ABSTRACT

GALLAGHER, DANIELLE MOLONEY. Opportunities for Mathematics Teacher Learning through Interactions with Data: Zooming Out and Zooming In. (Under the direction of Dr. Temple Walkowiak).

Data-based decision making has gained traction in educational settings (Barnes et al., 2019; Schildkamp & Datnow, 2022), and teachers are often expected to engage with data individually or in collaborative settings. While studies demonstrate that teachers may learn through interactions with data in professional development interventions (e.g., Kippers et al., 2018; Schildkamp et al., 2016), less is known about teachers' opportunities for learning with data "in the wild", especially with respect to elementary mathematics teaching and learning. This dissertation pairs two complementary studies that use different angles to investigate teachers' opportunities for learning through interactions with data in elementary mathematics. These studies were both situated in the same elementary school. The first study utilizes post-intentional phenomenology to center teachers' perspectives on their own learning experiences. The study also incorporates complexity theory to "zoom out" and examine this phenomenon from a broader, systemic perspective. Seven teachers shared their perspectives on their own learning experiences with data through interviews; interview data from two school and two district administrators provided additional information about teachers' learning experiences. Findings suggest that characteristics of the data, the nature of teachers' interactions with data, and features of the complex system shape teachers' learning experiences with data. Teachers reported having learning experiences when engaging with relevant, interpretable data, especially through meaningful interactions with colleagues in professional learning communities (PLCs). Relevant school-level influences included a broad, schoolwide conceptualization of data and embedded structures for teacher learning (i.e., PLCs, coaches). The second study zooms in on teachers' interactions with data in elementary mathematics PLCs. Participants included two grade-level PLCs, each consisting of five teachers and the mathematics coach. Through case study methodology, naturalistic observations were used to examine teachers' interactions with data in PLCs weekly over five weeks. Findings indicated that teachers interact with a broad range of student data in PLCs and noted that these interactions occur throughout the meetings (e.g., as teachers plan upcoming instruction, as they discuss assessments, etc.). During these interactions with data, teachers attended to student mathematical thinking with varying degrees of depth, and specific, descriptive discussions of student mathematical thinking afforded rich opportunities for teacher learning. These rich learning opportunities oriented teachers towards collaboration in the PLC and towards a shared perspective on the teaching and learning of mathematics. Together, these two studies provide evidence of opportunities for teacher learning through interactions with data. Practitioners can learn from these findings by expanding views of data to include non-traditional data sources (e.g., observations, student work samples) and by considering the extent to which assessments provide clear evidence of student thinking. Implications for research include future investigations of teachers' job-embedded learning opportunities with data and longitudinal studies to examine teacher learning over time.

Opportunities for Mathematics Teacher Learning through Interactions with Data: Zooming Out and Zooming In

by
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DEDICATION

To the students, teachers, and staff at Pinecone Elementary, Garden County Schools, and especially Coach Sam.

BIOGRAPHY

Danielle Moloney Gallagher is a doctoral candidate in the Elementary Education in Mathematics and Science program at North Carolina State University. Her research focuses on elementary teacher learning in professional learning communities, particularly around data use in mathematics education. During her time at NC State, Danielle worked on a number of research projects, investigating teaching practices that support equity and access in mathematics classrooms (VEAR-MI), simulations to promote preservice teachers' skills in eliciting and interpreting student mathematical thinking (SimulaTE), and interdisciplinary conversations around early mathematics education (Conversations Across Boundaries). In addition, she taught elementary mathematics methods courses for undergraduate preservice teachers and coordinated the annual Math Summit, a professional development conference for over 500 K-12 math teachers in North Carolina. Danielle has a love for working with local schools and teachers, beginning with her experiences as a classroom teacher and continuing through partnerships with schools as a mathematics coach, tutor, and professional development facilitator. Prior to beginning this doctoral program, Danielle earned a bachelor's degree in elementary education from the University of North Carolina at Chapel Hill and a master's degree in elementary education from North Carolina State University, and she worked as a fifth-grade mathematics and science teacher.

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CHAPTER 1: INTRODUCTION

This dissertation examines opportunities for teacher learning in elementary mathematics from a broad, systems-level perspective and through a narrow, microprocess approach. This chapter first provides background information, introduces the problem at hand, and describes the purpose and significance of the dissertation. Next, the chapter presents the research questions that will guide two qualitative studies (Study #1 and Study #2) and provides an overview of the methodology employed by Study #1 and Study #2. Key terms used throughout the dissertation are also defined. The chapter concludes with an overview of the remaining chapters.

Background

Over the past several decades, educational leaders and organizations have called for reforms to mathematics education that emphasize mathematical proficiency across multiple embedded strands (i.e., conceptual understanding, procedural fluency), as well as the importance of discourse and problem solving (National Research Council, 2001; NCTM, 1989, 2000, 2014; NGA Center and CCSSO, 2010). More recently, educators have acknowledged that pushing for high-quality mathematics instruction alone does not mean all students receive a high-quality education. There is a need to explicitly advocate for equitable, humanized mathematical experiences to disrupt patterns of marginalization in education (Aguirre et al., 2013; Aguirre et al., 2017; Huinker et al., 2020). Shifting the educational system towards high-quality and equitable mathematics instruction is a process that requires numerous resources: time, professional learning, and the collective capacity of educators, among others. Instructional improvement does not happen by accident, and recent publications have emphasized the importance of establishing a shared vision for mathematics instruction and a coherent instructional system, as well as the steps educators must take to make this vision a reality in classrooms (Cobb et al., 2020; Karp et al., 2020).

One of the essential steps is providing opportunities for educators to learn about high-quality mathematics teaching and learning. Teachers need opportunities to experiment with new teaching practices, and principals need a chance to observe what these practices look like in action. These learning opportunities should be aligned with the shared vision of mathematics instruction and should fit within a coherent instructional system for mathematics (Cobb et al., 2020). Despite the large amounts of money invested in professional learning (Harvey & Teledahl, 2022), opportunities for learning to support educational reforms are often disjointed, perhaps due to misalignment in goals, turbulence in educational and political systems, or resistance to change (Yurkofsky et al., 2020). This lack of coherence can quickly derail transformation efforts (Peterson et al., 1996; Yurkofsky et al., 2020), and there is a need for coherence across professional learning opportunities in educational systems that aim to improve elementary mathematics education.

One area that demonstrates a need for more consistent and coherent professional learning opportunities is the realm of data use in elementary mathematics education. There appears to be a misalignment between intention and expectations around data use (Mandinach & Schildkamp, 2021b). Teachers and administrators tend to share a common understanding that student data can be analyzed and used to improve learning outcomes. However, the explicit and implicit expectations around data use from policy makers, administrators, and district staff often emphasize quantitative data from standardized assessments that may not provide rich information about student thinking (Gummer, 2021; Lai & Schildkamp, 2013). This disconnect could potentially lead to policies and decisions that "undermine if and how teachers use data to improve teaching and learning" (Barnes et al., 2022, p. 278). In addition, having access to data does not necessarily indicate that educators will use the data, or use it in support of students (Faulkner et al., 2019; Marsh et al., 2006). There is a need for alignment across research, policy, and practice to support educators and provide learning opportunities that develop responsible, responsive, and sustainable data use practices.

