagues the school year ended before they reached the end of the curriculum. Therefore, Carol introduced the simulation. “You just looking at them [larkeys], and going, okay, so there’s lots of different ones. All sorts of variation, right? And you can talk about what variation there is.” These larkeys live in the forest, but when a fire destroys the habitat, so the story goes, they have to move to the prairie.

Carol:       And it tells you on the prairie, if you have long legs and stripes or solid, you have a 100% of survival chance. If you are spotted and have short legs, you

have a 0% survival chance. Because on the prairie, larkeys avoid predators by running away and hiding in long grass. So you continue, and now you've got some larkeys that had died. Like, oh, that one died because it is short and spotted.

The simulation leads to very distinct outcomes: Individuals with certain sets of traits survive; individuals with other sets of traits become extinct. This type of simplification is an inherent limitation of simple simulations of natural processes, which would otherwise become too complicated. It is therefore all the more important how a teacher frames the concept illustrated by the simulation.

For the teachers in this PLC, as with the teachers in the Inheritance-PLC, the teaching of variation had so far been framed in terms of distinct traits or distinct differences between individuals. Furthermore, the natural selection simulation bore the potential to show that variation could be framed in terms of the “weaker” traits becoming extinct.

**Discourse about and framing of variation as complex.** The teachers in the Adaptation-PLC were aware of the problem of framing traits as being better, having more worth, or being very different. The following excerpts show how the teachers problematized the ubiquitous expression “survival of the fittest.” In part, they referenced the information in the curriculum’s teachers’ guide. The analysis of the following excerpts revealed how teachers and the science expert considered different aspects of the science concept of variation by placing it in different contexts.

- 1 Carol: And as I was reading, I was guessing that the “survival of the fittest” is a  
2 misconception for students.  
3 [...]  
4 Ann: Right, the person with the biggest muscles, and the tallest, and the strongest.  
5 And everything “survival of the fittest” means is a bit [of a] fight, like  
6 people...

- 7 Carol: This is the misconception, fitness is really the number of offspring you have.
- 8 Lydia: But really, it is about small adaptations that occur, like maybe a whole bunch  
9 of...
- 10 Carol: ...and you have to fit the ecosystem.
- 11 Ann: Like the birds started off with one kind of peak, because there was nothing to  
12 compete with. And then they were developing different peak types because  
13 they were eating different things in order for them to all live and survive on  
14 the same island. You know—that are small adaptations.
- 15 [...]
- 16 Ann: [...] you know, to survive [pause] the things that are being imposed on them  
17 from the environment rather than the “best” equipped or something like that.
- 18 Carol: ...or the biggest, strongest...
- 19 Lydia: ...the fittest doesn't necessarily mean with the best condition, biggest teeth—  
20 so for me that means small adaptations.

In the discourse strand above, the teachers focused on two aspects: (aspect 1) the misguided idea of *fittest* understood as biggest, tallest, or strongest; and (aspect 2) the idea that over time, small adaptations lead to traits that give an advantage in survival. A third aspect (aspect 3), the idea that the environment plays a role (lines 10 and 17), was also mentioned.

After Vanessa, the science expert, had joined the group and was oriented to the teachers and curriculum, she also deliberated about the notion of “survival of the fittest” and expanded and deepened the discussion by adding additional aspects. First, she too brought up the influence of the environment that the teachers had already mentioned, and further expanded this idea:

Vanessa: So assuming you have established the variation and they have bought in, and they get that it is inherited. That's great. Then the question is, what does this mean? Well, it means that at any given moment somebody has gotten a really good [...] combination of traits that makes them particularly adept in that moment and that environment. Three days later, someone else might be really good. Next summer, someone else might be really good. So the notion that the environment is constantly changing, and so who is best will move from time to time.

Above, the relationship of variations of traits and variations of the environment was outlined.

With that, the notion of different time scales (aspect 4), was added—a crosscutting concept that students (and adults) struggle with:

Vanessa: So getting them around this idea that the environment is constantly changing—and you can start on a day cycle and then a week cycle and then a year cycle and then a 10-year and a 100-year cycle—I think something that is really hard for us humans, but especially for kids, is to think on scales that are grander than our lifespan. So these kids are 12. It is going to be hard for them to imagine 50 years, never mind 100 years. And for all of us it is really hard to really imagine a thousand years or even a million years of environmental fluctuation.

A brief foray into the sociohistoric background (aspect 5) of this quote helped establish what Darwin—as a scientist of the 19th century—actually meant by “survival of the fittest.”

Vanessa: And the notion of the fittest. I don’t think that phrase *survival of the fittest* shows up anywhere in Darwin’s writings whatsoever.<sup>15</sup> I think that was added later. And his notion is really it is just survival of the fit. You really just have to be fit enough to reproduce successfully. That is it. It is a pretty basic requirement.

The understanding that there is no dichotomy of traits, and of the notion of the fit as a complex combination of traits, carries an implicit social aspect (aspect 6).

Vanessa: So this notion that there is going to be lots of individuals that can survive that environment—for different reasons. They have different combinations of traits. [...] This notion that there is lots of variation, there is lots of ways to be successful—I think it is a really good self-esteem-implicit message as well.

And finally, the teachers discussed with Vanessa how it is important to take on humans as a special case (aspect 7).

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<sup>15</sup> In the fifth edition of the *Origin of Species* (published in 1869), Darwin began using the phrase “survival of the fittest,” which had been coined a few years earlier by British economist Herbert Spencer, as shorthand for natural selection (Gregory, 2009, p. 159).

- Emily: Kids get a little confused on that part because of the idea of, you know, for humans there really isn't the same survival issues that other species have. [...] we don't have quite the same type of pressures.
- Vanessa: Right. So you can make an argument that—or ask them, OK, so what is special about humans that is not true for all the other plants and animals? And the truth is we have got medicine. We have got sanitation. And we've got...
- Ann: The ability to manipulate our environment.
- Vanessa: The ability to manipulate our environment and we have the wits to manage, avoid—however you want to do it—overcome what would normally be predators. [...]
- Joe: The biggest difference is just the brain. I mean, basically, right?
- Ann: Yeah, that's our major adaptation.
- Vanessa: Right. And from the brain you get all of these other things: You get medicine, you get weapons, you get social interaction, you get wiliness.

This episode illustrates the extent of science-for-teaching discourse the group kept up around such a small science idea. The seven different aspects of “variation” that the teachers discussed with the science expert in connection with the quote “survival of the fittest” also show the complexity of a seemingly simple science idea (variation) taught in middle school science. To focus on the numerous aspects of the scientific concept of variation does not complicate the science, rather it shows *more* knowledge about *less* science. Through this “complexification,” without touching on more difficult or abstract science concepts, the discourse about science stayed relevant for teaching. This extended discourse, which contained various aspects of one science idea, offered learning opportunities for all of the teachers and had the potential to influence their teaching toward a more sophisticated and scientifically accurate representation of science.

The episodes presented below show how a more complex understanding of variation influenced the collaboratively developed lesson plan, and may have also influenced how one of the teachers addressed one student's argument.

**Discourse about science for slowing down teaching.** Through the extended discourse about the aspects of variation, the teachers recognized the importance of this science idea, which in turn prepared them for realizing and highlighting these aspects in their teaching. After Vanessa left, the teachers created a lesson plan that included the natural selection simulation. Instead of running through the whole simulation at once, they were careful to develop questions that would slow down the activity. First, they made sure students would stop after the first two generations (F1 and F2) to notice that at that point the variation was greater than in the parent generation (P), because the traits got mixed up through sexual reproduction.

Ann: Should I ask them, when you looked at the chart yesterday, what did P mean? Or F1? I could ask them that? Or I could ask them what were some of the variations that you saw?

Carol: Something more like, you know, about the variation. Or about the, you know, differences they noticed between the F1 and F3 generation so that they are seeing that really F1 and F3 should be very similar.

Ann: Maybe I could ask them, were all of the variations within the traits—did at least one larkey...

Carol: Is there variation in every feature?

Ann: Right. Was there variation for every feature? Because remember the whole thing was, well, did short-legged larkeys even exist at the beginning? So we could ask something about...

In this episode, the teachers wrestled with connecting science and teaching. Instead of focusing on how to make sure that all students would be able to run through the simulation in lockstep and without messing around (there were several ways this simulation could be done, which students are quick to figure out), the teachers wanted to make sure that the students would notice the change in variation that the beginning of the simulation exemplified. This, they argued, would be important not only for understanding adaptation, but also later in the unit for discussing why recessively inherited traits can seemingly skip a generation. The knowledge

about variation was important for teaching, because it influenced how the lesson that included the simulation was set up and taught, and consequently what learning opportunities were provided for students.

**Discourse about science peripheral to the curriculum topic.** The importance of the science expert was not so much that she brought in new science knowledge. The knowledge the science expert provided may have been, at least in part, already present within this group of experienced science teachers. The importance was that the time with the expert privileged talk about science before the teachers focused on the task of developing an improved lesson teachable within the next few days. The science expert's role and the time allotted to her visit allowed talk about science-for-teaching to happen. Often, this type of discourse is ousted because of the urgency of the task and norms of collaboration that do not allow for uncertainty. The situation with the science expert allowed Vanessa, for example, to engage the teachers in a discussion about a special form of inheritance with an on/off allele pair, which was not directly part of the curriculum or the knowledge students should have (similar to the chromosome banding discussed in Case I).

- 1 Vanessa: There is one, I think really nice Mendelian-type genetic story that I think  
2 might be accessible for middle school students, but could get at some of the  
3 complexity. And that is Labrador retrievers. So there are black Labs, there  
4 are brown labs, and there are yellow Labs, or blond, whatever you want to  
5 call them. There are three colors for Labs. There are two genes that control  
6 that. One is a gene that says brown or black. And the *other* gene says you get  
7 to see the color, you don't get to see the color. So both genes are binary,  
8 right? Brown or black, on or off. You end up with three colors. I don't even  
9 know if the genes are on the same chromosome—they might be totally  
10 unrelated to each other—and what I often like to say especially when I accost  
11 people in the dog park who have yellow Labs—I say, you have a yellow lab,  
12 but did you know that secretly, your Lab is either brown or black, you just  
13 can't see the color. And that's always kind of, whoa.
- 14 Carol: So that's what it is, then.

15 Vanessa: That's what it is.

16 Carol: So if they have the "see the color gene," then it will either be brown or black,  
17 but if they have the "don't see the color gene," then they turn out yellow.

18 [...]

19 Lydia: See or don't see.

20 Vanessa: See or don't see is one gene.

21 Lydia: And within the see—if you get to see it, then it is brown or black.

22 Vanessa: So every Labrador retriever is brown or black. But whether or not you see  
23 a gene or don't see a gene is on or off. And the point is not that it is  
24 dominant-recessive. That is not the point of the story. Although you could  
25 do those Mendelian genetics if you wanted to. The point is that we have  
26 variation in color, and its a mixture of genes that are controlling that. That,  
27 to me, is the message. If you wanted to do the Mendelian genetics you  
28 can, because it is straightforward—it's big B, little b and whatever letters  
29 you want to say—big C, little c. But the point would be you have multiple  
30 genes, but you are just looking at one trait.

In middle school, teachers don't need to teach students an example of multiple genes controlling one trait. This type of understanding is required neither by the curriculum nor by the standards, and will not be tested in any state assessment. Still, the teachers followed the explanation of the science expert very carefully, and included the example in the "notes for teachers" accompanying the collaboratively developed lesson plan. This science knowledge for teaching helped the teachers in two ways. First, they would not frame inheritance and adaptation in simplistic terms of dominant, recessive, and one gene/one trait, as someone who taught the lessons as written might be inclined to do. Second, a sophisticated understanding influenced both the teachers' expectations for students' understanding, and the teachers' work with students' ideas, as outlined in the next two sections.

At other points in the conversation, when Vanessa started to discuss science deemed not relevant for middle school, she was cut short by the teachers. For example, when she ventured

into epigenetics, the teachers made it clear that this might be interesting but was not necessary for their teaching, and that they needed to use the remaining time to finish developing the lesson. Therefore, when the teachers' stayed interested in science that was also not directly part of but peripheral to the science of their curriculum, like the on/off gene for the Labrador's colors, it indicated that this knowledge was nevertheless an important part of their science knowledge for teaching.

**High expectations for students' understanding.** After Vanessa left, the teachers started developing a lesson plan that could be taught in Ann's classroom. They started the lesson with low-level questions requiring one-word or purely descriptive answers (similar to the lesson plan in Case I). However, for the second half of the lesson, the teachers included tasks related to the nature of science (how science is done) that they had previously discussed with Vanessa. The teachers planned to ask groups of students to develop hypotheses about the changes in the larkeys' traits and why the changes happened over time, using their simulation data as evidence. The students had to prepare to defend their hypotheses in a whole class discussion. They were also asked to predict the consequences for the larkey population should this population be moved from one environment (forest) to another (grassland). While these questions were based on the original lesson, the teachers' expectations for students' understanding shifted from students providing predetermined simple answers toward students expressing their own ideas about science concepts.

**Working on students' ideas of adaptation.** After the lesson observation, the teachers in the Adaptation-PLC debriefed their observations and debated whether students really understood the concept of adaptation, especially whether they understood that the change is not in individuals but in the population. The teachers had observed one group of boys who had truly

argued about the individual versus population approach, and in the end had settled on the idea that the population changed. Yet another group had simply followed the (correct) lead of one of the students, and students in other groups hadn't said anything, so there was no evidence of their understanding. Students' written answers indicated that the idea about individuals changing due to the need to survive still prevailed. From these observations the teachers inferred that the students' understanding of adaptation was still fragile. So instead of moving on in the curriculum, they developed an extension to the lesson to challenge students' ideas again.

The teachers developed three scenarios. In each scenario, two people argued over the right explanation for (a) adaptation, (b) natural selection, and (c) species. The students would then need to decide which of the given arguments were correct and debate why they thought so. This activity would force the students to be actively engaged in making meaning of the concepts, and not just repeat the correct answer given to them. At the same time, the teachers could assess the students' current understanding of these concepts. Again, by developing these scenarios, the teachers spent considerable time on getting their own science, and consequently the science in the task, right. This repeated wrestling with science concepts further solidified the teachers' understanding, and this in turn potentially prepared them for understanding the thinking behind their students' contributions.

The following excerpt shows how Ann's nuanced understanding of the concept allowed her to recognize the nuances of a student's idea, which she could have otherwise easily interpreted as wrong. The task for the students was to argue which of the two statements (in the excerpt below) were correct and why. If they thought statement A was correct, they would go to one side of the room; if they thought statement B was correct, they should go to the other side of the room. Then they would discuss with like-minded fellow students how to make a good

argument for their decision based on what they had learned so far. The following is one of the prompts on the student worksheet (students used their own names in this prompt):

Lydia and Joe were discussing what they thought would happen to the frequency of fur colors if we suddenly moved the F6 prairie larkeys into the forest.

(a) Lydia says that most or all of the striped larkeys will die because they aren't adapted to the forest.

(b) Joe says the striped larkeys will adapt and their fur color will change to better fit the environment.

When Ann taught this lesson (this was not part of the PLC cycle and was not observed by her colleagues), all but one student moved to “Lydia’s side,” and the students supported the argument that the striped larkeys would die because they could be easily spotted by predators, while the spotted ones could hide and therefore survive and reproduce. This was meant to be a good explanation for the right answer. When Ann asked the student on the other side to explain her reasoning, she argued that the prairie larkeys would develop spotted fur. This is supposedly the wrong answer. However, Ann asked the student to expand on her thinking. The student was visibly uncomfortable in her position as the only one who thought differently, but also seemed sure that she had the right answer. So with lots of encouragement from the teacher, and very reluctantly and hesitantly, she laid out her reasoning: If all the prairie larkeys were moved to the forest, there would be so many that not all of them would be eaten by predators. Therefore, some would reproduce. Their litters would have variations in fur color, and the ones with kind of a more spotted fur would have a better chance to survive and reproduce. They would have other litters with variations in their fur patterns, and it was likely that there would be some spotted ones who had a better chance of not being eaten. So over many, many generations, the larkeys

would have changed fur color. After the student finished her argument, at least one other student said “this convinces me” and moved to her side. Unfortunately, the period ended then.

What happened? While the teachers referred to individual larkeys in the question, the student understood the question to be referring to the larkey population—a legitimate interpretation. It is likely that through the opportunity to talk through the importance of variation and the concept of adaptation of individuals versus populations, Ann had developed an explicit understanding of the mechanisms of natural selection. Without this explicit and in-the-moment teaching of accessible knowledge, combined with knowledge of the students and how to press a student for an extended explanation, it is probable that Ann would have dismissed this student’s reasoning and her potential contributions to the class’s understanding of the concept. Together, her knowledge of her student, her knowledge of teaching, and a complex knowledge of the idea of adaptation prepared a knowledge of science that allowed for the student’s ideas to be explored in the moment of teaching.

### **Comparison and Conclusions**

The teachers in both PLCs shared the experience of teaching middle school for many years, used a common curriculum, had similar expertise with students, and had a history of mandatory collaboration, all of which made it relatively safe for them to share their knowledge about students and teaching. In this regard, both groups were well equipped to collaboratively develop a lesson that would work well in their teaching contexts and with their students. However, these teachers were less experienced with talking about science and sharing science ideas about the content they were teaching. This type of discourse about science knowledge for teaching has not been part of middle school teachers’ normal routine. Although the protocol for the PLC cycles sets apart a time for this type of science discourse, only the teachers in the

Adaptation-PLC, whose science content study phase was supported by an outside expert, talked extensively about the science concepts inherent in the lesson. Subsequently, the teachers in the Adaptation-PLC developed lesson plans that differed considerably from the lesson plans of the Inheritance PLC. The teachers in the unsupported Inheritance-PLC developed a lesson plan that aimed for high student engagement, but included only simplistic science ideas and expected little of science understanding from students. The lesson plan prompted numerous questions from students, but the implications of these questions for learning science were barely considered during the collaborative PLC time.

On the other hand, the teachers in the supported Adaptation-PLC developed a lesson plan that had comparatively higher expectations for their students' intellectual engagement and understanding of science concepts. The collaborative time following the observation lesson in one teacher's classroom was devoted to collaborative work to further assess and strengthen students' science ideas. This may have also led to the observation teacher's openness to listening to the complicated reasoning of one of her students.

### **Science-for-Teaching: Simple Versus Complex**

The teachers in both PLCs engaged in discourse about the science they were teaching. The Inheritance-PLC's starting point of science discourse included a brief introduction of the lesson, and then the expectations about what science knowledge students would bring to the lesson. As Sarah stated: "This is the introductory phase, so a lot of kids don't know." The low expectations for students' initial understanding guided the level of discourse the group was willing to engage in, even when the lesson observation showed the variety of ideas and experiences that students had about genetic variation. In the end, the science-for-teaching discourse in this PLC cycle was mainly about facts, and the teachers' discussion about students

and teaching was disconnected from the understanding of science. The result was simplification of the science that was deliberated in the Inheritance-PLC.

The teachers in the Adaptation-PLC's collaboration started in a similar way: They considered students' misconceptions and then an introduction of the lesson. However, the visiting science expert shifted the discourse away from the practical issues of lesson planning toward the science inherent in the lesson. The ensuing discourse included numerous aspects of the three science concepts of variation, adaptation, and natural selection. These aspects neither complicated the science concepts nor added additional science concepts. Instead, they made the science concepts more complex. In other words, they showed the richness of the concepts in various contexts, without going into more sophisticated science research findings. This complexification of science influenced the teachers' expectations for students' science understanding and their ability to work with students' science ideas.

### **The Work of Complexification**

An extended science-for-teaching discourse about the complexity of science ideas opens up the context for distributed cognition (Hutchins, 2001). It provides three avenues for participating teachers: (a) various entry points and levels for learning and for contributing to the learning of others; (b) the public yet undirected dispelling of alternative science conceptions (that teachers may also have); and (c) the creation of a shared toolbox for adaptive teaching of science.

(a) Considering a science concept in different contexts and expressed in various discursive ways gives teachers who are initially uncertain about the concept more than one opportunity to learn and expand their knowledge. For teachers who know the concept well, it gives them the opportunity to contribute their way of understanding, to cross-check their science

ideas with less familiar aspects; it also potentially add details for a more complete understanding.

(b) Included in the complexification of science are ideas that seem logical but are scientifically incorrect or only partially correct. These ideas provide teachers with opportunities to discuss and dispel alternative conceptions from a scientific standpoint, without the need to identify misconceptions among students or colleagues. Teachers can then be prepared for new and diverse situations, which increases their ability for (c) adaptive teaching. Having discussed various aspects of a science concept gives teachers more than one way to approach the teaching of a concept, and to react to students' ideas, needs, strengths, and interests. This can enable teachers to encourage students to express their ideas, which can lead to unpredictable yet often rich discussions. These types of situations are best handled when teachers have a complex understanding of the idea themselves.

The notion of complexification relates closely to the conclusions of Schroeder, Scott, Tolson, Huang, and Lee (2007), who found in their meta-analysis of national research that enhanced context strategies are the most effective type of teaching strategy. Enhanced context strategies engage students' knowledge resources, interests, and environment. However, such enhanced context strategies require teachers to have a multidimensional understanding of a topic.

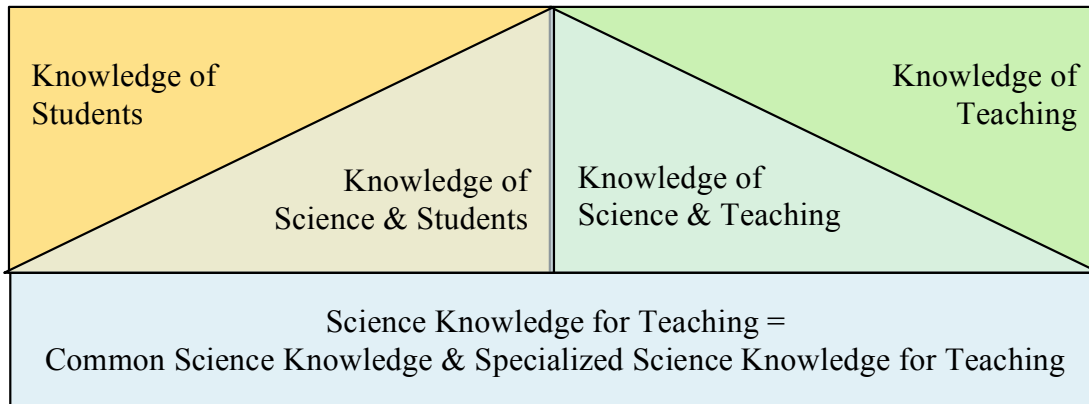
### **The Role of the Content Expert**

As the outside expert, Vanessa was well equipped to frame the science-for-teaching discourse as a learning opportunity for the teachers. None of the teachers within the group could have fulfilled this role, as they normally don't have the time to prepare, nor the mandate to teach their colleagues, even if the science knowledge they have in certain areas may be superior to that of their colleagues. Without a science expert, the notion of learning in a learning community connotes the idea of "not knowing," or an imbalance of "knowing," which is something

seemingly very difficult in the culture of schools, where learning is for the students, not for the teachers. Through Vanessa's way of staying with science knowledge that was both relevant for teaching and unknown in its relation to teaching and students, she could keep all the teachers, no matter their previous science knowledge, engaged and appreciative.

### **Connecting Science With Students and With Teaching**

Contrary to the didactic triangle with its three distinct objectives—teacher, students, curriculum—D. L. Ball and colleagues (2008) argue for a conceptual model that strongly emphasizes the role of content knowledge for teaching. This model, adapted for science, places the knowledge of science and students, science and teaching, and science content knowledge (comprising common science knowledge and specialized science knowledge for teaching) as equals. This article argues that science knowledge, and especially the complexification inherent in the specialized science knowledge for teaching, is the foundation for a close interrelationship between the knowledge of students and science, and of teaching and science. If teachers' science knowledge base is extensive enough, approaches to science can be adapted according to requirements that stem from the knowledge of students and knowledge of teaching. There is more to teaching than the subject that is taught: There is knowledge of students and knowledge of teaching that is independent of subject matter knowledge. However, for teaching science, the knowledge base of pure science cannot be reduced (Figure 2.7). Finally, this article argues that science content knowledge as needed for teaching is best developed in tandem with the knowledge of students and the knowledge of teaching. Therefore, it is knowledge development that has to be supported throughout a teacher's career.



*Figure 2.7.* Knowledge for teaching. Science content knowledge is the basis for science teaching; however there are also areas of teaching that are not related to the subject matter.

### **Content Professional Development Versus Professional Learning Communities**

Science knowledge gained in content PD outside of the school context often lacks direct usability for teachers' practice and transposability into their classrooms. On the other hand, science PLCs often lack the expertise and norms for extended science-for-teaching discourse that could influence teachers' science understanding and consequently their teaching practice. As convincing as the concept of teachers learning from each other is, the learning can only go as far as the knowledge within the group and the knowledge resources that are present and being accessed allow. In the case of the science knowledge needed for teaching, the limiting factors are the teachers' limited opportunities for content learning, limited time to prepare for collaboration around science, insufficient resources, the egalitarian culture of teachers, and, closely related, a general perception that teaching middle school science is easy. However, the knowledge needed for teaching is similar to the proverbial iceberg: Only a fraction is visible to outsiders. But unlike this metaphor, the substance and the boundaries of science knowledge for teaching are unclear

and different for each topic, grade level, and context. Bringing science content support into teachers' collaborative work can be one way to successfully combine content PD and PLCs.

M. Kennedy (1998b) suggested that short workshops may be criticized for the wrong reason: They may be insufficient not because they are short, but because the content may be irrelevant for teaching. If the content of a short science intervention provides the knowledge needed for teaching just in time to be instantly put into practice, then even a very short science PD could have a positive effect on teaching and student learning. As Case II in this study suggests, a brief science support for a teacher PLC, while the teachers prepare for teaching, could provide the venue for such short content PD.

## **Outlook**

This comparative case study can only suggest the relationship between science-for-teaching discourse, teachers' learning, and the influence on teachers' practice. Teachers' discourse is closely connected to their thinking. However, it can reveal only a small part of an individual's learning processes. Furthermore, the generalizations of these findings, when each PLC presents itself in a unique way, is in the eye of the beholder. The ideas and suggestions in this article may be corroborated through the reader's own experiences with teacher collaboration. In any case, this study adds a content focus to the studies of PLCs and to research about discourse for learning. The findings can support a vision of what kind of discourse in science PLCs can be expected to be productive in terms of improving teachers' practice. To support such discourse through facilitation and content intervention, examples of such discourse are imperative, and more examples are needed to fully develop a substantiated vision.

### Article 3

#### Every Voice Counts—Accountable Talk in Teacher Learning Communities

*Continuing thoughtful discussion among learners and teachers is an essential element of any serious education, because it is the chief vehicle for analysis, criticism, and communication of ideas, practices, and values. In the education of professionals, discourse serves additional purposes, which are related to building and sustaining a community of practitioners who collectively seek human and social improvement. The discourse of teacher education should also help to build collegiality within the profession and create a set of relations rooted in shared intentions and challenges. Such discourse should focus on deliberation about and development of standards for practice and on the improvement of teaching and learning.”*

*(A. F. Ball & Cohen, 1999, p. 13)*

#### Abstract

Learning in teachers’ professional learning communities (PLCs) depends on input from all participants. This is unlike traditional professional development (PD), where knowledge flows from the PD provider to the teachers. Therefore, learning opportunities in PLCs will be limited when conversations are congenial and polite but provide little content (Nelson, Deuel, Slavit, & Kennedy, 2010). This study explored the kinds of discourse that can support learning during teachers’ collaborative work. The study observed a 2-day PLC cycle that effectively fulfilled the PD project’s goals: to improve lessons from the commonly used curriculum, and to enhance the teachers’ science teaching practice. To analyze the quality and content of the teachers’ discourse, the Accountable Talk framework (Michaels, O’Connor, & Resnick, 2008) was used. This framework, initially developed to analyze academically productive classroom discourse, was adapted in this study to analyze discourse among science teachers. I predicted that teachers’ accountability to the community; to reasoning; and to their professional knowledge of

students, teaching, and science would be necessary attributes of a discourse that assists teachers' professional growth. The findings showed that as a group, the teachers expressed all of these accountabilities throughout the PLC cycle. Notably, the most productive discourse occurred when agreeable talk was disrupted because one of the teachers took a strong and persistent stand for one of these accountabilities. I concluded that discursive accountabilities to professional knowledge can overcome the culture of niceness and non-interference often found in schools. The framework of discursive accountabilities for science teachers showed utility for analyzing teacher discourse in PLCs. This framework could also provide guidance for discourse in PLCs, especially when the PLC sessions are facilitated by the teachers themselves. In such cases, the framework may replace the more behavioral "norms of collaboration" commonly used in PLCs.

### **Introduction**

Traditionally, professional development (PD) for teachers has been seen, similar to classroom teaching, as a one-way flow of information from the expert to the learner. Professional learning communities (PLCs) uproot this traditional view, because in PLCs, every voice counts toward the success of the PD. The purpose of this study was to examine how teachers in a PLC commit to professional accountabilities in their discourse when planning for teaching and student learning. Furthermore, this study explored how such accountabilities relate to the resulting learning opportunities for the participating teachers. This study also sought to provide researchers and PD providers with a conceptual and practical framework for analyzing and strengthening discourse in teacher-led PLCs. Strengthening discourse could support the shift away from teachers' norms of collaboration (Garmston & Wellman, 2009) and congenial conversations (Nelson, Deuel, Slavit, & Kennedy, 2010) and toward an understanding of discursive accountabilities in collaborative work.

The framework used for this study of discursive accountabilities is based on two existing frameworks: Accountable Talk, which was developed for academically productive classroom conversation (Michaels et al., 2008), and *content knowledge for teaching*, developed by D. L. Ball, Thames, and Phelps (2008). The resulting *accountable teacher talk* framework defines the following discursive accountabilities: (a) to the community, (b) to reasoning, and (c) to knowledge. Accountability to knowledge is further specified as accountability to (i) knowledge of science and students, (ii) knowledge of science and teaching, and (iii) content knowledge for science teaching (*science-for-teaching*). I hypothesized that if teachers in a PLC took on these different discursive accountabilities, then they would contribute diverse professional aspects of teaching practice to the conversation, and the discourse that would occur would be rich in learning opportunities and productive for the teaching task at hand. From this hypothesis, I developed the following three research questions:

1. How are the different discursive accountabilities expressed during teachers' collaborative work in a PLC?
2. Do discursive accountabilities create learning opportunities for teachers? And if so, how?
3. Can a conceptualization of discursive accountabilities based on the accountable teacher talk framework support analysis and design of teachers' collaborative work?

To pursue answers to these questions, teachers' discourse from an exemplary 2-day PLC cycle was analyzed. The discursive accountabilities of the science teachers who participated in the PLC were identified, and their correlation to potential learning opportunities was examined. This qualitative study provides the first empirical insight into the utility of the proposed framework of discursive accountabilities for analyzing and supporting teachers' professional

discourse. Enhancing professional discourse in PLCs is especially important if PLCs are to become a sustainable form of teacher-led, collaborative PD.

### **Literature Review**

Participating actively, sharing and discussing classroom experiences, and developing a common understanding of practice are mentioned in the research literature as important features of productive discourse, discourse that could yield new understanding and a change in teaching practice (Akerson, Cullen, & Hanson, 2009; Elster, 2010; Feldman, 1996; Goodnough, 2010; Lakshmanan, Heath, Perlmutter, & Elder, 2010; Parke & Coble, 1997; Roth et al., 2011; Thompson et al., 2009). However, only a few studies of science and mathematics PLCs have examined both the “construction and flow of information” useful for teaching (Melville & Wallace, 2007, p. 544) and focused in depth on the discourse that was central to teachers’ collaborative learning (Horn, 2008, 2010; Horn & Little, 2010; Little, 2007; Nelson et al., 2010; Slavit & Nelson, 2010). These studies illustrated two closely related aspects of the transformative nature of teacher collaboration: one is the quality of the discourse that occurs, which influences how the participants’ and the group’s understanding can grow for the benefit of their students; the other is the content of the discourse, the concepts, ideas, and norms that are conveyed.

### **Discourse for Teacher Learning**

Teacher collaboration is a promising form of PD that has been shown to have a positive effect on teaching and learning in classrooms (McLaughlin & Talbert, 2006; Vescio, Ross, & Adams, 2008). Discourse in collaborative settings has the potential to support teacher learning and deserves special attention. Based on Vygotsky’s and Wittgenstein’s ideas about language, Sfard claimed that “inter-personal communication and individual thinking are two varieties of

the same phenomenon” (Sfard, 2008, p. 432). From this premise, it can be concluded that *what* teachers talk about and *how* they talk will influence what they think, and vice versa. In addition, narratives are the primary means by which teachers can bring their interpretation of classroom events to the PLC. These narratives, told under certain conditions and with certain assumptions, may not only influence the listeners but also shape how the speaker perceives his or her own classroom (Bruner, 1987). In general, diverse forms of discourse that elucidate teachers’ own experiences and understanding can provide opportunities for teachers to learn from each other, negotiate meaning and norms, and consequently create a shared understanding of their practice (Little, 2007). Therefore, when teachers work together, how they talk, as well as what they talk about, is important.