Problem Statement and Significance

The field needs studies that look broadly at the educational system but also zoom in on teacher learning at a microprocess level (Kazemi et al., 2022; Moss, 2012; Yurkofsky et al., 2020). In addition, there has been a recent call for educational research approached through a lens of complexity, both in the study of data use (Gummer, 2021) and teacher learning (Strom & Viesca, 2021). This dissertation responds to these needs by offering two complementary studies that offer a macro- and a micro-perspective on elementary mathematics education.

There is also a need for research on the practice of data use in elementary mathematics education (Little, 2012), particularly with respect to teacher learning and evidence of student mathematical thinking. Studies on data use in elementary mathematics tend to focus on interim assessment data without closely attending to teachers' examination of student mathematical thinking (Oláh et al., 2010; Van Lare, 2016). Evidence of student mathematical thinking may provide teachers with more useful and relevant information than other forms of data and may be used to guide instruction (Datnow et al., 2021). In addition, teacher workgroups such as professional learning communities (PLCs) may provide fruitful opportunities for teachers to engage in on-the-job learning about data use. There is a need for research that examines the types of interactions that support teacher learning through analysis of student thinking and connections to instruction (Cobb et al., 2020). This dissertation contributes to the research on data use and teacher learning in elementary mathematics education by offering insight into how teachers are currently using data and the extent to which those interactions offer job-embedded learning opportunities. It highlights the types of PLC activities in which teachers attend to evidence of student mathematical thinking and demonstrates the extent to which teachers use that evidence to guide instruction. These findings could inform structures and supports in place for data use and teacher learning within schools and offer recommendations for schools and districts seeking alignment and improvement in these areas.

Purposes of Dissertation

The purpose of this dissertation, divided into two complementary studies, is to investigate teachers' opportunities for learning through their interactions with data. The purpose of Study #1 is to investigate teachers' learning experiences within the system of data use in one school. Narrowing in on data use in PLCs, the purpose of Study #2 is to investigate teachers' interactions with student data in PLCs and their opportunities for learning through those interactions.

Research Questions

Within this dissertation study, there are two related, yet distinct qualitative studies (one broad and one narrow). The broad study, Study #1, used a phenomenological approach to answer the following research question:

1) In one school, how do elementary teachers' learning experiences, in relation to mathematics teaching and learning, take shape through interactions with data in a complex learning system?

The narrow study, Study #2, used a case study approach to examine a slice of the teacher learning system: teachers' opportunities for learning as they interact with data in PLCs. The following research questions guided the study:

1) In what activities do teachers engage during elementary mathematics PLC meetings?
2) In elementary mathematics PLCs, (a) for how much time and (b) during what activities do teachers engage with student data?
3) In elementary mathematics PLCs, what are the characteristics of teachers' interactions with student data, including their attention to student mathematical thinking?
4) In elementary mathematics PLCs, what are the characteristics of rich opportunities for learning around student data?

Overview of Research Methodology

This dissertation is composed of two qualitative studies (one phenomenological and one case study) that offer complementary perspectives on teacher learning through data use in elementary mathematics education and attempt to acknowledge the complexity of the system. The first study utilizes a post-intentional phenomenological approach (Vagle, 2018) to investigate how teachers experience learning, related to the teaching and learning of mathematics, as they interact with data. This study incorporates complexity theories (Cochran-Smith et al., 2014; Ell et al., 2019) as a lens to investigate teachers' learning experiences as they emerge within a complex system. As recommended by Yurkofsky et al. (2020), the second study focuses on teacher learning at a microprocess level. Using an embedded single-case study methodology (Yin, 2018), the second study examines teachers' interactions with data in PLCs and the opportunities for teacher learning within those interactions.

Definitions of Terms

To support the reader's understanding of the study, definitions of terms are provided here.

1. *Data* is defined broadly as "information that is collected and organized to represent some aspect of schools" (Lai & Schildkamp, 2013, p.10).
2. *Student data* refers to any information that is collected formally or informally about current students.
3. *Interactions with data* refers to any engagement between individuals or groups and data (e.g., looking at data, discussing data, referencing data, analyzing data, planning responses to data).
4. *Student mathematical thinking* encompasses mathematical ideas, strategies, and reasoning that come from students at any point in time (e.g., past, present, future, hypothetical).
5. *Evidence of student mathematical thinking* refers to information gathered from current students about their mathematical knowledge, reasoning, or strategies (Datnow et al., 2021).
6. *Professional learning communities* are groups of educators including teachers, coaches, and administrators who collaborate to support teaching and learning.
7. *Learning experiences* were primarily relevant to Study #1. Because Study #1 was concerned with teachers' perspectives on their own learning, a *learning experience* was defined as a teacher's description of or reference to the acquisition of new information, knowledge, or skills.
8. *Opportunities for teacher learning* were operationalized in two ways, broadly across the dissertation and specifically to Study #2. Broadly, an opportunity for teacher learning is

defined as the potential for a teacher or a group of teachers to acquire new information, knowledge, or skills relevant to the work of teaching. In Study #2, the focus was on teachers' interactions in collaborative spaces; observations of PLC meetings served as a primary data source. Therefore, *opportunities for teacher learning* were operationalized in Study #2 as observable oral interactions between an individual or group and other people, ideas, resources, or representations.

9. *Teacher learning through interactions with data* was defined in two parts. First, through the process of engaging with data (see *interactions with* data; definition #3), teachers may develop skills or acquire knowledge about *how to engage with data* (i.e., data analysis and data literacy skills). Second, as teachers engage with data, they may learn *from the data itself*. This could include (but is not limited to) acquiring information, knowledge, or skills related to the work of teaching and learning mathematics (e.g., learning about students, mathematical content, instructional practices).

Overview of the Dissertation

The subsequent chapters of this dissertation proposal proceed in the following manner. Chapter 2 provides background on the relevant literature for each study. Chapter 3 is a manuscript sharing the findings of the broad phenomenological study, and Chapter 4 is a manuscript describing the narrow case study (target journal: *Journal of Teacher Education*). Chapter 5 presents implications across the two studies and is written for a practitioner audience that includes school and district leaders (target journal: *Educational Leadership*). Chapter 6 provides a summary of the dissertation and next steps for future research.

CHAPTER 2: BACKGROUND AND OVERVIEW

This chapter begins with an overview of the theoretical underpinnings that informed this dissertation. The following sections provide an overview of the relevant literature on coherent instructional systems, professional learning communities, and teachers' interactions with data and student thinking in the context of the broader educational system.

Purpose Statement

As a reminder, the purpose of this dissertation is to broadly describe teachers' learning experiences within the system of data use in elementary mathematics education in one school, and then to narrowly zoom in and characterize teachers' interactions with data and their opportunities to learn from data in elementary mathematics PLCs.