I am aware of only a few studies that closely examine the discourse of math teachers (Horn, 2008, 2010; Horn & Little, 2010; Little, 2007; Nelson et al., 2010; Slavit & Nelson, 2010) and only two studies of science teachers’ collaboration (Feldman, 1996; Melville & Wallace, 2007). The generalizability of these studies with regard to the characteristics of teachers’ discourse is further limited by the facts that the studied collaborations were either exceptionally well functioning or had only voluntary participants (Feldman, 1996; Horn, 2010; Horn & Little, 2010), and that the researchers functioned as either facilitators or participant observers. These factors influenced the collaboration within the researched PLCs and may have contributed to the reported successes. Nevertheless, these studies report important findings about the quality and content of teachers’ discourse.

**Quality of discourse in PLCs.** Research on PLCs has found that teachers’ learning from and with each other is complex (Opfer & Pedder, 2011) and, among other factors, is dependent on the quality of the discourse (Curry, 2008; McLaughlin & Talbert, 2001; Nelson et al., 2010;

Slavit et al., 2011). One of the few multifaceted accounts of teachers' science discourse was provided by Feldman (1996). He joined a group of eight experienced physics teachers who had chosen to collaborate weekly for action research on their own practice. Feldman's study synthesized 2 years of this collaboration and explicated the importance of the quality of discourse within a PLC. Feldman identified the three discursive practices that were most productive. First, he identified that anecdote telling elicited further anecdotes that exemplified or clarified the teachers' understanding and prompted questions and discussions about teaching practice. Second, he identified ideas from within the group or from resources outside the group that were picked up, tried out, and reflected on. When the teachers shared their experience with this type of experimentation, they were able to learn from each other and for their practice. And third, Feldman identified systematic and collaborative action research that involved the first two practices but worked explicitly with student data. However, Feldman noted that generalizing and theorizing based on classroom data was often met with resistance and was weakened by the difficulties in making teachers' tacit knowledge of teaching public. Through this work, Feldman illustrated different qualities of teachers' collaborative work. He also pointed out some of the difficulties, such as reasoned discourse based on evidence, encountered even by experienced teachers who had chosen to collaborate due to their own interest.

In their research, Horn and Little (2010) and Horn (2010) went into further detail about productive discourse in math PLCs. They provided in-depth analyses of sharing-of-experience incidents, and how this sharing supported teachers' learning. From the conversations of a highly collaborative math group, Horn (2010) extracted two types of productive discourse moves related to experience sharing. One type was the detailed recounting or *replay* of a particular teaching event; the other type was the description of an anticipated or imagined classroom

situation, or a teaching *rehearsal*. These two types of discourse moves also provided the basis for presenting, revising, and elaborating complex teaching situations, which generated knowledge that was both situated in the teachers' particular practice and generalizable across different teaching situations.

Furthermore, Horn and Little's (2010) paper "Attending to Problems of Practice: Routines and Resources for Professional Learning in Teachers' Workplace Interactions" identified a specific discourse sequence that went beyond the sharing of experience and that seemed especially conducive to teachers' learning: "normalizing, specifying, revising, and generalizing" problems of practice (p. 193). In *normalizing* the particulars of an (unsettling) experience, colleagues marked the event as within the range of the "normal," or as a teaching situation they or others had also experienced. If this normalization became the foundation for *specifying* the implications of this experience for student learning and for teaching practice, and the foundation for exploring alternative interpretations and solutions (*revising*), then the discourse could become productive in a deductive and inductive way (*generalizing*). The discourse was productive either by building principles of practice from specific teaching situations, or "relat[ing] models of teaching to the particulars of unorganized experiences" in the classroom (p. 196). Productive discourse is thus creating usable knowledge for teaching that enables teachers to respond in a more principled way to future incidents similar to the ones discussed. Thus, sharing experience that leads to generalization is a first step in building a shared theory of teaching among the collaborating teachers.

Theory building was also the focus of a study by Slavit and Nelson (2010). Over the course of one year, they studied teachers' inquiry work in a PLC that was part of a large PD intervention across six school districts. The teachers in this PLC were especially concerned about

students' engagement in specific mathematical tasks, and how the structure of a task could foster student engagement. Over the course of the study, teachers revealed different, often competing, instructional approaches to this problem. Through making their beliefs about and approaches to teaching public, teachers could learn from each other and move toward a shared understanding. However, Slavit and Nelson concluded that teachers' ability to learn from evidence, such as classroom observations and student work, was constrained in the PLC, not only because of time restrictions but also because of the teachers' collaborative norms and the lack of skilled facilitation. This prevented, in part, the generation of shared theories of teaching, and subsequently the ability to apply such theories to make instructional decisions. These results confirm the difficulties generally found in the science PLC literature regarding inducing and applying generalizations across teaching events (Akerson et al., 2009; Doppelt et al., 2009; Elster, 2010; Goodnough, 2010; Robertson, 2007; Roth et al., 2011).

Characteristics of productive discourse were extracted from the literature about teacher discourse in PLCs. These characteristics were found to match the facets of the Accountable Talk framework (Michaels et al., 2008). Consequently the Accountable Talk framework, originally developed to foster academically productive discourse in science classrooms, was chosen and adapted as the foundation for the conceptual and analytical framework developed for this study.

**Content of discourse in PLCs.** Melville and Wallace's (2007) detailed account of a professional discourse between teachers provides some insight into the content of teachers' talk. In this example, narratives provided the possibility of the discourse's content (knowledge and practice) to be *transposable* (able to be moved from one context to another) and *transferable* (able to be moved from one person to another) (Hargreaves, 1999). "Through narrative transactions, focused on issues of direct interest to teachers, opportunities were opened for

knowledge and practice to be both transposed and transferred” (Melville & Wallace, 2007, p. 555). The content of teachers’ discourse included experiences with teaching a curricular unit which opened up teaching practice to the scrutiny and critique of colleagues; societal and environmental issues of science that would help engage students in the content; suggestions of putting the unit into a more local context (Tasmania, Australia) and a more global context; and potential links to teaching chemistry and the nature of science. As all of the teachers had previously taught the discussed topic and shared a similar school context, they could effectively participate in this discourse and transfer and transpose the shared knowledge so it could affect their own practice.

The literature about mathematics PLCs provides additional detailed accounts of how teachers wrestled with the relationships between subject-specific concepts, teaching, and students’ understanding. Slavit and colleagues (2011), for example, reported on the importance of talk about content knowledge for teaching (D. L. Ball et al., 2008) for their collaborative work about students’ number sense. The researchers described in detail the teachers’ discourse about students’ diverse mental math strategies, and how the teachers’ newly developed instructional practices could serve the multiple types of learners in their classrooms.

This discussion illustrates the ways in which equity became a centerpiece of group discussion around number sense development. Explicit attention was given to the ‘bunch sitting out there’ throughout the year, and the teachers were now able to provide multiple forms of instruction to address the learning needs of their wide variety of learners. (Slavit et al., p. 127)

However, this discourse about the mathematical thinking of *all* students occurred only in the fifth year of the teachers’ collaboration, and it signaled a true shift toward equitable teaching.

This suggests that discourse about certain kinds of content, especially when related to subject matter knowledge, takes considerable time to develop in PLCs.

### **Norms of Collaboration**

PLCs have the potential to support all teachers and their practice in schools and school districts. PLCs also show promise of being self-sustaining and low cost, particularly when the teachers themselves facilitate this kind of PD work. However, teachers work in a professional culture where their independence and artisanship has been traditionally valued as integral to teaching (Huberman, 1993; Little, 2007; Lortie, 1975). Traditionally, to interfere with or critique a colleagues' practice would not have been tolerated. Nowadays, disagreements in PLCs are still avoided and knowledge, ideas, and beliefs are often kept private (Nelson et al., 2010), thus limiting the learning opportunities for teachers. In order to foster a more productive collaborative climate, schools and PD providers train teachers as facilitators so they can lead their colleagues' collaboration. Also, "norms of collaboration" for the participating teachers are usually established. Both approaches have potential weaknesses. First, teacher facilitators are faced with the dilemma of being responsible for leading their fellow teachers despite their collegial culture which could violate "professional norms of equality and independence" (York-Barr & Duke, 2004). Second, the norms of collaboration that are often adopted as guidelines for collaboration are mostly behavioral and procedural norms (like pausing or putting ideas on the table) (Garmston & Wellman, 2009; A. Kennedy, Deuel, Nelson, & Slavit, 2011). While such norms can support a group in getting their collaboration started, they may also reinforce the culture of niceness. For example, while "presuming positive intention," the seventh of the norms of

collaboration developed by the Center for Adaptive Schools,<sup>16</sup> may help teachers maintain a safe environment when they share ideas, it may also prevent teachers from asking for clarification or critiquing someone's contribution—two discourse moves that are important for productive discourse (Little, Gearhart, Curry, & Kafka, 2003). Because norms of collaboration do not address the professional content that is discussed in collaboration, and thus will neither support the facilitator's work of leading productive collaboration nor teachers' learning, a more suitable framework for teacher collaboration seems necessary. The following section outlines a framework that is designed to support science teachers' substantive participation in discourse and their responsibility for each other's learning during their collaborative work.

### **Conceptual and Analytical Framework for Accountable Teacher Talk**

In general, teacher learning is a very complex issue and depends on many different variables (Opfer & Pedder, 2011). As research shows, the quality and content of discourse is central to teachers' learning and their improvement of practice. Research also shows that discourse that involves subject matter issues is very challenging and sophisticated (Curry, 2008). To approach teacher learning through teacher discourse in PLCs, a framework needs to contain features of the discourse's quality and content, the interrelationship between discourse quality and content, and their correlation with learning opportunities. For the framework to be applicable, it should also be closely connected to or even derived from teachers' practice. In addition, the framework should be concise and modest enough so it can be used (a) to find and interpret patterns of productive discourse in a highly contextualized setting, and (b) to decontextualize the findings so they can be used to understand discourse in similar, but not identical, contexts. A framework should also be useful for sharing the findings with researchers,

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<sup>16</sup> See the "Norms of Collaboration" poster by the Center for Adaptive Schools. Downloaded from the Thinking Collaborative website: <http://www.thinkingcollaborative.com/norms-collaboration-toolkit/>

PD providers, and teachers so it can support productive discourse in the collaborative work they are involved in.

The accountable teacher talk framework is designed to fulfill such requirements. The framework draws its foundation from deliberative discourse (Burkhalter, Gastil, & Kelshaw, 2002) and from Michaels, O'Connor's and Resnick's Accountable Talk framework that was developed from and for "academically productive classroom talk" (Michaels et al., 2008, p. 286). This framework has proven its utility in the classroom and for sharing findings with the greater educational community. To strengthen the properties of the content with regard to knowledge, D. L. Ball, Thames, and Phelps' (2008) theory of content knowledge for teaching was incorporated. This theory determines dimensions of pedagogical content knowledge and subject matter knowledge for teaching. For this study, both frameworks were combined to provide the basis for the adapted accountable teacher talk framework.

The accountable teacher talk framework is grounded in cultural-historical and sociocultural theory. Cultural-historical theory acknowledges that situations emerge within certain traditions that have developed over the course of time (Engeström & Sannino, 2012). School culture has had a tradition of teachers being the lone fighter and the individual artisan (Huberman, 1993; Little, 2007; Lortie, 1975). This tradition has been hard to change due to teachers' position as the only adult within their own classrooms. Close collaborative work between teachers is still more the exception than the norm. This school context fosters a code of no intervention and diplomacy. It is most likely that teachers bring this code of conduct into a PLC which keeps the discourse between teachers, when there is no strong facilitator, at a friendly but superficial level. This level of talk seldom includes novel or differing ideas. It is therefore not very conducive to teachers learning from each other or creating new and innovative products.

Sociocultural theory views social interaction as a prerequisite for learning, primarily in the form of talk, as talk and thought are understood to be closely related (Sfard, 2008). Through talk, meaning can be negotiated and new knowledge can be constructed. Consequently, the quality and the content of the discourse—how teachers talk and what they talk about—determines, in large part, what individual teachers can learn from each other, and what new knowledge and new ways of practice can emerge. In this way, talk provides a window into both teachers' learning and teachers' practice. This also constitutes the importance of focusing on discursive accountabilities to improve the impact of PLCs on teachers' practice.

### **Accountabilities in Discourse**

A wide range of accountabilities can be seen in the discourse in different PLC contexts, and these can change from cycle to cycle, or differ even from one discursive exchange to the other. The accountabilities also differ for each PLC participant. Talbert (2009) points out that teachers in successful PLCs demonstrate mutual accountabilities and shared responsibilities for all their students, but also that teachers often tend toward compliance to bureaucratic requirements. In congenial conversations as described by Nelson (2010) the accountability seems to be to the culture of niceness and to the well-being of one's colleagues. For example, in an interview that was part of the larger study this article is drawn from, Kimberley, an experienced teacher, explained:

I am not that kind of person. I mean, I am kind of quiet. So I do not take the role of know-it-all in the group. I just don't like to—because we are all professionals. And I think sometimes people feel like, oh, they know that, and they are sharing that, and you know, I didn't—you know what I mean? People don't like to admit that they don't know something. [...] Even if somebody says something wrong in the group, nobody says anything and they just kind of look at each other. [...] I don't involve myself in those kinds of conversations, so I just kind of stay away or I change the subject. I like to stay (with) positive energy.

Kimberley refers to the importance of keeping the PLC a safe place for everyone. And trust is indeed frequently noted in research as the prerequisite for honest and productive talk (Borko, 2004; Eraut, 2007; Melville & Wallace, 2007; Talbert, 2009). But what are the characteristics of a discourse that sustains trust and still enables a professionally productive discourse? This type of talk, described in the literature as leading to a change in practice, shows accountabilities to reasoning and to the use of knowledge in addition to an accountability to the community (Horn, 2010; Horn & Little, 2010; Slavit et al., 2011). These accountabilities are similar to the ones described in the Accountable Talk framework by Michaels and colleagues (2008). Consequently, moving discourse from “polite, congenial” and compliant to bureaucratic requirements to a more productive “collegial dialogue” (Nelson et al., 2010) about students, teaching, and subject matter ideas would require a shift in discursive accountabilities. Accountabilities in discourse are defined for this study as the accountabilities a teacher takes on for the information that is exchanged in the PLC and that this information agrees with the teachers’ professional standards.

### **Accountable Talk as the Basis for the Analytical Framework**

The process of teachers collaboratively improving their teaching practice is driven by the discourse and interactions that take place in a PLC. Collaborative settings are sometimes even referred to as “discourse communities” (Michaels, O’Connor, Hall, & Resnick, 2010; Michaels et al., 2008; Putnam & Borko, 2000). The quality of the discourse is therefore closely linked to the knowledge that can be accessed and created through such discourse, as Michaels and colleagues (2008) stated:

Disciplinary knowledge advances through a process of peer review and critique. Ideas must be explicated so that others can interrogate them, challenge them, build upon them,

or support them. This is especially clear in the advancement of scientific knowledge and theorizing. Many scientists have commented on the role of the community in building an evolving and cumulative body of accepted (but always provisional) “truths.” (p. 292)

This study used the Accountable Talk framework developed by Michaels and colleagues (2008) over the last 15 years as a basis for analyzing and conceptualizing discourse that is conducive to creating content knowledge for teaching. This framework has been designed to foster “academically productive classroom talk.” The framework initially stems from discourse analysis of reasoned talk between adults and shows similar characteristics to democratic deliberation.<sup>17</sup>

Studies that have examined math and science teachers’ conversations characterize similar facets of discourse as described in the Accountable Talk framework (see Figure 3.1). Slavit and colleagues (2011), in the following example, summarized the characteristics of dialogue in a productive PLC:

Conversations that entered the level of critical dialog did so mostly as a result of the teachers’ own collective ability to make their beliefs and theoretical perspectives public, use classroom data to frame issues, and take the risk to challenge each other’s theories. (p. 114)

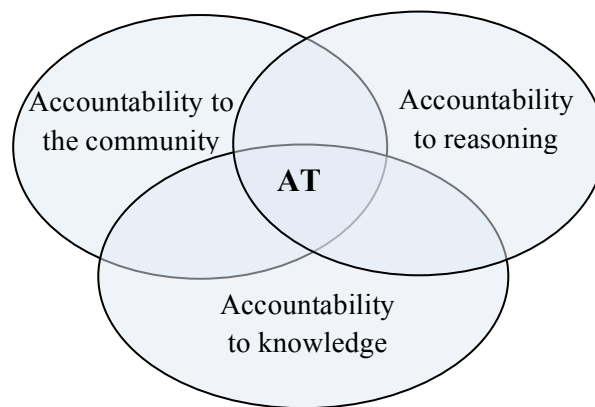
The statement, “make their beliefs [...] public” illustrates the Accountable Talk facet of accountability to the community; “use classroom data” illustrates accountability to knowledge; and “challenge each other’s theories” illustrates how accountability to standards of reasoning could play out in teacher talk.

When using Accountable Talk for analysis, the focus turns to the quality of the discourse through the characteristics of discourse that are important for accessing, developing, and creating

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<sup>17</sup> “Public deliberation is a combination of careful problem analysis and an egalitarian process in which participants have adequate speaking opportunities and engage in attentive listening or dialogue that bridges divergent ways of speaking and knowing” (Burkhalter, Gastil, & Kelshaw, 2002, p. 398).

usable science knowledge for teaching. When talk is reasoned, and not just an exchange of facts and opinions, existing knowledge can be activated and accessed, and tacit knowledge can emerge. If this knowledge is applied to real or imaginary teaching situations, its usability can be evaluated.



*Figure 3.1.* Facets of the Accountable Talk (AT) framework. Idea derived from “Deliberative Discourse Idealized and Realized: Accountable Talk in the Classroom and in Civic Life” by S. Michaels, C. O’Connor, and L. B. Resnick, 2008, *Studies in Philosophy and Education*, 27(4), 283–297.

The following section outlines the facets of the Accountable Talk framework (see Figure 3.1) and illustrates the framework’s usefulness in the PLC context, with examples from the math and science education literature. However, PLC discourse differs from classroom discourse in an important way. In a setting where professionals exchange ideas, knowledge is more equally distributed throughout the group, as is the responsibility to orchestrate accountable discourse. In a middle or high school classroom, the responsibility for Accountable Talk lies with the teacher. While a facilitator could play a similar role in a PLC, it can be expected that teachers will adhere, at least in part, to the standards of Accountable Talk on their own. For example, Michaels and colleagues (2010) stated that “it is important for teachers to ask students to make clear the sources of knowledge that they are using. Teachers can help students by continually pressing

them for accurate and sufficient information” (p. 30). In a PLC, the teachers engaged in Accountable Talk could be expected to press each other for accurate and sufficient information.

### **Accountability to the Community**

Researchers concerned with PLCs emphasize the importance of trust and a safe environment as the basis for open discussion and learning (Borko, 2004; Melville & Wallace, 2007; Nelson et al., 2010). However, they also report that participants in PLCs can stay in a state of “behave as if we all agree” (Grossman, Wineburg, & Woolworth, 2001, p. 955) and remain at a level of superficial, collegial talk (Nelson et al., 2010), thus limiting the potential for learning. Accountability to the community that supports learning goes well beyond being friendly and supportive, it rather “instantiate[s] a culture of deliberation, it gives access to participants’ thinking” (Michaels et al., 2008, p. 287). In this type of discourse, participants listen to one another’s contributions, build on one another’s ideas, ask clarifying questions or encourage others to provide more information. The speaker also tries to fathom what information others need to understand (Grossman et al., 2001).

Accountability to the community creates an alliance between colleagues and “garner[s] support for the often emotionally intense work of teaching” (Horn, 2010, p. 238); it prevents takeover by the loudest and most assertive voices, which can silence the expertise of quieter colleagues (Achinstein, 2002; Grossman et al., 2001; Slavit et al., 2011); and it prevents silent colleagues from holding on to alternative theories of teaching and learning without being challenged (Slavit & Nelson, 2009).

Little and Horn (2007) discovered a discourse routine they called “normalizing problems of practice” (p. 81). When a participant in a PLC shares a problematic event, the others in the group suggest that this kind of problem of practice may be inherent to the profession, and that it

has happened or can happen to others, too. One of the functions of normalizing problems of practice is to establish an environment in which participants feel safe to share complex and even unsettling experiences. This leads to trust and solidarity among the members of a PLC, which are prerequisites for open and honest sharing of experiences, beliefs, and ideas. Replays of classroom events (Horn, 2010) serve a similar function.

Talk that is accountable to the community alone will make for pleasant collegial discourse (Nelson et al., 2010), but will not enable the group to expand and develop its collective knowledge for teaching. To facilitate learning, discourse also has to be reasoned.

### **Accountability to Standards of Reasoning**

Teachers do not have a tradition of conducting a reasoned conversation about their own practice in the teaching profession (Nelson et al., 2010). Furthermore, making underlying and often tacit reasoning explicit is an intrinsic problem in all practice-oriented professions, not just in teaching, (Eraut, 2007). Horn (2010) identified such scarce episodes of pedagogical reasoning as

units of teacher-to-teacher talk in which teachers exhibit their reasoning about an issue in their practice ... when they describe issues in, or raise questions about, teaching practice, and these descriptions are accompanied by some elaboration of reasons, explanations, or justifications. (p. 237)

This accountability to standards of reasoning can be, according to Horn, “single-turn utterances” or “multiparty co-constructions over many turns of talk” (p. 237). Horn used these episodes of pedagogical reasoning in her analysis of teacher talk to compare learning opportunities across PLCs.

According to, Michaels and colleagues (2008), characteristics of accountability to the standards of reasoning include searching for premises, evaluating evidence, and connecting evidence through logical relations to collectively derive a substantiated concept. To reach this goal, teachers have to explain their reasoning, justify their assumptions, and self-correct when new arguments emerge. Reasoning in a way that links the specifics of classroom events so that generalizations of practice can emerge (inductive reasoning), while also connecting principles of teaching to specific problems (deductive reasoning), can support teachers' development of usable knowledge for teaching and consequently of teaching practice more substantiated by evidence. However, the value of an argument is closely interconnected with the knowledge that is reasoned about. The most elaborate reasoning process can support, but also obstruct, the development of knowledge and understanding if the facts and evidence are false, inadequate, or unrelated to the problem.

### **Accountability to Knowledge**

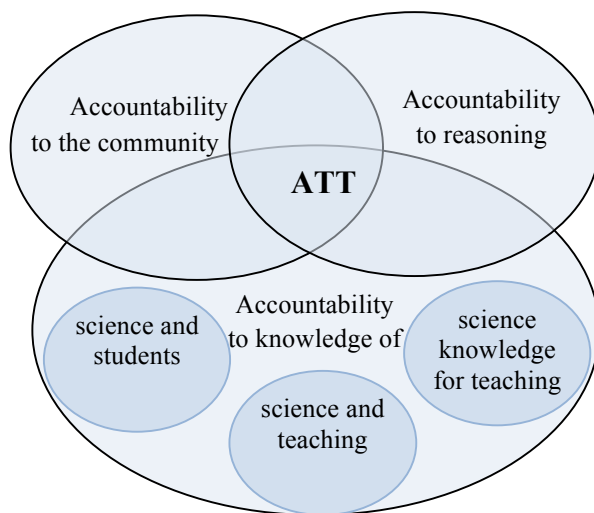
“Talk that is accountable to knowledge is based explicitly on facts, written texts, or other publicly accessible information that all individuals can access” (Resnick, Michaels, O'Connor, 2010, p. 184). Discourse about science can draw from a wide field of evidence-based knowledge available through trusted published resources and experts. However, these resources are often difficult to access, and need translation into the science that is needed for teaching. In areas of science teaching and student learning, science-specific publications are rare (Thompson, Windschitl, & Braaten, 2013; Windschitl, Thompson, & Braaten, 2008), and not yet sufficiently distributed to further teachers' science knowledge for teaching in school-based PLCs. Furthermore, the specific context in which teachers work necessitates that contextualized knowledge be available. Teachers' own experiences and classroom artifacts are also important

resources for teachers' learning and for the improvement of practice (Little, 2007). Therefore, accountability to knowledge in teacher talk will also rely on evidence drawn from teaching and students' learning.

**Accountability to content knowledge for science teaching.** Content knowledge for science teaching includes several domains (D. L. Ball et al., 2008). Three of the domains were adapted for science teaching and are included in the accountable teacher talk framework: (a) science knowledge for teaching, (b) knowledge of science and students, and (c) knowledge of science and teaching (see Figure 3.2). Being accountable to science knowledge for teaching means deliberating the science that is inherent in the curricular units and learning segments in order to make sure the science is accurate and appropriate for science teaching. This deliberation includes common content knowledge as is usually found in science textbooks. However, teachers develop science content knowledge over the course of their career that is specific to science teaching. For example, professionals who work in the sciences may know one representation of a science concept that is suitable for their work. Teachers, in contrast, need to know a variety of representations of a science concept as well as each representation's benefits or limitations with regard to the science, to their students, and to teaching. Only then can they decide which representation is appropriate for a certain teaching situation.

These domains of content knowledge for teaching often do not have enough "facts" available in a proven or even generally accepted form to provide a sufficient foundation for decision making in a specific context. Therefore, the definition of accountability to knowledge has to be expanded and should include evidence from teachers' own experiences and classrooms. Data collected by teachers can well inform instructional decisions (Slavit et al., 2011), and anecdotal evidence drawn from teaching experience is also a valuable source of knowledge

(Little, 2007). Horn (2010) described, for example, how replays (recounts of personal experiences of a specific event) and rehearsals (anticipated, envisioned, or prototypical accounts of events) can provide the evidence base for consultation and elaboration in a PLC. In addition, accountability to knowledge also requires that inferences based on experience and anecdotal evidence be tested in the classroom so that the PLC can gain more valid data to work with. This type of inquiry can unveil alternative ideas and misunderstandings about science teaching, substantiate best practices through evidence, and help teachers continually develop teaching and learning.



*Figure 3.2.* Facets of accountable teacher talk. This diagram integrates the content knowledge for teaching framework with the Accountable Talk framework. Content knowledge for teaching from “Content Knowledge for Teaching. What Makes It Special?” by D. L. Ball, M. Thames, and G. Phelps, 2008, *Journal of Teacher Education*, 59(5), pp. 389–407. Accountable Talk framework from “Deliberative Discourse Idealized and Realized: Accountable Talk in the Classroom and in Civic Life” by S. Michaels, C. O’Connor, and L. B. Resnick, 2008, *Studies in Philosophy and Education*, 27(4), 283–297.

In general, accountability to knowledge means that all participants present evidence in an honest and thorough manner, challenge each other when evidence is insufficient or inappropriate,

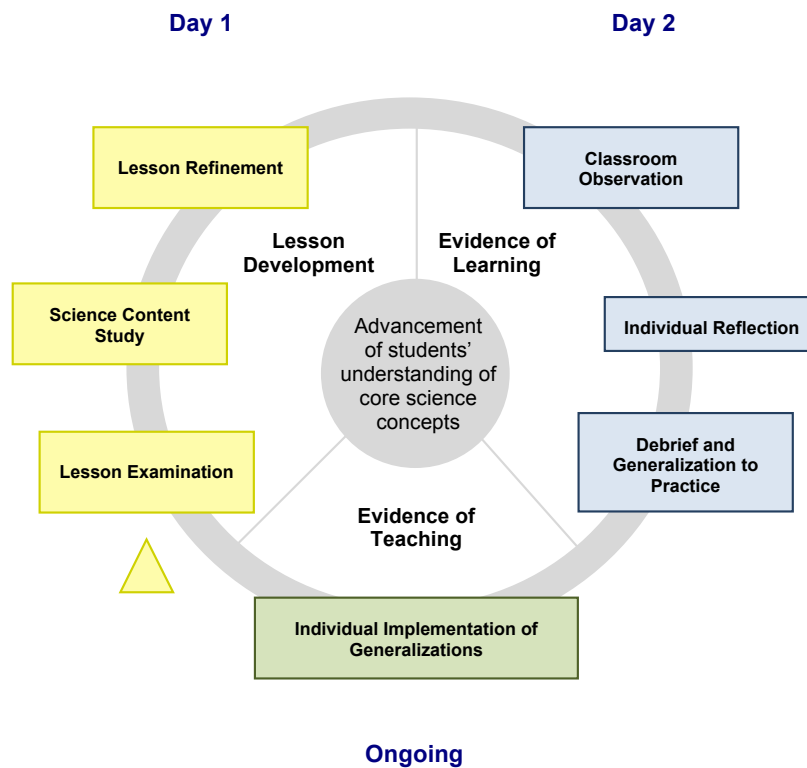
and consult outside expertise if evidence or knowledge is not sufficiently available within the group. Little and Horn (2007) describe how a highly collaborative math PLC made use of outside expertise in the form of their joint participation in practice-related PD, and through a network of invested educators outside their PLC.

### **Hindrances to Accountable Talk**

If Accountable Talk were easy to accomplish, the underlying frustration among researchers who have studied discourse in teacher communities wouldn't be evident. Many factors discussed in the literature might prevent "deep conversations" (Nelson et al., 2010). In a culture of non-interference, where anecdotes are shared only to "justify personal preferences or convey social solidarity" and are not utilized as a resource for learning (Little, 2007, p. 225), teachers can miss important learning opportunities. Further, the perception of a teacher as an artisan implies that each teacher has his or her own style that cannot be judged on the basis of theories or principles (A. F. Ball, 1994; Huberman, 1993), and this perception might prevent teachers in PLCs from discussing problems of practice. The culture of niceness (Nelson, 2009), taken-for-granted understanding and assumed concepts (Eraut, 2000), and the urgency of tomorrow's task (Horn & Little, 2010) can thwart the expression and discussion of different beliefs and even of different experiences. However, accountabilities to bureaucratic requirements that go beyond and, in some instances, against teaching and learning in the classroom—such as accountability to test scores and teaching standards, to local and national policies, and to school and district policies—can be counterproductive (Ingersoll, 2012; Talbert, 2009). These potential hindrances to Accountable Talk indicate that the quality of the discourse in a PLC and the resulting opportunities for learning are dependent on the larger context in which the PLC is positioned.

## Professional Development Design Context

Observing for Evidence of Learning (OEL), a PD model for collaborative work among science teachers, has been implemented by school districts in the Pacific Northwest of the United States since 2005. Emerald School District,<sup>18</sup> in which this study took place, began implementing the OEL program in 2009 through a Math and Science Partnership grant. Middle school science teachers participated in this mandatory PD for approximately three 2-day PLC cycles per year for 3 years. This study took place during the last (ninth) PLC cycle in the school district.



*Figure 3.3.* Two-day collaborative PLC cycle. The six phases of the protocol span 2 days; the implementation of generalizations for teaching is the work of individual teachers between cycles.

During each 2-day PLC cycle in the OEL program (see Figure 3.3), a group of teachers work together to improve the curriculum they are currently teaching to better serve their unique

<sup>18</sup> Pseudonyms are used for all names of individuals, schools, and school district throughout this article.

student populations. At the same time, the OEL program aspires to encourage professional discourse in order to enhance the general teaching standard over time. To prepare for the PLC cycle, the teachers choose a learning segment (several lessons that lead to the learning of a science concept) from their common curriculum that includes concepts their students have had difficulty understanding. During the 2 days of collaboration, a detailed protocol guides groups of teachers through the following phases. On Day 1, teachers engage in (a) *lesson examination*, during which they have an opportunity to share past teaching experience; (b) a *science content study*, during which the teachers are encouraged to discuss and solidify their understanding of the learning segment's scientific concepts; and (c) *lesson refinement*, during which the teachers work on improving the learning segment. On Day 2, teachers engage in (d) *classroom observation*, during which teachers have an opportunity to teach a lesson from the learning segment and observe students' interactions; after which they have (e) *individual reflection* time; and (f) *debrief* together the observed evidence of students' learning, which results in further improving the learning segment. Between the PLC cycles, teachers (g) implement in their own classrooms the *generalizations to practice* that they as a group had agreed on.

The PLC observed for this study had an additional content study day with a science expert prior to the 2-day PLC cycle. The science expert also visited the group for 1.5 hours on the first day of the PLC cycle. The three discourse episodes that were chosen for this article did not include the science expert. The first and second discourse episodes took place during the first day of the PLC cycle and represent discourse that happened before the science expert joined the group that day. The third episode represents discourse from Day 2 of the PLC cycle, prior to the classroom observation. In the third episode, the input from the science expert has clearly influenced the teachers' conversations.

## **Setting and Participants**

The setting for this study was the ninth and last PLC cycle for the Emerald SD's middle school physics teachers (the Physics-PLC). The participants knew each other well and were familiar with the demographics of the students who attended the different schools, and the resulting demands for teaching. They were also versed in using the OEL protocol and process.