Theoretical Underpinnings

Complexity Theories

Known by many names, such as complex systems theory, complex adaptive systems, or simply complexity, complexity theories have gained popularity in educational research in recent years (Hetherington, 2013; Strom & Viesca, 2021). These theoretical perspectives, which have roots in physics and mathematics, use complex systems thinking to analyze the behavior of networks composed of individual interconnected parts (Sammut-Bonnici, 2015). Complexity theories attempt to broaden traditional approaches to educational research by unpacking the dynamic, evolving, and interwoven components involved when trying to understand even the most seemingly simple phenomena in educational systems. Any single phenomenon in the educational system is connected to and potentially impacted by a vast number of features. Following the lead of other researchers (Gummer, 2021; Strom & Viesca, 2021), complexity theories will be used in this dissertation as a lens to study data use and teacher learning. Additional information about complexity theories is provided in Chapter 3.

Complexity theories have recently been applied to studies of teacher learning (Ell et al., 2019; McKie et al., 2023; Strom & Viesca, 2021). Teacher learning is both individual and collective, affected by individual, organizational, and interactional elements of a complex system (Borko, 2004; Opfer and Pedder, 2011). Because complexity assumes a network is constantly connecting and evolving, it is impractical to analyze one component in isolation without considering how it exists within the broader system. Applying complexity theories to teacher learning shifts the focus away from the teacher alone and recognizes that agency over teacher learning is distributed among multiple influences, both within and beyond the teacher (Strom & Viesca, 2021). This perspective requires considering the nested systems of influence that impact teacher learning to various degrees (Cochran-Smith et al., 2014; Opfer & Pedder, 2011). In their study, for example, Opfer and Pedder (2011) examined interactions within and between teachers (individuals), who took part in professional development activities, and who were nested in schools. Other studies have extended the range of influence even further, considering the impact of teacher beliefs and political decisions on teacher learning (Pajares, 1992; Postholm, 2012). Analyzing professional learning through the lens of complexity theories expands the perspective beyond looking at features of professional development activities to include the interplay between contexts, beliefs, interactions, policies, and more. Each of these factors can contribute to learning experiences and can interact with the other elements in distinct and relevant ways.

Understanding teacher learning is a complex task, and over the years multiple theories have developed to guide the study of teacher learning. Rather than relying solely on one theory, this dissertation draws upon and interweaves two theories of teacher learning: complexity and socioconstructivism. This approach, advocated by Boylan et al. (2018), acknowledges that any theory or model is inherently limited and alone is unable to fully capture the dynamic processes of learning in an intricate, interconnected world. By using more than one theoretical lens, a researcher can simultaneously tap into the advantages and address the limitations of different perspectives.

Socioconstructivism

In addition to complexity theories, a second lens through which teacher learning is viewed in this dissertation is the lens of socioconstructivism. Socioconstructivism has been utilized in educational research to emphasize two main tenants. First, humans learn through opportunities to wrestle and experiment with new ideas in real situations; in other words, humans engage in activities that allow them to construct knowledge (Kanselaar, 2002). Second, social interactions play a key role in that construction of knowledge. According to Adams (2006), "As the creation of knowledge cannot be separated from the social environment in which it is formed, learning is viewed as a process of active knowledge construction (Woolfolk, 1993) within and from social forms and processes" (p. 245-246). This perspective emphasizes social collaboration that allows learners to actively engage with and reflect on various learning experiences. This theory informs this investigation into teachers' professional learning experiences in PLCs, a setting in which teachers have the potential to actively make meaning of their work with students (i.e., analyzing student work samples, planning instruction, recalling observations of students, etc.) in collaboration with their colleagues.

Zooming Out, Then Zooming In: Complementary Perspectives on Mathematics Instructional Improvement

High-quality, equitable mathematics instruction encompasses a range of teaching practices that develop multiple, interwoven strands of mathematical proficiency (National Research Council, 2001; NCTM 2014). These teaching practices are designed to elicit student thinking (Kazemi & Franke, 2004), facilitate student-to-student discourse of mathematical concepts and representations (Chapin et al., 2013; Smith & Stein, 2018), and promote problem-solving. Equitable instruction specifically provides *all* students with access to high-quality mathematics instruction in ways that disrupt historical patterns of marginalization and exclusion in mathematics education (Wilson et al., 2019).

Providing all students access to high-quality, equitable mathematics instruction does not simply happen overnight, nor is it enacted through a simple, one-size-fits-all solution (Cobb et al., 2020). This approach is a deviation from ways of teaching and learning mathematics that have become institutionalized over many years, and change efforts require shifts in both practices and beliefs across many areas of the educational system (classroom, school, community, district, policy). These shifts require professional and organizational learning among teachers and administrators, a process which is complex, non-linear, and develops over time. As evidenced by other efforts to transform organizations, success is unlikely unless change is viewed as a long-term process that occurs through multiple phases across an entire system (Kotter, 1995). Thus it is useful, perhaps even essential, to take a broad, systems-level perspective when discussing efforts to improve mathematics instruction.

With the lens of complex adaptive systems in mind, it is crucial to acknowledge that a broad, macro-system view of instruction in mathematics education is only one method of examining improvement efforts. Such a wide lens cannot hope to capture the infinite complexity and nuance that exists at the micro-level as the interwoven components of the system interact in dynamic, evolving ways. Narrow, microprocess studies provide value through their ability to capture the inner workings of a phenomenon, investigating interactions and small shifts that can lead to change (Little, 2012). Think of the multitude of factors impacting just one teacher's interactions with data in one moment, and then expand that to include evolving learning opportunities across multiple days for multiple teachers in multiple schools. A teacher's actions may be influenced by structures and decisions at the macro-level, and those actions at the micro-level may shift the implications of macro-level policies (Goldstein, 2008; Little, 2012).

As a result of these dynamic relationships, scholars across the field of education are calling for studies that pair a wide, macro lens with a narrow investigation of interactions and processes at the micro-level. In the realms of data use (Coburn and Turner, 2012; Little, 2012), professional learning (Kazemi et al., 2022), and continuous improvement (Yurkofsky et al., 2020), researchers are zooming out to paint a broad picture of the system, then zooming in to gain an in-depth understanding of a slice of that system. Following these recommendations, this dissertation approaches the multiple, nested systems of teacher learning with two complementary perspectives. Study #1 investigates teachers' learning experiences with data within the broader educational system. Study #2 narrows on teachers' interactions with data in PLCs, attending to their opportunities for learning.

Coherence Across Systems of Elementary Mathematics Education

With a broad, systemic perspective in mind, instructional improvement in mathematics education involves consistent, sustained efforts across multiple dimensions. There is a need for coherence across professional learning opportunities in a district, including the teacher learning subsystem and professional learning for other role groups (i.e., principals, coaches) (Jackson & Cobb, 2013; Kazemi & Resnick, 2019; Penuel, 2019). The success of an initiative is often dependent on its implementation, and many cases of unsuccessful educational reforms can be attributed to inconsistent (or complete lack of) learning opportunities (Peterson et al., 1996). Therefore, developing coherent learning opportunities across role groups can support change efforts. It is in part through these professional learning experiences (job-embedded, pull-out PD, or others) that educators develop their instructional vision; therefore, these opportunities are more likely to be effective when consistent content, messaging, and vision is delivered throughout (Cobb et al., 2020).