### **School District**

With about 19,000 students, Emerald School District (SD)<sup>19</sup> is a relatively large school district in the Pacific Northwest region of the United States. It serves a medium-sized city as well as suburban and rural areas. Emerald SD has a robust science program that supports science learning from elementary school onward, and it provides its teachers with a variety of PD opportunities. From 2003 to 2006, the school district adopted inquiry-based curricula for middle school science. Science teacher retention in Emerald SD has been high in recent years, so by the time this study took place in 2012, most of the middle school science teachers had been teaching the same curriculum for a few years and were quite familiar with its instructional approach and content. The science materials needed for the curricula are refurbished at the district's science resource center. For OEL implementation, the district collaborated with a small nonprofit organization that supports public school science education in the region. This organization works closely with local scientists and science educators.

### **Middle Schools and Middle School Teachers**

Emerald SD has five middle schools, each with five to seven science teachers for grades 6 through 8. The sizes of the middle schools range between 600 and 1,100 students. Emerald SD

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<sup>19</sup> Pseudonyms are used for all names of individuals, schools, and school districts throughout this article.

middle school students' ethnicities are comparable to the state's general student population: 60–65% of students are White, 10–19% are Hispanic, 5–20% are Asian, 11–21% are Asian/Pacific Islander, and 2.5–5.5% are Black. About 9% of students are Transitional Bilingual and 8–14% of students receive special education. Emerald SD's results in the state's eighth-grade science assessment in 2012 (78.6%) were considerably higher than the state average of 66.4%. The five middle schools serve a wide range of communities with regard to socioeconomic status. This diversity is reflected by the state science assessment test scores. For example, on average only 19% of Rosegarden Middle School's students are eligible for Free and Reduced Price Meals (FPM), and 91% of its students met the assessment's science standards for eighth grade in 2012. On the other side of the school district, 65% of Eastside Middle School students are eligible for FPM, and in 2012 only 60% of its eighth-grade students met science standards (Office of Superintendent of Public Instruction, 2012). The teachers are well aware of this disparity and do what they can in the given context to leverage learning opportunities for their students.

The seven participants in the Physics-PLC represented all five of Emerald SD's middle schools. They were experienced eighth-grade teachers, with an average age of 45 and average teaching experience of 15 years. Four teachers had a master's degree, but none had a degree in physics. However, all had participated in summer PD about physical science, and at least two of the teachers had previously participated in physics PD.

### **Science Experts**

The science expert who supported the Physics-PLC was a well-known physics education expert in the region who was very experienced in working with science teachers on physics content. The expert's visit was organized by the PD providers. However, the teachers in the

Physics-PLC had explicitly asked the school district's science administration for a science study day with the science expert prior to their collaborative work on the topics of force and motion.

## **Methods**

This qualitative study of teachers' collaborative work employs a strong discourse analysis component.

### **Data Sources**

The data for this study was gathered from two main sources: observations of the Physics-PLC's collaboration, and one-on-one semistructured interviews with all but one participant.

**Observations.** The participants' discourse during the 2-day PLC cycle was audio recorded in its entirety, and parts of the cycle were also video recorded. In addition, I took field notes while present in a "peripheral membership role" (Adler and Adler, 1998, as cited in Merriam, 2009, p. 124). Thus, while I was known to some of the participants, I did not interact with them during the observation. The recordings and field notes provided the basis for determining which episodes contained rich discourse about content knowledge for science teaching (Erickson, 1986).

**Interviews.** The one-on-one semistructured interviews were conducted days or weeks after the observed PLC cycle. Therefore, lesson plans and student artifacts served as prompts for the teachers to recollect the events. During these interviews, the science teachers reflected on their stance toward the science content knowledge necessary for supporting science learning in their classrooms, on how they had experienced the science content negotiation during the observed PLC cycle, and on how the science discourse had influenced their practice. The science expert was asked about her preparation for and reflection on the OEL content study phase she

had supported. Interviews with school administrators and the OEL program director rounded out the picture of the context in which the PLC cycle took place. All interviews were audio recorded. Because each participant's answers, and time available for the interview, differed, the content discussed during the interviews varied widely.

**Secondary data.** Lessons in the Force and Motion curriculum (STC) were reviewed and used to compare the science resources provided by the curriculum (in the teachers' guide and student book) and the science knowledge for teaching that the group explored discursively.

### **Data Analysis**

The PLC cycle chosen for this article represents a typical, yet not average, manifestation of this type of collaborative work. The Physics-PLC's collaborative work was rather productive in terms of the teaching artifacts created, and the group's discourse was quite dense and focused. The analysis includes only talk that was teacher-led, when no science expert or outside facilitator was present. Three episodes were chosen from this discourse. These episodes were chosen because the teachers had developed a theme over multiple turns, most of the teachers were contributing, and the episode seemed to be especially rich with learning opportunities for the group and for individual teachers. Therefore, these episodes were good for analyzing (a) how the different discursive accountabilities might be expressed during teachers' collaborative work in a PLC; (b) how discursive accountabilities might open up learning opportunities for teachers; and (c) whether a conceptualization of discursive accountabilities as outlined in the accountable teacher talk framework could support the analysis and design of teachers' collaborative work.

The analysis of these three episodes composes the main part of this study. A more holistic portrayal of the context in which the discourse took place is provided to help the reader better understand and evaluate the implications of the findings and their validity within their own

circumstances. Primary data sources were the audio recordings of the observed PLC cycle and field notes. Secondary data sources were interviews with five of the seven participating teachers, and documents such as curriculum materials; lesson plans, including notes for teachers; and student worksheets. Because the recordings stretched over about 9 hours, they were analyzed in the following stages: (a) The chronological flow of the conversation during the 2-day PLC cycle was transcribed to understand the purpose of the collaborative work and the dynamics of its discourse in general. (b) Several discursive episodes that were related to an idea, science topic, or problem of practice were extracted. These discursive episodes were analyzed for the broad categories of accountability to the community (AC), accountability to reasoning (AR), and accountability to knowledge (AK). (c) Three discursive episodes were chosen to best exemplify the different discursive accountabilities of all teachers. (d) These three discursive episodes were analyzed several times. The predetermined descriptive codes (Appendix D, Table D.1) served as a guideline for the first round of coding. In the following rounds of coding, these codes were adapted and new codes were added according to the patterns that emerged from the analysis. While going through this analysis, the utility of the proposed framework was questioned. Table D.2 (Appendix D) shows the final codes.

During coding and analysis, attention to context and frequent reference to teacher interviews and teacher-developed documents helped decipher situated meanings of utterances, taken-for-granted information, and tacit understandings. This back and forth through the different levels of representation provided some safeguard against losing the bigger picture and supported the interpretation of the discourse.

## **Patterns and Themes in the Discourse**

The process of coding involved reflecting on the conceptual importance and analytical value of the coded utterances, as well as their meaning in the given context, since “in qualitative coding we identify, elaborate, and refine analytic insights from and for the interpretation of data” (Emerson, Fretz, & Shaw, 1995, p. 151). When coding and reviewing the data, tentative patterns and themes within and across discursive episodes emerged, such as teachers’ preferences for certain discursive accountabilities, and patterns for supporting as well as disrupting the discursive flow. Memos written during this process captured ideas, reflected on these patterns and themes, enabled inductive and deductive reasoning about emergent findings, and helped to organize patterns and themes and to establish which preliminary findings might be most significant for answering the research questions. The most pervasive patterns and themes were tested against each other and against the proposed framework.

## **Going Beyond the Data: Hypotheses and Predictions**

The first questions were about what discursive accountabilities were expressed and how. After these questions had been considered, new questions arose: How and why might the different discursive accountabilities have opened up learning opportunities for teachers. The original codes and the framework were further developed into an empirically grounded accountable teacher talk framework. The framework’s key features, based on the analyzed discourse, may help to determine tendencies and traits of teacher discourse that are conducive for deliberating and developing content knowledge for science teaching in collaborative teams. The utility of this accountable teacher talk framework can be tested by applying hypotheses that emerge from the framework in new contexts.

## **Study Limitations**

In PLCs, teachers' discursive interactions and the learning correlated with these interactions are highly contextualized and influenced by many organizational, cultural, and personal factors. Every PLC observed yields unique data. And, as with all qualitative research, there is no one right way to interpret and present data and findings. Since this study examined only one PLC, the generalizability of the findings is quite limited. However, several years of experience with similar PLCs helped me to discern the usual from the particular, and thus identify patterns that are likely to hold true across different settings. Readers may concur with the findings based on their own experience and thus generalize across the contexts to their own.

Teacher learning is an extremely complex process (Opfer & Pedder, 2011). A limitation to the analysis of the relationship between certain aspects of discourse and learning opportunities is that other factors that also influence learning opportunities may be missed. Furthermore, any hypothesis about causalities would require more than one case. It is in general the fate of small qualitative studies to add one puzzle piece at a time to the complex picture. If the piece adds new ideas and some clarity in its specific area, then the study is worthwhile.

## **Findings**

On a Wednesday morning, the seven eighth-grade science teachers in the Emerald SD met in the library of one of the middle schools to develop strategies and lessons that would help their students better understand the concepts of force and motion. It was almost the end of the school year, and the teachers were tired; some of were them sick, coughing and sneezing. However, they were energized by a previous content study day with Denise, a physicist and an expert in the teaching of physics. And they were ready to merge their teaching experience with new ideas about the concepts of force and motion to improve their curriculum, their teaching,

and their students' learning. Over 2 non-consecutive days, an intensive, fast-paced, and concentrated discourse ensued, and the teachers developed not only lesson plans for two periods, but also a pre/post assessment and a video that showed students an experiment about unbalanced forces. At the very end of the second day, a poster with a sketch of the experiment central to the lessons was copied for each school to use to support students' sense-making

This group of teachers had been meeting for 3 years, for eight cycles of collaboration, which had enabled these very diverse teachers to find modes of productive collaboration. They clearly knew one another's strengths and valued one another's experience, while acknowledging one another's idiosyncrasies. And despite some humorous and sometimes testy contributions, it was always clear that they were all committed to helping each other improve what they were doing in their classrooms.

Analysis of the group's discourse showed that while all of the teachers expressed all discursive accountabilities, individual teachers exhibited a tendency to express certain accountabilities over others. This kind of accountable talk not only supported the development of the various artifacts for teaching, but provided learning opportunities for the teachers. Each of these learning opportunities by itself may have been rather insignificant, but taken together, they illuminated a theme in the data: The discourse episodes that were most productive in terms of learning opportunities happened when one of the teachers assertively embraced one particular accountability and thus disrupted the agreeable flow of the discourse. These episodes also showed how intertwined and interdependent the facets of accountability are.

The following section presents three discursive episodes that seemed especially productive. It includes an analysis of what accountabilities were expressed, how they were expressed, and to what effect. Also discussed is how being accountable to different facets of

discourse opened up learning opportunities for the teachers and the group as a whole. To label accountabilities without interrupting the text too much, the following abbreviations/codes are used:

Accountable to the community = AC

Accountable to reasoning = AR

Accountable to knowledge = AK

Accountable to knowledge of science and students = AKS

Accountable to knowledge of science and teaching = AKT

Accountable to knowledge of science content = AKC

These abbreviations are linked with a hyphen where they supported each other, and by a slash when they were intertwined. For example:

AKS-AR = The discourse is accountable to knowledge of science and students, and supported by reasoning.

AKT-AR/AKS = The discourse is accountable to knowledge of science and teaching through reasoning with knowledge of science and students.

To indicate a hesitation or a pause in talking, a hyphen in quotes is used (“-”). Explanations, modes of talking, or indiscernible words are put in parentheses ( ). Talk that was not an essential part of the episode was left out for easier readability; this is indicated by an ellipsis in square brackets [...].

### **Assuming Discursive Accountabilities**

This section presents three discourse episodes. While all accountabilities were expressed at all times, a different accountability played a major role in each episode's flow of discourse: accountability to standards of reasoning in episode 1, accountability to knowledge of science and students in episode 2, and accountability to science content knowledge in episode 3.

**Episode 1: Accountability to reasoning.** Eric, one of the teachers, acted as the PLC facilitator. He guided the group through some initial organizational discussion, and then brought up the first prompt in their protocol: to review and discuss generalizations the teachers had drawn from their previous PLC cycles in order to implement these into practice. While Keith was ready to write the group's ideas on a big poster paper, Eric encouraged his colleagues' input. After two generalizations to practice had been briefly discussed, the following discourse ensued:

Eric: So, I do want scaffolding in here, one of our scaffolding strategies. I think that is one of our stronger pieces, scaffolding in a logical framework/organized framework; very intentionally in the sequence, in a real logical sequence? [...]  
And as a third one I would like to add flexibility, because in truth, scaffolding changes based on what kids are able to do or not do.

Larry: I don't like that. Because scaffolding is not part of the picture of flexibility. If you have flexible scaffolding, you fall over. I don't like the two concepts together.

Eric suggested adding scaffolding because he thought it was one of the group's "stronger pieces." In that instance, he was accountable to teaching (suggesting a teaching strategy) as well as to the community, by praising their collaborative effort (AKT-AC). He justified adding flexibility through reasoning with students' needs (AKT-AR/AKS). This line of discourse could have ended there. If all of the teachers had assumed they knew what Eric meant and agreed with his statement, they could have written a brief statement on the poster paper and moved on to another topic. However, Larry interrupted the flow of agreeable talk by pointing out that a "flexible scaffolding" is an illogical metaphor (AR-AKT). With this move, he forced the group's tacit understanding of these teaching strategies to be made public.

Eric: I added that [apologetically], I personally, just because if, to me, if scaffolding is too inflexible, you end up with a thing like "this is how we gonna do it!" And when you are having kids that have demonstrated that they

are not ready to move forward along our continuum? I don't know. [...] Let's say we are doing our first day's lesson, right, and things are going south, the next day, you might tweak things, change our scaffold, because, wait a second, we need to go back a step, or we have something missing in our scaffold.

Paul: There is something we didn't even think about here! The idea that scaffolding provides some supports, and you are gradually take them away. So you have less to hold on to. You know, instead of having a blank page, having some graphic organizers.

Eric took the opportunity to explain his reasoning with a hypothetical teaching scenario (AKT-AR/AKS), while Paul added some definition to the idea of scaffolding (AKT). Both contributions gave the group an opportunity to compare and align what "scaffolding" meant for their teaching. After two more exchanges, Donna spoke, trying to reconcile the meaning of scaffolding and flexibility (AC-AKT).

Donna: I think what Larry is saying is that there are two separate ideas and they should not be all under scaffolding. One is scaffolding, and one is flexibility how you teach it. I think that was what Larry was saying. Is that correct Larry?

Amanda: And I agree with that.

Larry: When we talk about a consequential framework, and when we are saying it is flexible, they are too counterintuitive to me to be together.

Donna: So there are two strategies, they may be in the same lesson, but they are not the same strategy.

Again, with Donna's attempt to clarify and Amanda's agreement (AC), the episode could have ended. However, Larry persisted and pushed for more clarity (AR), which Donna tried to offer (AR) with additional explanation. This gave Eric the opportunity to clarify his own and potentially others' ideas about these teaching strategies (AC-AR and AKT), while being at the same time very respectful to the community.

Eric: I am glad we are arguing about it. [...] I think the idea what I've said was simply this: that scaffolding is not the ultimate goal. The ultimate goal is student learning. It's a means to an end. And if you have to change the scaffold part way through, like, this is just not working, you have the freedom to do that. But I respect the fact that these are two separate ideas. So, that's a good conversation.

[...]

Larry: I wanna get this down. So are we are saying: flexibility to change lessons...

Keith: Flexibility because it allows...

Eric: There is a certain amount of prediction that we are making when we create a scaffold.

Keith: Right.

Eric: We are expecting if we do this, then kids do that...

Keith: There is an expected outcome...

Eric: Right, so when they don't go there...

Paul: Functions as a formative assessment...

[...]

Keith: This is an ability to provide formative assessment, this is ongoing formative assessment, right? I'm recognizing that.

Donna: I think you are right.

[...]

Eric: I am glad you labeled it "assessment"...

Carrying on each other's argument (AC), the group further negotiated what it meant for them to offer students support through scaffolding, while being flexible in their teaching. As a group they realized the overarching theme of formative assessment (AKT and AR-AC). After this exchange, they noted on their poster paper:

- |   |
|---|
| <ul style="list-style-type: none"><li>❖ Scaffolding<ul style="list-style-type: none"><li>➤ Putting information in an organized framework</li><li>➤ Creating a logical sequence for the students' experience</li></ul></li><li>❖ Flexibility (Formative Assessment)<ul style="list-style-type: none"><li>➤ Ability to change lesson based on outcomes of student responses</li></ul></li></ul> |
|---|

Three accountabilities were prominent in this discursive episode. First, there was a constant accountability to the community: The teachers actively showed interest in one another's contributions; they gave, for the most part, one another time to express their thinking; Eric acknowledged their collaborative work; Donna supported the group's understanding by clarifying Larry's argument; and all built on one another's ideas. And, in this relatively short exchange, all voices in the group, with the exception of Barbara's, were heard. Larry's insertions could have been easily dismissed or even seen as offensive. However, the teachers in this group knew each other well enough to take Larry's skepticism as a valid contribution, worth further consideration.