Because teachers are typically the frontline professionals expected to implement instructional changes in classrooms, it is essential that teachers are given opportunities to learn about the proposed high-quality teaching practices in mathematics education reforms. Consistent with research on effective practices in teacher learning, these learning opportunities should be grounded in teachers' work in their current classrooms, occur over a sustained duration, and exhibit coherence with other components of the instructional systems (Darling-Hammond et al., 2017; Desimone, 2009). For example, instructional materials such as student assessments should reflect the same vision and learning goals as teachers' instructional practices, so student learning is assessed in a manner consistent with the teaching approach.

Unfortunately, incoherence is an issue that consistently plagues educational improvement efforts. The field of education is faced with the challenge of establishing coherence across a multitude of stakeholders who may each have their own vision of high-quality instruction (Nawab & Sharar, 2022, Yurkofsky et al., 2020). When parents, district staff, policy makers, and teachers offer unique perspectives on what constitutes mathematical success, it can be difficult to establish a coherent instructional system. Another challenge comes from the number of competing priorities that exist in school districts (Cobb & Smith, 2008; Spillane et al., 2006). For example, professional development (PD) experiences may encourage teachers to shift towards conceptual instructional strategies, but accountability pressures may push teachers to teach procedures using tips and tricks and only make short-term gains in student learning. Incoherence can also exist in miscommunication across a district, in the lack of organization in teacher learning structures, or in differing interpretations of reform efforts (NC2ML, 2018; Penuel, 2019).

Teachers' Interactions with Data

Broadly, the push for standardized testing and accountability in the US has led to an emphasis on data-based decision making (DBDM) in many PLCs (Marsh et al., 2006). Much of the focus on data use in education is how to improve outcomes for students, and teachers are often required to analyze and discuss data during PLC meetings with the intention of using that analysis to guide instructional decisions (Means et al., 2010).

Research consistently reveals that data use in education is a complex process (Gummer, 2021; Ikemoto & Marsh, 2007; Oláh et al., 2010). Data alone is devoid of meaning, and it is only through the process of interpretation and sensemaking that data is made meaningful and transformed into knowledge that can be used to make decisions (Coburn et al., 2009a; Coburn et al., 2009b; Honig & Coburn, 2008; Marsh et al., 2006; Marsh, 2012). Therefore, the influence of interpretation is present any time an individual interacts with data. While much of the push for DBDM in education comes from the belief that using data will streamline decision making and consistently lead to clear-cut, effective solutions, DBDM is not the straight-forward, objective process it claims to be (Coburn et al., 2009a; Kennedy 1982; Faulkner et al., 2019).

Because teachers are the frontline experts who work up close and personal with students, it is particularly important to understand how teachers engage with data and which interactions lead to meaningful and beneficial outcomes. Research suggests that the process of data use occurs across three broad stages: defining data, analyzing data, and responding to data (Marsh et al., 2006; Marsh, 2012), with teachers' interactions with data developing over time as they move through these stages (Cosner, 2011). Chapter 3 provides in-depth information about teachers' perspectives on their interactions with data, and Chapter 4 offers information about teachers' interactions with data in PLCs.

Teacher Learning in Professional Learning Communities

Teacher learning opportunities exist within a complex, evolving system, occurring in both formal and informal spaces through interactions with colleagues, students, resources, activities, and even social media. Amid this complexity, researchers have attempted to identify key features of professional learning experiences that may be correlated with learning outcomes. It appears the topic of the learning experience (content focus), how teachers engage during the experience (active learning; collective participation; modeling), and the potential for learning to occur over time (duration) may all impact learning (Darling-Hammond et al., 2017; Desimone, 2009; Garet et al. 2001). In addition, research suggests that these learning experiences cannot be isolated but must instead align with other learning opportunities and teachers' work in their own classrooms and schools (coherence) (Desimone, 2009; Garet et al. 2001).

Professional learning communities (PLCs), described in further detail in Chapters 3 and 4, are one type of learning opportunity aligned with several of these features. The idea for a PLC comes from the theory that teachers learn in community (Stoll et al., 2006; Wenger, 1998). The past few decades have seen a push for teacher collaboration, and that collaborative time is often structured during the school day in the form of these learning communities (Horn & Little, 2010; Cobb et al., 2020). PLCs can be defined broadly, such as an entire school, or more narrowly, as in specific teams within a school (DuFour & Eaker, 2009). At the elementary level, PLCs tend to be grade level teams; at the secondary level, the groups are more often subject specific. Other educators, such as coaches, specialists, and administrators, can occasionally or consistently collaborate with teachers in PLCs. Due to increasing attention on these groups as sources of school improvement, state and district policies often require the formation of PLCs in schools (Farley-Ripple & Buttram, 2014). While this means that PLCs are more often formal working groups, informal groups that develop naturally can also serve as learning communities (Wenger, 1998). PLCs can serve as spaces for teachers to interact with data and have the potential to support teacher learning. These details are described in Chapters 3 and 4.

Conceptual Framework for this Dissertation

There is a need for studies that examine teachers' opportunities for learning through data use from a lens of complexity, acknowledging the multiple, nested systems that interact and influence outcomes. This dissertation responds to that call by examining this phenomenon from multiple angles in two complementary, yet distinct studies.

Figure 2.1 offers a simplistic illustration of the multiple, nested levels on influence that could impact teacher learning and data use in elementary mathematics education. Each ovals represents potential influences on teachers' interactions with data and learning opportunities in elementary mathematics. The ovals are overlapping, separated by dotted lines. These features are used to imply that these levels are nested, with boundaries that are fluid, not rigid. The nested levels are constantly overlapping, interacting, and evolving, and teachers' experiences with learning and data use are deeply entwined within and impacted by these interactions.

Figure 2.1

Multiple, Nested Levels of Influence within the Complex System of Data Use

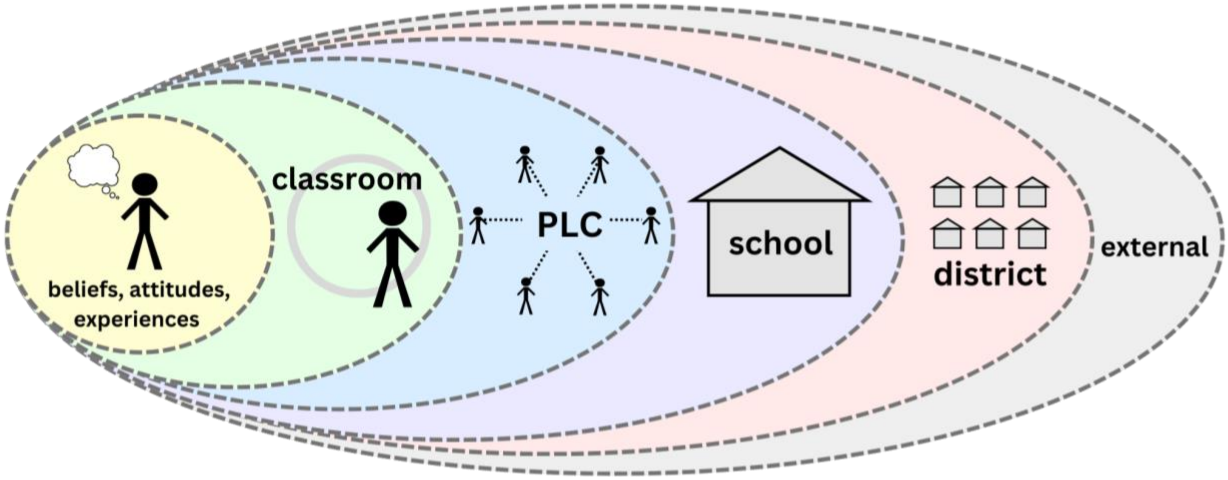
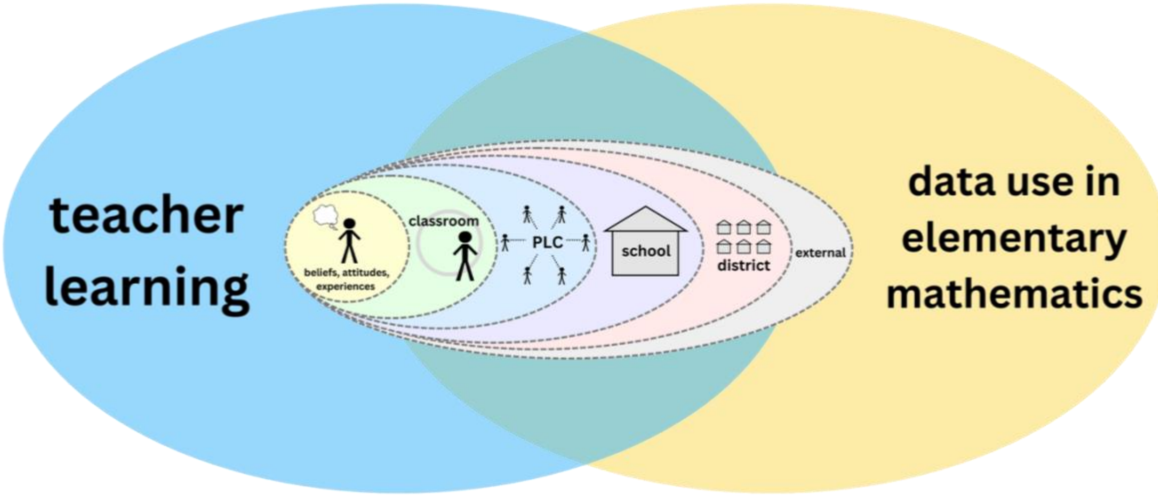


Figure 2.2 situates these nested levels within the systems of elementary mathematics data use and teacher learning. Think of this image as a cross section. Each nested level extends beyond this image in far-reaching, interacting, and evolving ways. The system of data use in elementary mathematics overlaps with teacher learning, and both systems are broader than the nested levels of influence examined in this dissertation. Despite its limitations, this image communicates two points. One, this dissertation examines elementary mathematics data use from a perspective of complexity, attending to this phenomenon within a broader system. Two, the studies in this dissertation examine both teachers' interactions with data and the learning that may emerge through those interactions. This is represented by the partial overlap of the blue "teacher learning" oval and the yellow "data use" oval.

Figure 2.2

Conceptual Framework for the Dissertation



Building off this conceptual framework, the two individual studies were developed. The first study investigated teachers' learning experiences with data use in elementary mathematics from a broad, systems-level perspective. It was situated within the context of one school and highlights the voices and experiences of teachers. Teachers' learning experiences are centered in this study, zooming out to consider possible influences from the broader system (Figure 2.3). The second study narrows in on teachers' interactions with data in elementary mathematics PLCs (Figure 2.4). It examines these interactions at a fine-grained level, attending to the characteristics and potential opportunities for learning within the interactions. The research questions guiding each study are described in the following section.

Figure 2.3

Visualization of Study #1: Zooming Out on Teachers' Learning Experiences with Data