Second, the teachers not only stated their ideas, they reasoned with teaching (Eric), and with logic (Larry). Eric justified his argument with deductive reasoning, illustrating his statement that "scaffolding is too inflexible" with a potential teaching scenario.

Third, the teachers used their knowledge of teaching, built through experience, but also general knowledge about teaching strategies and concepts/definitions (Paul) of teaching. In this way, the group negotiated the meaning of two principles in teaching, scaffolding and flexibility, and reinterpreted the latter as a formative assessment.

**Episode 2: Accountability to knowledge of science and students.** Prior to the arrival of the science expert, the group discussed which upcoming lesson or learning segment would be most important to focus on improving. Keith had been encouraging the group to review the *Washington State K–12 Science Learning Standards* (Office of Superintendent of Public Instruction, 2009) for guidance on what concepts were important for them to teach. The standards state the following:

In grades 6–8 students learn to measure, record, and calculate the average speed of objects and to tabulate and graph the results. They also develop a qualitative understanding of inertia. Students learn to predict the motion of objects subject to opposing forces along the line of travel. If forces are balanced, the object will continue moving with the same speed and direction, but if the forces are not balanced, the object’s motion will change. (p. 66)

The standards give a performance expectation for speed:

Measure the distance an object travels in a given interval of time and calculate the object’s average speed using  $S = d/t$  (e.g., a battery-powered toy car travels 20 meters in 5 seconds, so its average speed is 4 meters per second). Illustrate the motion of an object using a graph, or infer the motion of an object from a graph of the object’s position vs. time or speed vs. time. (p. 66)

These requirements prompted the following discussion.

Amanda started by recounting what she had been doing in her classroom (AKT). Next, Keith’s reasoning about a teaching challenge (AKT-AR) was supported by Larry with a rhetorical question about the feasibility of a discrepant event for speed (AKT).

Amanda: My kids get a lot of this already. Except for the speed thing, that’s like the new thing with these carts for me. And then revisiting, what is going on with this fan, what do you know already, what should that cart do. [...] And they know that already from previous lessons.

Keith: That’s what I’m a bit nervous about. [...] I think some of the lessons prior to this are introducing information already. So, anything discrepant, I think, is going to be a little harder to do. Coming up with something they haven’t [indiscernible: heard yet?], an explanation or event that doesn’t make sense to them is a bit more difficult.

Larry: For speed it is impossible. How do you have a discrepant event for speed?

This discourse episode, mainly based on the accountability to the knowledge of science and teaching (AKT), could have ended there, if all participants had actively or tacitly agreed that a “discrepant event for speed” would be hard to come by and inferred that it would be more

important for them to focus on a later part of the unit. However, in this excerpt, it was Donna who interrupted the flow of agreeable discourse with her strong accountability to knowledge of science and students (AKS). From her interjection, an almost 15-minute discourse developed about students' conceptual understanding of speed. In the following excerpts, only the key segments are presented.

Donna: But conceptually, they [students] still have a hard time what is a rate and what is speed. I mean, they are eighth graders and maybe [middle school name] is very different than the other schools. But mathematically, and understanding what a rate is, and what that means, and understanding what it actually means. Not how to calculate it. I mean, yes, distance over time, they can do that—but that's all they do, and then you present two numbers that don't match [?] and they, "Oh, two numbers, let's divide it."

Again, Donna showed accountability to the community by making the problem her own "maybe [middle school name] is very different than other schools," and thus invited help from her colleagues (AKS-AC). Peter supported her claim by confirming her statement (AKS-AC).

Peter: Oh, that's what I notice that in high school, also. The concept of ratio.

Next, the teachers negotiated what it means to understand speed (AKS and AKC). The teachers built on each other's ideas about the relationship between the mathematical and science idea of speed (AKC-AC), until Donna tried to clarify that the struggle to conceptually understand proportions permeates science teaching throughout (AKT, AKS-AR).

Donna: They don't understand that.

Larry: But that is a mathematical concept.

Amanda: It is science, too.

Paul: It's a proportional thinking.

Amanda: They learn it in math, but to transfer it into science—and just for some reason they can't always transfer.

Donna: They have a hard time even in math. They learn how to go through the motions, but they do not really understand it. Conceptually, they don't. I mean, you have two kinds of kids. You have the kids who understand what a rate is and then speed is really easy for them. And then you have the kids who don't understand what it means for something to be a rate or proportion. And those are the kids who struggle with density. Yeah, they can calculate, but they don't really get what it means. They can solve a problem but they don't understand what proportion is. They either get a proportion or they don't get a proportion. And I am trying to help them understand.

Donna reinforced her accountability to knowledge of science and students (AKS), this time airing her empathy with their struggles and the need to find a way to help the students who do not easily understand the concept of proportion. After some exchanges, Barbara asked a testy question about what the group wanted students to learn (AR-AC). While Amanda referred to the teaching standards for an answer (AKT), Barbara referred to a resource (Bransford, Brown, & Cocking, 2000) that describes how students learn (AKS). Both approached the same problem with a different accountability.

Barbara: Here is the question, do you want them to conceptually understand what that proportion, rate, time is? Do you want them to conceptually really understand that? Or do you want them just to calculate it?

Amanda (referring to the standards): So, students are expected to calculate the speed at a certain time and the average speed. After having experience with how far the car has traveled, and timing, you should be able to give them a problem where it does say, Keith started at 0 seconds, and traveled to 3 meters, in this amount of time, what was Keith's speed. And they should be able to do it...if they understand anything at all.

Barbara (referring to an excerpt from *How People Learn*, Bransford et al., 2000): But, #3 on here would say that they don't automatically make these connections. So there ought to be some way to help them make these connections more. They won't just automatically do it, one experience and then they are able to jump over and use that.

While Barbara added to Donna's strong accountability to the knowledge of science and students (AKS) and pushed the group to think deeper, Larry answered the question with a personal statement (AC) and added the problem of assessment—how to know that students really understand a concept—combining AKT and AKS. He also changed the perspective of the problem, from the students' perspective to his problem as a teacher, a view that was taken up by Barbara. Keith's questions that follow summarized both perspectives (AKS and AKT).

Larry: To answer your question. I want them to understand the concept—but I don't necessarily know how to test that they understand the concept. I know, I can see it that they can calculate it, but that doesn't mean that I know that they understand that concept. I don't know how to assess. What about they understand of the phenomenon of speed? Then I don't think it is necessary to stick it into our standards and worry about it. [...]

Barbara: What I was thinking, is, depending on what you want, if they have something that is basically aimed at a math kind of thing, but they don't really have it, then maybe something has to be scaffolded in there in order for them to get the concept that is part of our standards.

Keith: So what is it that they don't understand? And we want them to understand?

The teachers then had an exchange about instantaneous versus average speed, and a discussion about whether students need to understand speed in order to describe motion or determine whether balanced or unbalanced forces are acting on an object. This clarified some of the underlying science concepts and science content questions the teachers had (AKC), which helped them later in the cycle when they planned their lesson about unbalanced forces.

Then, Donna led the group back to the problem that for some students, math stood in the way of understanding speed (AKS). This opened up the opportunity for Paul and Keith to share their more unconventional approach to introducing speed.

Donna: If you understand what it [speed] means, you can figure it out without using fancy math skills.

- Keith: I don't know if everybody has done it. In coordinated science, we do the kinematics thing.<sup>20</sup> So having kids look at things graphically in order to understand speed—to get deeper.
- Paul: They work through a bunch of experiences to come up with what speed means. So they recognize constant speed.
- Keith: Maybe we need to move away from, I think, rather than giving them a lot of paper and pencil experiences early on, we got to give them physical modeling experiences early on. Actually watch things move. And try to interpret speed versus necessarily calculate it in the beginning; just have them look at it. What do you notice about the speed? And then arrive at this ratio later on. How do you think we could calculate this, and are some of the measurements we can take as the things are moving on? We can measure the distances; maybe we can measure the time. What if we put those things together, how could you manipulate those two numbers? We can divide them, we can multiply, what do you think would work? So don't give them the equation, give them some time to arrive at the equation as a class. What do we have to use here in order to find the speed, what does speed mean. I think the problem we are facing here, if we just give them the equation, like after day number two, and saying just plug in some numbers. They start using this thing and now they just rely on this equation as a crutch.
- Donna: I think you are right.
- Keith: I think you say, you know what, for the first week, there is no equation. I am not going to tell you the equation. And you just let them have experience after experience until they figure it out.
- Paul: That's operational kind of definition approach: Here is the thing we have, have something happening, how can you describe it.
- Keith: We got forces, the forces cause things to move, is there a way for us to interpret that movement. Is there some kind of value we can assign to the movement? Yeah, we can assign this thing called speed. What is speed? What is speed really. Force them to figure it out.
- Larry: I like the idea!

Paul was an experienced and thoughtful teacher who was at the end of his career. He remained rather quiet during the PLC discourse. Keith and Paul often worked closely together for planning and reflecting on their teaching; Keith could therefore present their shared

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<sup>20</sup> Kinematics is motion considered abstractly, without reference to force or mass.

experience of using a conceptual approach to teaching speed. Keith and Paul explained this approach at length, not as an anecdotal record of “how I do things,” but in response to the group’s need to solve their problem of practice: how to teach students about speed so that they could gain a conceptual understanding, and not just plug numbers into a formula. This need was articulated over a long discourse stretch—it took over 40 exchanges about speed to come to this part of the discussion. Discourse of this length was not found in most of the other PLCs observed during the course of this research. Because the teachers discussed all accountabilities, and continuously reinforced accountability to knowledge of science and students, they seemed to have propelled their discourse to a level that could influence their approach to teaching speed (see more details in the section on “Learning Opportunities Through Accountable Teacher Talk”).

**Episode 3: Accountability to science content knowledge.** On Day 2 of the PLC cycle, the group met during first period before going to Donna’s classroom to observe the lesson they had collaboratively developed. Eric, who taught in a classroom adjacent to Donna’s so they could align their teaching, told the group what their students had done before the upcoming lesson, and what learning they (Donna and Eric) had seen or not seen so far. After some clarifying conversation within the group, Eric started to facilitate the group as they observed students. At this point, Barbara interrupted the flow of discourse, according to the protocol, by asking a science content question (AKC).

Barbara: Can I ask you guys something for clarification for me? Before that push, when it is just sitting there, could you say that there was static friction force on there? I mean not that the kids—I am asking for me.

Eric: And the kids said that. The kids would say that.

Paul: Right, and you have to get something [in there] to overcome. There is—

Barbara's question for her own understanding was validated by Eric and Paul when they pointed out that this was a problem for students too, which indicated that this problem was truly important to discuss (AC-AKS). So Barbara continued with her thinking:

Barbara: There is, because, wouldn't there also be a normal force on this thing? Oh, but that is not horizontal.

Paul: The force here doesn't occur until their forces apply. So whatever force you apply, there is a force pushing back. And that force is static friction; you have to overcome that. If you measure that force, that force is different from the sliding friction.

Eric: And if we just had our object here, and a vector going back for static friction, that is implying that that object is going to move in the direction of static friction. That's why there can't be that static friction arrow, until we start an applied force. That was helpful for me.

While Paul gave a concise explanation of static friction (AKC), Eric added the representational aspect to the explanation (AKC), and with "That was helpful for me" indicated that this was still new understanding for him, too (AC).

Barbara: Okay, and that was—there is something that is a force that would be there?

Eric: That is totally a misconception that this kind of created. That was that idea like, oh, there is a static friction and they draw the arrow. Yes, there would be a static friction if we push on that object. But until we push on it we are not able to draw that. Correct?

Barbara: So, if we, let me just—if I may continue—if we pushed on that object and it didn't move, than you could say that there was static friction?

Eric: Yes.

Barbara: Okay!

Barbara and Eric continued to co-construct and consolidate their fragile understanding of static friction (AKC), validating their exchange (AC) through the statement that this was a misconception students had to overcome as well (AKS).

Eric: So we have to have that applied force before we can actually put it in force pairs, that was helpful for me to hear that.

Paul: I mean the notion, if it is at rest, you know, you can say the net forces are zero. Like there are all kinds of forces acting on them, including horizontal forces, like air pressure, which are balanced out. So your air is pushing in all directions, these forces cancel out. So that's one that your kids included, that, you know, the forces are there, but, you know, it's not net forces.

Eric: I'm glad you brought up net forces.

Paul completed the explanation by turning the attention to net forces, which are zero when an object is not moving (AKC). However, the science explanation was expanded by including students' possible reasoning (AKS). To close the episode, Eric acted accountable to the community again by praising Paul's contribution (AC).

In this episode, Barbara assumed a strong accountability to science content knowledge by asking a science question for her own understanding as a teacher. PLCs often don't answer these types of subject matter questions, or they discuss them only superficially. There may be many different reasons for this: Nobody is really sure about the answer and appropriate resources are not easily accessible; teachers fear exposing their science knowledge to the scrutiny of others when trying to answer such a question; time is short; or the question is not seen as important for teaching in the first place. None of these reasons to avoid discussing the science content question applied here. Because the PLC had support from a science expert in the form of a content day prior to the PLC cycle and a visit during the first day of the PLC cycle, the teachers had already discussed and refreshed their understanding of the most foundational concepts, so Eric and Paul felt prepared to answer the question. Furthermore, the participation of the science expert brought the importance of the teachers' science understanding to the forefront, thus placing AKC firmly beside AKT and AKS. And because the teachers constantly kept up accountability to the community, not only with their words but also with the friendly tone of this exchange, the

situation stayed safe for Barbara to continue asking until she felt she had the necessary understanding to move on.

### **All Teachers Assuming All Discursive Accountabilities**

In other PLCs that were observed for this research, the accountabilities expressed were often predominantly to the community and to the teaching method or technique. The teachers in those PLCs shared their own teaching experiences and their ideas about teaching developed lesson plans that incorporated a variety of instructional strategies. These conversations were friendly and focused, and the developed lessons were engaging and enjoyable for students. However, while talking about teaching strategies implies knowledge about student learning and science content, most of the time this knowledge remained tacit. Consequently, this knowledge could not be compared, aligned, modified, or expanded. This limited the aspects of science teaching and student learning that were discussed. The result was agreeable talk that glossed over uncertainties and differences in understanding. The learning opportunities for the participating teachers and the innovations for teaching were limited.

In contrast, the teachers in the Physics-PLC expressed all of the facets of accountable teacher talk throughout the PLC cycle. And instead of talking only about students' interest and teaching strategies, accountability to students and to teaching always included the implications for science learning. However, the participants took on different accountabilities at different frequencies and levels of complexity. Eric, for example, in his role as facilitator, showed a strong accountability to the community throughout the 2 days. When he suggested that scaffolding should be a focus for this PLC cycle's lesson planning, he stated:

I need a lot of help with that because I am not a linear thinker. So, those of you who are "linear," the more you keep us on track in our lesson scaffolding, always pushing forward

in a logical manner, I am very grateful for that.

Even if Eric's role as facilitator potentially gave him the authority to lead the group along the protocol toward fulfilling the task of coming up with a teachable lesson plan, he made it clear that he was not in any way superior as a teacher. Thus, he invited participation and at the same time stayed within the norms of an egalitarian school culture.

Donna also showed constant accountability to the community, as she listened carefully to other participants' contributions, she was always ready to help clarify what was meant. In episode 2 she demonstrated that her other strong accountability was to the knowledge about science and students. Her detailed interpretation of her students' struggles to understand the concept of speed ensured a continued and deep conversation about science and students. This may also have been influenced by her role as the observed teacher, responsible for teaching the collaboratively developed lesson in her classroom.

Larry's and Keith's main accountability was to the knowledge of science and teaching. While Larry often mentioned outside requirements for teaching, like state standards and assessments, Keith shared his teaching experience combined with his knowledge of science and teaching.

Paul's strongest accountability was to science content knowledge, and he contributed to the discussion whenever explanations of science concepts remained unclear. Barbara and Amanda didn't show preferences during this PLC cycle; instead they contributed all facets of accountable talk. Barbara showed strong accountability at times to the knowledge of science and students (episode 2), and at times to science content knowledge (episode 3). In short, the teachers of the Physics-PLC showed different preferences for the facets of accountable teacher talk, but as a group, they engaged in the full range of facets throughout the PLC cycle.