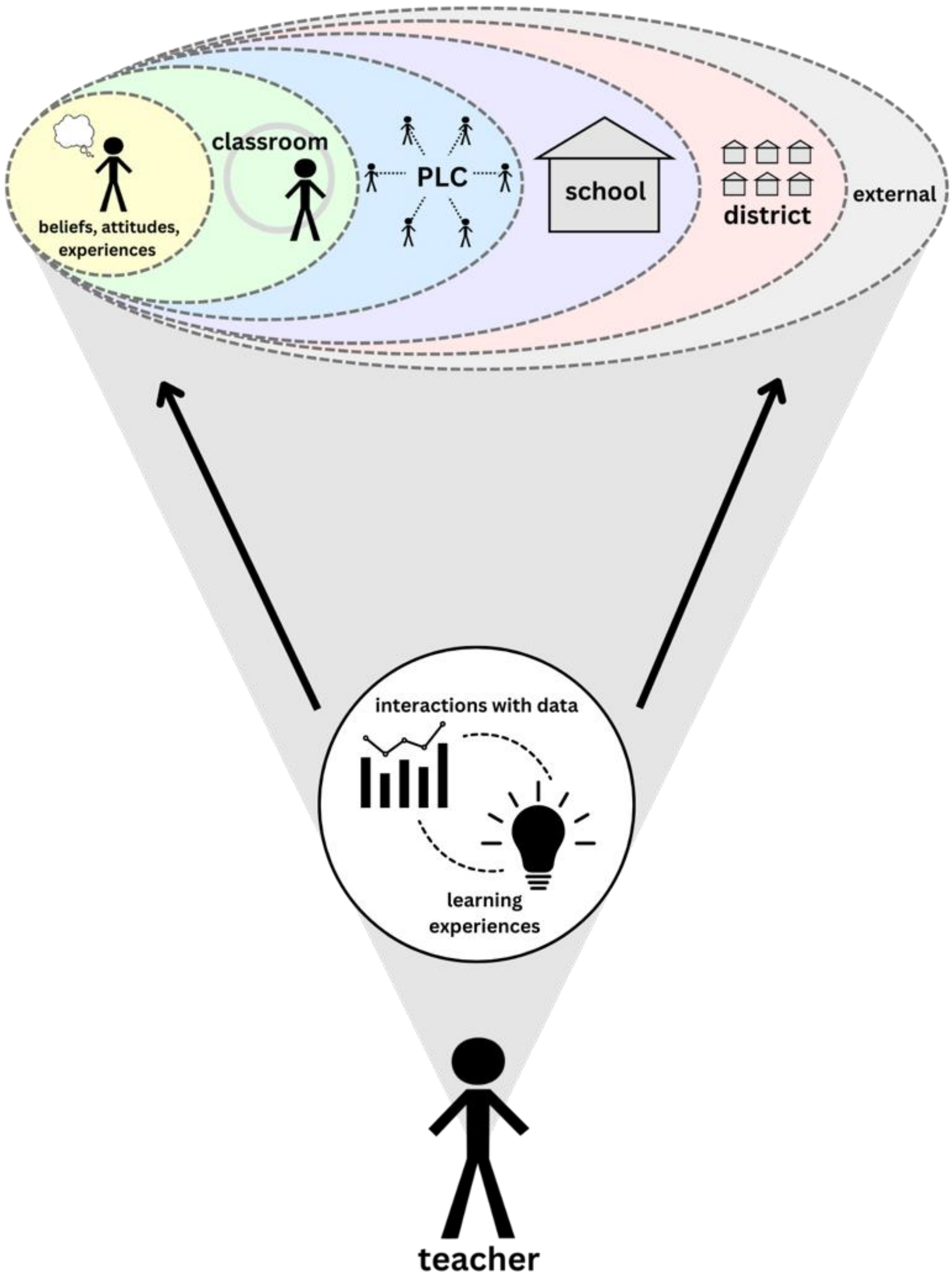
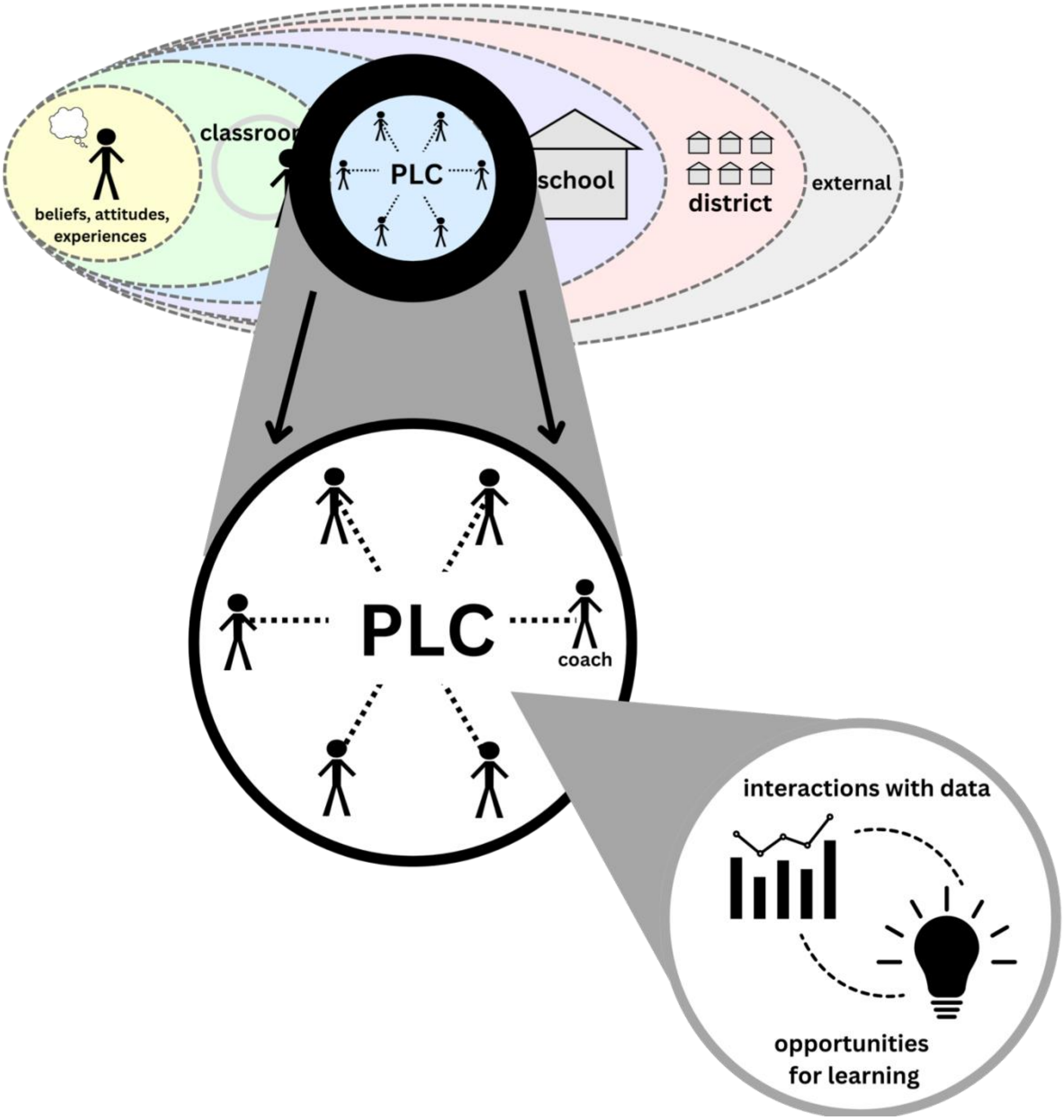


Figure 2.4

Visualization of Study #2: Zooming In on Interactions with Data in PLCs



Research Questions

Through a broad, systemic lens, Study #1 addressed teachers' learning experiences with data use in elementary mathematics. This study was guided by the following research question: In one school, how do elementary teachers' learning experiences, in relation to mathematics teaching and learning, take shape through interactions with data in a complex learning system?

Study #2 used a narrow focus to examine teachers' experiences with data use in elementary mathematics PLCs. This study was guided by the following research questions:

1) In what activities do teachers engage during elementary mathematics PLC meetings?
2) In elementary mathematics PLCs, (a) for how much time and (b) during what activities do teachers engage with student data?
3) In elementary mathematics PLCs, what are the characteristics of teachers' interactions with student data, including their attention to student mathematical thinking?
4) In elementary mathematics PLCs, what are the characteristics of rich opportunities for learning around student data?

Positionality Statement

It is essential for qualitative researchers to be aware of and disclose their positionality with respect to the study at hand (Creswell & Poth, 2016). For this reason, I have included a positionality statement for Study #1 in Chapter 3 and for Study #2 in Chapter 4. Here, I share information about my positionality with respect to the dissertation as a whole.

My inspiration for engaging in this research stemmed from my own experiences as a teacher and teacher educator. Engaging with teachers and witnessing their learning (or lack thereof) sparked a desire to research teacher learning around elementary mathematics, particularly within the context of a school system. I have a passion for supporting the work and improvement of public schools, in part because of my experiences as a public-school teacher. I have been previously employed in this school district as a classroom teacher and part-time mathematics coach. This positionality brought both benefits and challenges to the research. It is possible that participants were not fully transparent in their interview responses or behaved differently during observations because of my previous roles in the district. However, my pre-existing relationships with the school system also built trust with the participants (i.e., not an outsider). I have shared similar experiences and worked in similar contexts as many of the participants. Conducting research in this district allowed me to bring an insider perspective to the work and to have a more accurate and robust understanding of the participants' experiences. Finally, my role in the district also offered me access to teachers and staff at a time in which many districts were stretched thin for resources (i.e., dealing with implications of the COVID-19 pandemic) and might otherwise be unwilling to participate.

Summary of the Chapter

This chapter first described the theoretical underpinnings of my research: the application of complexity theories and socioconstructivism for teacher learning. Next, the chapter presented an approach to educational research, namely the complementary perspectives of macro-system and microprocess studies. The chapter then provided an overview of the literature around teachers' interactions with data and teacher learning in PLCs. The chapter concluded with a conceptual framework, research questions for the dissertation, and a positionality statement.

CHAPTER 3: STUDY #1

Zooming Out: The Complexity of Teachers' Experiences with Learning through Data Use

Data-based decision making (DBDM) has gained popularity in educational spheres over the past decades (Barnes et al., 2022). This model, based on practices from industry and manufacturing, suggests that collecting and analyzing data leads to clear, objective decisions that improve the efficiency of operations in an organization (Marsh et al., 2006). Educational proponents of DBDM argue this model leads to increased student outcomes, but despite the longevity of the practice, DBDM has not produced the tremendous gains that it promised (Coburn & Turner, 2011; Marsh et al., 2006). Research suggests several factors, two of which are most relevant to this study and described here, may contribute to this phenomenon. One, developing the skills to analyze and utilize student data meaningfully and equitably is a complex process, one that requires learning over time (Cosner, 2011; Ikemoto & Marsh, 2007). Time for learning is often not afforded to educators who are asked to implement DBDM. Two, misalignment in the goals and expectations of DBDM is common in the field of education (Mandinach & Schildkamp, 2021b). Differences in goals of data use (e.g., accountability, continuous improvement) and definitions of data (e.g., test scores, student work samples) could contribute to lack of clarity, skepticism, and poor implementation of data use practices. There is a need to better understand teachers' experiences of data use, particularly their learning experiences, while also considering the impact of broader expectations for data use. The purpose of this study was to examine teachers' learning experiences with data in elementary mathematics, from a lens of complexity and in the context of the broader educational system. As a phenomenological study, the focus was on teachers' perspectives on their own learning;

therefore, a learning experience was defined as a teacher's description of or reference to the acquisition of new information, knowledge, or skills.

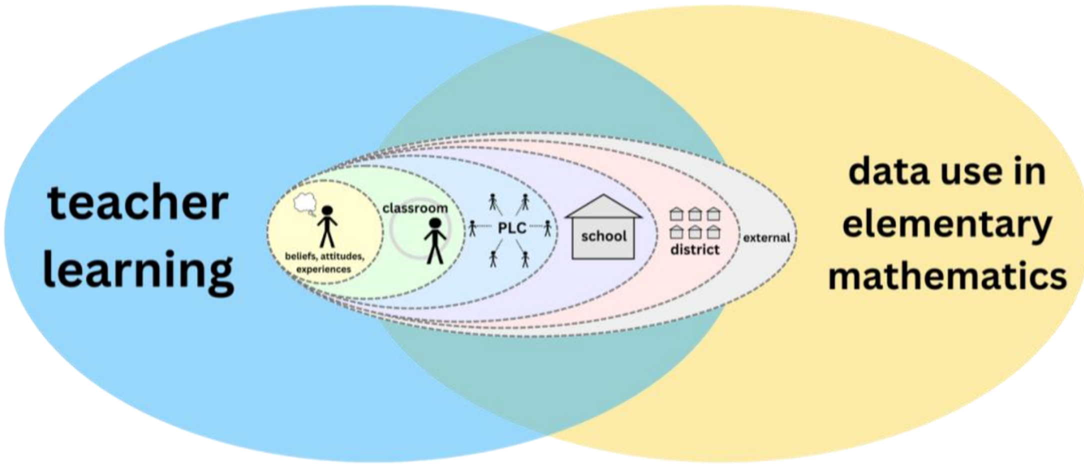
Literature Review

Complexity Theories

Complexity theories have provided a valuable tool for examining complex phenomena in education, including teacher learning (Ell et al., 2019; McKie et al., 2023; Strom & Viesca, 2021). Complexity proposes that systems are dynamic, evolving networks composed of multiple levels that interact across the system (Poth & Bullock, 2023). Complexity acknowledges the "nestedness" of these levels (Cochran-Smith et al., 2014, Davis & Sumara, 2006), each operating as its own system within the larger ecosystem of the educational community. Complexity provides a framework for examining the interconnectedness of multiple nested components that can interact in influential and unpredictable ways (Poth & Bullock, 2023). Both teacher learning and data use exist within a complex educational system (Figure 3.1), and a complex systems approach explicitly identifies and examines interactions across these nested levels. In addition to nestedness, complex systems are characterized by adaptation, self-organization, and emergence (Cochran-Smith et al., 2014, Davis & Sumara, 2006). Complex systems are not controlled by one entity; rather, they continuously organize and adapt in unpredictable and non-linear ways, allowing for the potential of new, "emerging phenomena" to develop in the process (Mason, 2008; Strom & Viesca, 2021). Adopting a complex approach to studying teacher learning focuses on the emergence of learning through these dynamic interactions (Ell et al., 2019; McKie et al., 2023; Strom & Viesca, 2021).

Figure 3.1

Visual Representation of Nestedness within a Complex System



While nestedness, adaptation, self-organization, and emergence have been identified as key characteristics of complex systems, scholars have also investigated conditions of the system that allow for emergence (Cochran-Smith et al., 2014; Davis & Simmt, 2003). Davis and Sumara (2006) point to three pairs of conditions that operate in tension within complex systems (specialization, trans-level learning, enabling constraints). Specialization describes the degree to which individuals' beliefs, feelings, motivations, and backgrounds are similar to (internal redundancy) or different from one another (internal diversity) (Davis & Sumara, 2006). A system displays trans-level learning when it is not solely controlled by a central authority (decentralized control), and individuals have agency to engage with and "bump against" other people, ideas, representations, and resources (neighbor interactions) (Davis & Sumara, 2006, p. 143). Finally, enabling constraints point to the tension between alignment within a system, especially around goals or mandates (coherence), and disparate ideas or unexpected disruptions that may surface (randomness) (Davis & Sumara, 2006).

Recent scholarship has also acknowledged the complexity of data use in schools, emphasizing that DBDM is "a complex system of interacting components" (Mandinach &

Schildkamp, 2021a, p. 1). Like teacher learning, data use "operates at multiple levels of the classroom, school and district and is influenced by the perspectives of multiple groups of stakeholders" (Gummer, 2021, p. 5). As a result, scholars have advocated for a systems-level view of data use in education (Coburn and Turner, 2012; Gummer, 2021; Mandinach & Schildkamp, 2021a). This study attended to the intersection of teacher learning and data use (Figure 3.1), using complexity as a lens to investigate how learning did or did not emerge through data use and to examine potential influences across nested levels of the system. The following sections describe what is known about teachers' use of data and learning experiences and note how teachers' interactions with data may be influenced by these nested levels.