In addition, the five facets of accountable teacher talk (AC, AR, AKS, AKT, and AKC) were nearly always connected with or attached to each other. AC created a safe discursive environment: The teachers listened attentively to each other's contributions, giving everyone time to formulate thoughts and ideas, and praising the value of input. This safe environment made it possible for reasoning to become the norm of the discourse. This was probably the most distinct characteristic of this PLC, compared with other, less productive groups. Teachers in other PLCs often disrupted teachers' reasoning about a statement. For example, attempts of reasoning that started with "because" were cut short by teachers either moving on with the theme, or finishing each other's sentences. Both moves signaled an implicit understanding that the other teachers already knew what a colleague wanted to say. While this might have been true on occasions, the presented episodes from the Physics-PLC show that when a group has the interest and the patience to listen to reasoning, different approaches to teaching can emerge that are worth debate. This shows the close connection between AC and AR. Only when accountability to the community is high can reasoning be strong.

Because reasoning was a solid part of the Physics-PLC's discourse, there was also the opportunity for the teachers to be accountable to knowledge. In other words, knowledge was not only shared, but through reasoning there was a need to support and justify knowledge with teachers' experience, anecdotal evidence from their practice, and other knowledge resources.

Because all aspects of professional accountability were present in the discourse, a full picture of teaching for students' learning could emerge. Learning opportunities for the teachers occurred because through accountability to the different knowledge domains, teachers who were inclined to be more focused on one domain were exposed to explications and reasoning for less

familiar perspectives on an idea. In this way, meaning was negotiated and ideas were aligned (episode 1), and knowledge was constructed and consolidated (episodes 2 and 3).

### **When Accountability Disrupts the Flow of the Discourse**

The discourse that was most productive in terms of learning opportunities occurred when one of the teachers took a strong stand toward a particular accountability and thus interrupted the agreeable flow of discourse. This caused the group to stay with one topic for an extended time, and for the talk to take unpredicted turns and detours, and explore new territory. Larry's insistence on resolving the apparent contradiction of scaffolding for learning and flexibility in teaching, Donna's consistent return of the conversation back to students' understanding, and Barbara's strength in admitting that she still had a very fragile understanding of some of the science, moved the group as a whole as well as the individual teachers to reconsider what they thought they knew. However, disrupting the flow of the professional discourse would not have resulted in extended and intensive discursive episodes had the teachers not engaged in all facets of accountable teacher talk throughout the PLC cycle.

### **Learning Opportunities Through Accountable Teacher Talk**

The three discursive episodes show some of the different kinds of learning opportunities a PLC can offer participating teachers. All of the teachers were familiar with the instructional strategies of scaffolding and formative assessment. However, their need to discuss the strategies' meaning and implications (episode 1) became clear through Larry's doubt about the logic of reasoning. The discourse that followed showed that the ideas about teaching in this group were not fully aligned. While in the end, the teachers might still have held somewhat different ideas about scaffolding and formative assessment, through their discourse they could at least move

closer to a shared understanding of instruction (Little, 2007), or what Slavit and Nelson (2009) called “instructional theory building” (p. 202).

During episode 2, the discussion about what students struggle with conceptually, what they should understand about speed, and how this understanding could be measured created the need to find a teaching approach that was different from the teachers’ traditional way of teaching and the one suggested in the curriculum. This gave Paul and Keith the opening to share their ideas and approach to teaching and learning. Larry, who was an experienced teacher who had been frustrated with the idea of student conceptual understanding without the means to assess such understanding, recognized the potential of the approach described by Paul and Keith. When he was interviewed he recounted his first attempt at changing his teaching practice accordingly:

Also I got a great idea from Paul and Keith when we were talking about speed, because the kids don’t ever know what speed is. They only know how to compute it. So when he said if you let them find it organically—I have never done that before. So this year, I gave them a cart, I gave them a meter stick, and I gave them a timer, and I said, “Find the speed of the car when you push it and let go of it.” And every table had to work it out. Now, five-eighths—you know, I have eight tables—so five in every class were able to get it eventually, and then three of them needed a little bit of help. But I didn’t tell them how to do it, I said, “How fast do you go in your car?” Well, 50 miles per hour. And we would equate that to, well, isn’t that the same as a certain amount of distance? And they would figure that out. I feel like they understood [...] Well, I feel like they did it very well, and they understand it better—they aren’t forgetting it. Last year—all the years previous, they forget it. Every day we have got to re-learn it. But this year, they haven’t. They know that it is distance divided by time. [...] I used to spend that long beating it into them. And now they can do it for themselves and I think that is a great way to teach. So I appreciated Paul’s advice on that.

The other teachers were farther along in teaching the curriculum that year, but indicated that they would also try this approach in the next school year. The discussion about students’ problems in learning a science concept led to the group’s shared understanding that they needed to improve their practice (transfer and transformation of knowledge). This was followed by a

suggested teaching approach that matched the newly created shared understanding and need. What would have been merely an interesting idea in another context, here was seen as the solution to a problem of practice that could be readily implemented in the classroom (transposability of knowledge). At the beginning of episode 2, the teachers could not have known that the time and commitment invested in this discourse would pay off, so this episode shows the value of an intrinsic accountability to professional knowledge—knowledge of students, teaching, and science—compared to a purely goal-oriented approach that would have privileged the task over such lengthy considerations.

Episode 3 illustrates how one discourse episode can provide different learning opportunities for different teachers. Barbara sorted out her beginning understanding by directly eliciting explanations to her question about static friction. Eric, by answering her question, solidified his own, still fragile understanding that he had gained during the content intervention with the science specialist. Paul, by adding the aspect of net forces to the explanation, may have further supported Barbara and Eric to solidify their understanding of the concept, and may have offered the other participating teachers some new ways of thinking and talking about it. It sounds simple: to ask a question about something you are not sure of and have your colleagues help you understand. However, this is one of few incidents observed where science questions were asked and answered in a PLC. I infer that such situations occur when all of the accountabilities of professional teacher talk are in place: AC to provide for a safe environment where honest questions can be asked, AKC that sees science understanding as a prerequisite for science teaching, and AKS and AKT to keep the discourse focused on the teachers' professional responsibilities and the context they are teaching in.

## **Limitations of the Findings**

Due to the close interrelationship of the five facets of accountable teacher talk, the coding was sometimes ambiguous. As Michaels and colleagues have pointed out, discourse moves can accomplish several purposes simultaneously, and “many-to-many mapping between forms and functions” is inevitable (Michaels et al., 2008, p. 293). I tried to code according to the most obvious professional accountabilities expressed in the presented episodes, and to avoid overinterpreting. However, my own partiality toward the teachers and toward the idea of the framework may have skewed the findings toward a certain intended outcome. Further discussion with experts in the education field will lead to better validation or to a modified version of these findings.

## **Discussion**

The discursive episodes presented here were from a mandatory PLC with all eighth-grade science teachers from one school district. Their collaboration was facilitated by one of the participating teachers. This type of mandatory collaboration without an outside facilitator may be more the norm than the exception in school districts. In the literature, most teacher collaboration studied was voluntary or supported by a university researcher. This study adds the findings of an exemplary PLC within an ordinary context to the discussion of teacher learning through collaboration.

## **Accountable Teacher Talk for Analysis**

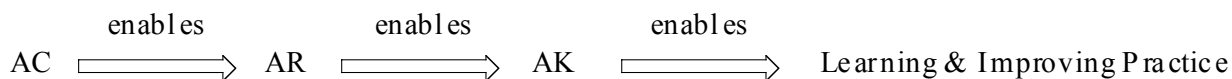
The accountable teacher talk framework helped to characterize the teachers’ discourse and to better understand what made it more productive than the discourse of other PLCs in similar contexts. While the content discussed is unique for each PLC, *how* it is discussed is

comparable. Analyzing and characterizing the Physics-PLC discourse led to highly descriptive codes (Appendix D, Table D.2). These codes should be applicable to analysis of other discursive events among science teachers, and may be expanded and modified by doing so. Analyzing the quality of teachers' discourse with this framework could be important for school districts and PD providers who are responsible for collaborative teacher PD. The framework and the codes can enable observers as well as participants to detect the strengths and weaknesses of the discourse, and to find a way to improve the productivity of the collaboration.

The facets of accountable teacher talk are interdependent. If teachers are accountable to only some of the facets, such as to the community and to knowledge of teaching, the quality of the discourse—and therefore the productivity in terms of learning opportunities and ideas for improved teaching practice—will be limited. Accountability to the community is clearly a prerequisite for the other accountabilities to be expressed. However, the descriptive codes for accountability to the community show that even within this one facet, different characteristics mark different qualities. “Listening without interrupting” is less productive than “asking for opinions or beliefs.” And some accountability to the community prompts are more closely linked to accountability to reasoning than others. Listening with the intention to understand the other's reasoning and asking clarifying questions to better understand one's own reasoning is an example of a distinct quality. It seems that the greater the number of different characteristics of accountability to the community that can be found in a discourse, the higher the possibility that other accountabilities are expressed as well (Figure 3.4).

Accountability to reasoning in turn is closely connected to accountability to knowledge. Stating knowledge without reasoning does not provide learning opportunities or reasons for a change in practice. A statement that teaching for conceptual understanding is important says

little, without the reasoning for why this is important and how it could be accomplished. Especially difficult in the common culture of niceness in schools is the accountability to reasoning characteristic of “critiquing.” Critiquing is essential to discourse in the science research community, and is one characteristic of the nature of science, but it is challenging for science teachers to follow this principle of their trade. Having a teacher model this characteristic of accountability to reasoning without criticizing colleagues, and having a group that takes this critique seriously, is a rare learning opportunity in itself. Lastly, being accountable to all domains of science-for-teaching knowledge ensures that both teachers’ and students’ learning moves toward a better understanding of science and science teaching. Consequently, the accountable teacher talk framework can also provide language, prompts, and examples to guide teachers toward more accountable talk.



*Figure 3.4.* Proposed interdependence of accountabilities in talk (AC = accountable to the community, AR = accountable to reasoning, AK = accountable to knowledge)

### **Using Accountable Teacher Talk as a Guide**

By strengthening accountabilities to reasoning and to knowledge, teachers place their professional accountabilities above cultural-historic norms of collaboration that are non-productive. The codes of the accountable teacher talk framework can be used as prompts and thus provide detailed guidance for all participants in a PLC to support productive discourse. Such prompts could also supplant the behavior-oriented norms of collaboration frequently seen in school settings.

In particular, a focus on the facet of accountability to knowledge and its three sub-facets (AKS, AKT, and AKC) can have three positive effects: First, teachers explore their need for knowledge, and may therefore request from their district sufficient knowledge resources in an accessible form. The teachers of the Physics-PLC did this by asking for an additional study day concerning the content they were supposed to teach. Second, teachers' specific experiences and classroom data act as knowledge resources and become a stronger factor in deliberation—as opposed to stating generalities only (Curry, 2008). As Little (2007) explains: “We have a growing body of evidence that attending closely to experience enhances the potential for learning and instructional improvement in particular ways” (p. 237). Little elaborates that such experiences need to be shared in order to find patterns in students' development of understanding. This in turn informs decisions for and in teaching, which leads to teacher learning and improvement of practice within their unique contexts. Third, being accountable to knowledge means opening up one's experience and understanding to scrutiny and critique. Thus tacit knowledge can be elicited, and there is less risk that unsupported beliefs or suboptimal understanding of content will remain unchallenged.

Knowing the characteristics of productive teacher discourse could also lead to the development of tools that can be used by teachers themselves, or by PD providers who work with entire school departments to prepare them for independent collaborative work. Such tools could also be used to quickly analyze the quality of a discourse in order to provide support for a more professionally valuable collaboration.

### **Accountable Teacher Talk Enacted**

If we expect Accountable Talk in classrooms (Cazden, 2001; Michaels et al., 2008), we should also expect it in teachers' collaborative work. Classroom discourse as described by

Michaels and colleagues is astoundingly similar to the discourse among teachers in the observed PLC. Therefore, coaching teachers to improve the quality of their own discourse may not only improve what knowledge they can share and develop and how they can support each other to improve their practice, it may also have implications for their classrooms. Teaching practices coevolve throughout various contexts, and the practice of collaboration among teachers can influence expectations for collaboration in their classrooms and vice versa.

Practicing accountable discourse can also influence the school culture. None of the Physics-PLC teachers shied away from sharing their experiences and their problems of practice, expressing concern or doubt about what was discussed, or asking questions and helping each other clarify what their contributions meant. They continuously practiced accountable talk. Thus, they showed an implicit understanding that the quality of their collaborative work could only be as good as their own input, and they relied on the facilitator only for organizational issues such as keeping time and moving the agenda along. This seems to be a real shift in culture. Because when teachers are the designated facilitators of their colleagues, two cultural traditions potentially clash: PD is still viewed as a traditional one-way transmission of knowledge, while at the same time, the egalitarian tradition in schools may prevent leadership among colleagues (Spillane & Healey, 2010). In an interview for the larger study this article draws on, a teacher from another PLC commented about a senior colleague who was new to their school and to the PLC: “I think a facilitator would have been able to pull him into a group and get him working, more than a peer would have.” This teacher assumed that a facilitator from the outside would have had more authority than a peer. Teacher facilitators are in no position to make their colleagues participate in a meaningful way if they are reluctant to do so on their own account. In schools, maybe more so than in any other collaborative setting, facilitation works only to the

degree to which participants agree to be facilitated (Spillane, Halverson, & Diamond, 2004). Avoiding this clash of traditions can lead to superficial talk and shallow work. However, if PLC participants take on the accountabilities for productive and professional discourse, a PLC can provide learning opportunities for its participants and get quality work done without an outside facilitator in the traditional role of PD leader.

However, the most productive talk occurs when accountable yet agreeable talk gets interrupted by a teacher's assertive stance toward a specific accountability, such as accountability to reasoning, or to knowledge of science and students. As A. F. Ball and Cohen (1999) stated:

Some disequilibrium is required for such learning. It would not be sufficient simply to see what one already assumes about students, learning, and content; one would also need to see others' assumptions, differences in their content and effects, or unexpected effects of one's own ideas or practices. (p. 14)

A strong stand toward one of the facets of accountability could provide such a "change-provoking disequilibrium" (Opfer, 2012, p. 389), especially in well-functioning groups.

### **Implications and Next Steps**

Next steps would be sharing these findings and the framework for accountable teacher talk with selected teacher educators and developing tools for teachers' professional development. Should the accountable teacher talk framework appear promising for improving the quality of teachers' discourse in pilot groups, a joint PD effort to bring both frameworks into schools: Accountable Talk for students and accountable teacher talk for teachers, so that discourse in both contexts—classrooms and PLCs—could coevolve.

While the goals for teacher collaboration are often clearly mapped out, the best way to support such collaboration is less clear (Talbert, 2010). The accountable teacher talk framework of discursive accountabilities offers guidance in one important area of collaboration.

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## APPENDIX A:

### Balanced and Unbalanced Forces

Washington State K-12 Science Learning Standards (2009, p. 66)

#### Standards for Grades 6-8

EALR 4: Physical Science  
 Big Idea: Force and Motion (PS1)  
 Core Content: *Balanced and Unbalanced Forces*

In prior grades students learned to use basic tools to measure force, time, and distance. In grades 6-8 students learn to measure, record, and calculate the average speed of objects and to tabulate and graph the results. They also develop a qualitative understanding of inertia. Students learn to predict the motion of objects subject to opposing forces along the line of travel. If the forces are balanced, the object will continue moving with the same speed and direction, but if the forces are not balanced, the object's motion will change. These concepts and principles prepare students for a more formal understanding of mechanics in high school and help them make sense of the world around them.

Content Standards	Performance Expectations
<i>Students know that:</i>	<i>Students are expected to:</i>
6-8 PS1A <i>Average speed</i> is defined as the distance traveled in a given period of time.	<ul style="list-style-type: none"> <li>• Measure the distance an object travels in a given interval of time and calculate the object's <i>average speed</i>, using <math>S = d/t</math>. (e.g., a battery-powered toy car travels 20 meters in 5 seconds, so its <i>average speed</i> is 4 meters per second).*a</li> <li>• Illustrate the <i>motion</i> of an object using a graph, or <i>infer</i> the <i>motion</i> of an object from a graph of the object's position vs. time or <i>speed</i> vs. time.*b</li> </ul>
6-8 PS1B <i>Friction</i> is a <i>force</i> that can help objects start moving, stop moving, slow down or can change the direction of the object's <i>motion</i> .	<ul style="list-style-type: none"> <li>• Demonstrate and <i>explain</i> the <i>frictional force</i> acting on an object with the use of a physical <i>model</i>.</li> </ul>
6-8 PS1C Unbalanced <i>forces</i> will cause changes in the <i>speed</i> or direction of an object's <i>motion</i> . The <i>motion</i> of an object will stay the same when forces are balanced.	<ul style="list-style-type: none"> <li>• Determine whether <i>forces</i> on an object are balanced or unbalanced and justify with observational <i>evidence</i>.</li> <li>• Given a description of <i>forces</i> on an object, <i>predict</i> the object's <i>motion</i>.*c</li> </ul>
6-8 PS1D The same unbalanced <i>force</i> will change the <i>motion</i> of an object with more <i>mass</i> more slowly than an object with less <i>mass</i> .	<ul style="list-style-type: none"> <li>• Given two different <i>masses</i> that receive the same unbalanced <i>force</i>, <i>predict</i> which will move more quickly.</li> </ul>

#### Mathematics Connections

*a	6.1.F	Fluidly and accurately multiply and divide non-negative decimals.
	6.2.E	Solve one-step equations and verify the solutions.
	6.2.F	Solve word problems using mathematical expressions and equations, and verify the solutions.
	6.3.B	Write ratios to represent a variety of rates.
	6.3.D	Solve single- and multi-step word problems involving ratios, rates, and percentages, and verify the solutions.
*b	5.5.C	Construct and interpret line graphs.
	7.5.A	Graph ordered pairs of rational numbers and determine the coordinates of a point in the coordinate plane.
*c	7.2.H	Determine whether or not a relationship is proportional and explain your reasoning.

## APPENDIX B:

### Forces and Motion

Toler, D. J., & National Science Resources Center. (2000). *Energy, machines, and motion: Teacher's guide*, p. 218

#### Forces and Motion

When an unbalanced force acts on an object, the object will accelerate, or change its speed. The change in motion produced by the unbalanced force is seen in the acceleration of the object. The acceleration can be a change in speed or a change in the direction of the motion of the cars. The greater the unbalanced force acting on the cars, the greater the acceleration. This relationship is summarized in Newton's Second Law of Motion:  $F = ma$  (force equals mass times acceleration).

When an unbalanced force acts parallel to the motion of an object, the resulting acceleration changes only the speed of the object. Forces acting in the direction of the motion increase the speed of the object; those acting opposite the motion decrease the speed. If a constant unbalanced force acts on an object, the object will have a constant acceleration, which means there will be a steady change in the speed of the object. In these inquiries, students will measure changes in speed only at various points in the motion of the cars and gather evidence that, with the fan running, the speed of the fan car increases as the car moves farther along the path.

## APPENDIX C:

### Inheritance, Variation, and Adaptation

Washington State K-12 Science Learning Standards (2009) (pp. 78–79)

#### Standards for Grades 6-8

EALR 4: Life Science  
 Big Idea: Biological Evolution (LS3)  
 Core Content: *Inheritance, Variation, and Adaptation*

In prior years, students learned that differences in inherited characteristics might help organisms survive and reproduce. In grades 6-8 students learn how the traits of organisms are passed on through the transfer of genetic information during reproduction and how inherited variations can become adaptations to a changing environment. Sexual reproduction produces variations because genes are inherited from two parents. Variations can be either physical or behavioral, and some have adaptive value in a changing environment. In the theory of biological evolution the processes of inheritance, variation, and adaptation explain both the diversity and unity of all life.

Content Standards	Performance Expectations
<i>Students know that:</i>	<i>Students are expected to:</i>
6-8 LS3A The scientific <i>theory</i> of <i>evolution</i> underlies the study of biology and explains both the <i>diversity</i> of life on Earth and similarities of all <i>organisms</i> at the chemical, cellular, and molecular level. <i>Evolution</i> is supported by multiple forms of scientific <i>evidence</i> .	<ul style="list-style-type: none"> <li>• <i>Explain</i> and provide <i>evidence</i> of how biological <i>evolution</i> accounts for the <i>diversity</i> of <i>species</i> on Earth today.</li> </ul>
6-8 LS3B Every <i>organism</i> contains a set of <i>genetic information</i> (instructions) to specify its traits. This information is contained within <i>genes</i> in the <i>chromosomes</i> in the <i>nucleus</i> of each cell.	<ul style="list-style-type: none"> <li>• <i>Explain</i> that information on how cells are to grow and <i>function</i> is contained in <i>genes</i> in the <i>chromosomes</i> of each cell <i>nucleus</i> and that during the process of reproduction the <i>genes</i> are passed from the parent cells to offspring.</li> </ul>
6-8 LS3C Reproduction is essential for every <i>species</i> to continue to exist. Some plants and animals reproduce sexually while others reproduce <i>asexually</i> . <i>Sexual reproduction</i> leads to greater <i>diversity of characteristics</i> because offspring inherit <i>genes</i> from both parents.	<ul style="list-style-type: none"> <li>• Identify sexually and asexually reproducing plants and animals.</li> <li>• <i>Explain</i> why offspring that result from <i>sexual reproduction</i> are likely to have more diverse <i>characteristics</i> than offspring that result from <i>asexual reproduction</i>.</li> </ul>
6-8 LS3D In <i>sexual reproduction</i> the new <i>organism</i> receives half of its <i>genetic information</i> from each parent, resulting in offspring that are similar but not identical to either parent. In <i>asexual reproduction</i> just one parent is involved, and <i>genetic information</i> is passed on <i>nearly unchanged</i> .	<ul style="list-style-type: none"> <li>• <i>Describe</i> that in <i>sexual reproduction</i> the offspring receive <i>genetic information</i> from both parents, and therefore differ from the parents.</li> <li>• <i>Predict</i> the outcome of specific <i>genetic</i> crosses involving one <i>characteristic</i> (using <i>principles</i> of <i>Mendelian</i> genetics).</li> <li>• <i>Explain</i> the survival value of <i>genetic variation</i>.</li> </ul>
6-8 LS3E <i>Adaptations</i> are physical or behavioral changes that are inherited and enhance the ability of an <i>organism</i> to survive and reproduce in a particular <i>environment</i> .	<ul style="list-style-type: none"> <li>• Give an example of a plant or animal <i>adaptation</i> that would confer a survival and reproductive advantage during a given <i>environmental</i> change.</li> </ul>
6-8 LS3F <i>Extinction</i> occurs when the <i>environment</i> changes and the adaptive <i>characteristics</i> of a <i>species</i> , including its behaviors, are insufficient to allow its survival.	<ul style="list-style-type: none"> <li>• Given an <i>ecosystem</i>, <i>predict</i> which <i>organisms</i> are most likely to disappear from that <i>environment</i> when the <i>environment</i> changes in specific ways.</li> </ul>

## Standards for Grades 6-8

	Content Standards	Performance Expectations
6-8 LS3G	<i>Evidence</i> for <i>evolution</i> includes similarities among anatomical and cell structures, and <i>patterns</i> of development make it possible to <i>infer</i> degree of relatedness among <i>organisms</i> .	<ul style="list-style-type: none"><li>• <i>Infer</i> the degree of relatedness of two <i>species</i>, given diagrams of <i>anatomical features</i> of the two <i>species</i> (e.g., chicken wing, whale flipper, human hand, bee leg).</li></ul>

## APPENDIX D

Table D.1

*Initial Codes for Analyzing Discourse*

Facets	Accountable to the community	Accountable to standards of reasoning	Accountable to knowledge
<b>Descriptive Codes</b>	Participants listen to each other (no interruption of episode)	Explaining: <ul style="list-style-type: none"> <li>• explaining the “how”</li> <li>• explaining the “why”</li> <li>• justifying statements</li> <li>• searching for premises</li> </ul>	Referencing knowledge of science and students: <ul style="list-style-type: none"> <li>• student work</li> <li>• student thinking/talking</li> <li>• student data</li> <li>• statements of own understanding of students’ knowledge</li> </ul>
	Information: <ul style="list-style-type: none"> <li>• providing information</li> <li>• following up with more information</li> <li>• making opinions/beliefs public</li> </ul>	Reasoning: <ul style="list-style-type: none"> <li>• deductive reasoning: applying generalizations to single events</li> <li>• inductive reasoning: generalizing from single events</li> <li>• connecting through logical relations/pointing out causalities</li> </ul>	Referencing knowledge of science and teaching: <ul style="list-style-type: none"> <li>• statements of own practice</li> <li>• replays of events</li> <li>• rehearsals of events</li> </ul>
	Clarification: <ul style="list-style-type: none"> <li>• clarifying a question</li> <li>• eliciting more information</li> <li>• asking for opinion/belief</li> </ul>	Critiquing: <ul style="list-style-type: none"> <li>• evaluating a statement</li> <li>• expressing probabilities</li> <li>• providing alternatives</li> <li>• engaging in self-critique</li> <li>• reframing a problem or statement</li> </ul>	Referencing knowledge of science and society: <ul style="list-style-type: none"> <li>• ideas about the influence of the concept on community and society</li> </ul>
	Reassurance: <ul style="list-style-type: none"> <li>• normalizing problem of practice</li> <li>• providing reassurance</li> <li>• providing emotional support</li> </ul> Connection: <ul style="list-style-type: none"> <li>• connecting information</li> <li>• building on others’ contributions</li> </ul>		Pure science content knowledge: <ul style="list-style-type: none"> <li>• facts, written sources, general acknowledged concepts in science</li> <li>• statements of own understanding of content (thus opening it up for scrutiny)</li> <li>• statements of own understanding of the relationship between knowledge and task</li> </ul>

	<b>Not accountable to the community</b>	<b>Not accountable to standards of reasoning</b>	<b>Not accountable to knowledge</b>
	Participants get interrupted	Stating as fact without reasoning; Judging without reasoning	Referencing hunches and ideas (unfounded, unexplained)
	Uncertainties stay unchallenged	Taking “evidence” for face-value	Working with science concepts without checking for accuracy
	Accounts of problems of practice are dismissed or turned away	Leaving ideas unrelated	Talking about student abilities without referencing student work, student thinking, student data
		Gatekeeping: Contributions are rejected because of students, beliefs, values, own knowledge <sup>a</sup>	

*Note.* These codes were derived from discourse examples in the research literature.

<sup>a</sup> See “Collective Sensemaking About Reading: How teachers Mediate Reading Policy in Their Professional Communities,” by C. E. Coburn, 2011, *Educational Evaluation and Policy Analysis*, 23(2), pp. 145–170; and “Teaching Replays, Teaching Rehearsals, and Re-Visions of Practice: Learning From Colleagues in a Mathematics Teacher Community,” by I. S. Horn, 2010, *Teachers College Record*, 112(1), pp. 225–259.

Table D.2. *Descriptive Codes and Prompts for Accountable Teacher Talk*

Facets	Accountability to the community (AC)	Accountability to standards of reasoning (AR)	Accountability to knowledge (AK)
<b>Descriptive Codes / Prompts That Characterize ATT</b>	<p>Participation:</p> <ul style="list-style-type: none"> <li>• Listening to others (no interruption of episode)</li> <li>• Showing interest through nodding or other visual cues</li> </ul>	<p>Explaining:</p> <ul style="list-style-type: none"> <li>• Explaining the “how”</li> <li>• Explaining the “why”</li> <li>• Justifying statements</li> <li>• Searching for premises</li> </ul>	<p><b>Accountable to knowledge of science and students (AKS)</b></p> <p>Referencing:</p> <ul style="list-style-type: none"> <li>• Written resources and general acknowledged concepts of student learning</li> <li>• Student work</li> <li>• Student thinking/talking</li> <li>• Students’ understanding in general</li> <li>• Student data</li> <li>• Own understanding of students’ knowledge</li> </ul>
	<p>Information:</p> <ul style="list-style-type: none"> <li>• Providing information</li> <li>• Following up with more information</li> <li>• Making opinions/beliefs public</li> <li>• Connecting information</li> <li>• Building on others’ contributions</li> </ul>	<p>Reasoning:</p> <ul style="list-style-type: none"> <li>• Deductive reasoning: applying generalizations to single events</li> <li>• Inductive reasoning: generalizing from single events</li> <li>• Connecting through logical relations/pointing out causalities</li> </ul>	<p><b>Accountable to knowledge of science and teaching (AKT)</b></p> <p>Referencing:</p> <ul style="list-style-type: none"> <li>• Written resources and general acknowledged concepts of science teaching</li> <li>• Replays of events</li> <li>• Rehearsals of events</li> <li>• Prediction of/expectation for events</li> <li>• Teaching artifacts</li> <li>• Own practice</li> </ul>
	<p>Clarification:</p> <ul style="list-style-type: none"> <li>• Clarifying a question</li> <li>• Eliciting more information</li> <li>• Asking for opinion/belief</li> <li>• Clarifying others’ statements</li> </ul>	<p>Critiquing:</p> <ul style="list-style-type: none"> <li>• Evaluating a statement</li> <li>• Expressing probabilities</li> <li>• Providing alternatives</li> <li>• Engaging in self-critique</li> <li>• Reframing a problem or statement</li> </ul>	<p><b>Accountable to science content knowledge (AKC)</b></p> <p>Referencing:</p> <ul style="list-style-type: none"> <li>• Written resources and general acknowledged concepts in science</li> <li>• Own understanding of content</li> <li>• Own understanding of the relationship between knowledge and task</li> </ul>
	<p>Reassurance:</p> <ul style="list-style-type: none"> <li>• Normalizing problem of practice</li> <li>• Providing reassurance</li> <li>• Providing emotional support</li> <li>• Praising and reaffirming contributions</li> </ul>		

*Note.* These codes include themes and patterns derived from the analysis of teachers’ discourse in a science PLC. The codes could also guide productive discourse during teachers’ collaborative work.

## Curriculum Vitae

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### Academic Degrees and Certificates

- Ph.D.** 2008–2013 **Postgraduate Studies**  
College of Education, Curriculum & Instruction, Science Education  
University of Washington, Seattle, Washington, USA  
Thesis: Science-for-teaching Discourse in Science Teachers' Professional Learning Communities
- 2005 **Residency Teacher Certificate**  
State of Washington, USA  
Endorsements: Biology & Chemistry
- 1996 **Certificate In Teaching of German as a Foreign Language**  
International House London, United Kingdom  
University of Cambridge, United Kingdom
- 1992 **State Certified Teacher for Secondary School (Gymnasium)**  
Bayerisches Staatsministerium für Unterricht und Kultus, Germany
- M.Ed.** 1989 **Master in Science Education**  
Technische Universität München, Germany  
Specializations: Biology & Chemistry

### Professional Experience

- 2005–2012 **Program Coordinator, Program Manager, Independent Contractor**  
Center for Inquiry Science at the Institute for Systems Biology, Seattle, USA
- 2001–2005 **Editor and Executive Producer, Head of Science Division, Freelance Contributor**  
FWU Institute for Film and Image in Science and Education, Grünwald, Germany  
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- 1992–2002, 2011 **Secondary Science Teacher: Biology grades 5–13, Chemistry grades 9–12**  
Seattle World School, Seattle, Washington, USA  
Deutsche Schule London, Richmond, United Kingdom  
Secondary Schools (Gymnasium), Germany
- 1990–1992 **Science Teacher Apprenticeship**  
Secondary Schools (Gymnasium), Germany

### Publications and Presentations

- Thompson, J., Hagenah, S., Laxton, K. Lohwasser, K. (2012, April) *Problems with and without Ceilings: How Mentoring Communities Frame and Solve Problems around Ambitious and Equitable Teaching and Learning*. Poster presented at AERA conference, Vancouver, BC, Canada
- Riley Black, D. & Lohwasser K. (2010, April) *Systems Education Approach to Science*. Poster presented at the 9<sup>th</sup> International Symposium, Institute for Systems Biology, Seattle, WA

- Kiehle, C. & Lohwasser K. (2009, April) *Observing for Evidence of Learning—Teacher Professional Continuum Research Project*. Poster presented 8<sup>th</sup> International Symposium, Institute for Systems Biology, Seattle, WA
- Lohwasser, K. (2004). Didaktische FWU-DVD "Süßwasserfische": Anregungen zum Einsatz im Unterricht. *Medienzeit Aktuell*, (2), 12-14.
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- Heller, W., Rosemann, D., Osswald, W. F., Benz, B., Schönwitz, R., Lohwasser, K. (1990). Biochemical response of Norway spruce (*Picea abies* (L.) Karst.) towards 14-month exposure to ozone and acid mist: part I--Effects on polyphenol and monoterpene metabolism. *Environmental pollution* 64(3-4), 353-366.
- Multimedia (author and executive producer): FWU (2001-2005)
- TV Documentary (co-editor): Bavarian Broadcasting Service and FWU (2003)