Data Use Among Teachers

How Teachers Define Data. Teachers tend to define data in multiple ways. One type of data teachers use on a regular basis is information about student learning progress. Teachers may collect data about student learning with classroom assessments, such as quizzes and tests, or through external assessments, such as state standardized assessments (Sun et al., 2016). While many forms of assessments can provide information about student learning, teachers tend to value accessible, current data sources (Datnow et al., 2021; Marsh et al., 2006). Teachers also gather data about student learning through their daily interactions with students (Schildkamp, 2019; Witte et al., 2023). Observational data is sometimes considered an informal data source in the literature, but it is typically valued by teachers (Barnes et al., 2022; Schildkamp, 2019). Beyond student learning data, teachers may interact with other sources of information about students, such as behavioral data, attendance data, or demographic data (Sun et al., 2016).

How Teachers Analyze Data. As they analyze data, teachers often consider multiple types of data and multiple data points simultaneously (Honig & Venkateswaran, 2012; Ikemoto

& Marsh, 2007; Schildkamp, 2019). Teachers believe their interpretations are stronger and more accurate if they look at multiple forms of data instead of one data point in isolation (Honig & Venkateswaran, 2012). To analyze student learning data, teachers often attend to student scores, assessment questions, and skills. Teachers may compare students' overall scores to a set standard of proficiency, sometimes grouping students into "levels" based on their scores (e.g., "high", "average", "low") (Datnow et al., 2018). Other times, teachers may look at specific assessment items to consider students' performance of specific skills (Cosner, 2011; Horn et al., 2015). This may include examining and unpacking frequently missed questions. Throughout this process, teachers constantly make interpretations and attributions about student learning (Bertrand & Marsh, 2015; Horn et al., 2015; Oláh et al., 2010). Bertrand and Marsh (2015) found that teachers attributed student performance to four factors – instruction, student understanding, test wording, student characteristics – and highlighted the problematic nature of focusing on student characteristics. Attributions that focused on instruction or student understanding represented areas that were possible to change and that teachers had some agency over. However, when teachers attributed data results to student characteristics (e.g., students in special education, English language learners, unmotivated students), it was typically in a way that implied they as teachers had no control over the situation, therefore placing blame on students rather than their own teaching practices. These differences in interpretation have implications for how teachers respond to and utilize data.

How Teachers Respond to Data. The literature presents mixed findings about teachers' responses to data. Some sources say that utilizing data is the most complex phase of data use, and it can be both difficult and rare for teachers to implement a plan in response to student data (Datnow & Hubbard, 2015; Marsh et al., 2015). For example, Means et al. (2009) found that teachers often feel the pressure to just "move on" after analyzing data because of time constraints, curriculum pacing, and uncertainty about the best instructional response. Other sources suggest that teachers are constantly responding to student data; it just may not be in response to thoroughly analyzed data (Jimerson et al., 2021). When teachers do respond to student learning data, they often make changes to their future instruction. These changes might include adjusting the format (e.g., small groups, stations) (Van Lare, 2016), pacing (Jennings & Jennings, 2020), or content focus (Horn et al., 2015) of instruction. Another typical response involves identifying students to receive targeted instruction (Horn et al., 2015; Oláh et al., 2010). Teachers also make meaningful changes to instruction by critiquing the efficacy of their past instruction, although this may be a less common response (Cosner, 2011; Sun et al., 2016). Critiquing past instruction may lead teachers to borrow more effective strategies from colleagues (Van Lare, 2016) or meaningfully alter their teaching methods (e.g., incorporate visuals and manipulatives) to support identified student needs (Oláh et al., 2010).

Teachers' Learning Experiences with Data. Research suggests that teachers can experience learning when interacting with data (Datnow et al., 2021; Schildkamp et al., 2016; Supovitz & Sirinaides, 2018). Several studies point to learning experiences that increase data literacy skills, such as using data to address an identified problem (Ebbeler et al., 2017; Kippers et al., 2018; Schildkamp et al., 2016). Horn et al. (2015) found that, through interactions with data, teachers developed conceptual resources for teaching and noted connections to their future work. Supovitz and Sirinaides (2018) investigated teachers' perspectives on their own learning, and teachers reported learning experiences related to student thinking and to mathematics instruction. Most studies investigating teacher learning through interactions with data take place in the context of professional development interventions, and few studies (e.g., Horn et al., 2015) consider learning experiences that occur naturally in educational settings.

Influence of Teachers' Beliefs, Attitudes, and Experiences with Data Use

Individual factors play a key role in teachers' experiences with data; beliefs, knowledge, motivations, feelings, and past experiences with data can all influence how teachers interact with and learn from data (Coburn & Turner, 2011; Ikemoto & Marsh, 2007). The existing research suggests that teachers' beliefs, attitudes, and feelings towards data are quite varied. In their study, Schelling and Rubenstein (2021) found that teachers acknowledged the benefits and utility of using data to understand and respond to their students' needs. However, many of those teachers simultaneously experienced negative emotions around data use. Teachers' beliefs about their autonomy and capacity for data use seem to be mixed (Datnow & Hubbard, 2015; Schelling & Rubenstein, 2021). Research suggests that teachers may feel unprepared to analyze and use data, a reality which may contribute to negative feelings towards data and fewer learning experiences (Dunn et al., 2013). However, research suggests that teachers' feelings towards data use can change, as in the case of professional learning opportunities that improve teachers' perceptions of data while also building their capacity for data use (Ebbeler et al., 2017; Kippers et al., 2018).

Influence of Professional Learning Communities on Teacher Data Use

In many cases, teachers engage with data in collaborative spaces such as professional learning communities (PLCs). These communities often provide support for teachers as they work with data and can influence their interactions with data (Sun et al., 2016; Datnow & Hubbard, 2015). Collaborative groups can support data analysis through practices such as collaborative grading or analyzing student work samples (Cosner, 2011; Kazemi & Franke, 2004). PLCs may provide space for teachers to discuss differing interpretations of data during the analysis process (Coburn et al., 2009a). Teachers also work together in learning communities to develop responses to data. Within these groups, teachers can share a range of instructional ideas (Marsh et al., 2015) and develop plans for future instruction (Cosner, 2011; Horn et al., 2015; Young, 2006). While learning communities have become a popular space for data use, the quality of interactions with data seem to vary across groups (Datnow & Hubbard, 2015; Schildkamp & Datnow, 2022). For instance, Young (2006) found that discussion among colleagues in one PLC focused on sharing anecdotes and remained relatively superficial, while another PLC dove deep into analysis of student work, noticing trends across students in multiple classes. In the second case, collaboration allowed teachers to gain insight from one another and generalize across the grade level, making the data analysis stronger. Several factors, including teacher expertise (Datnow & Hubbard, 2015) and conversation routines (Horn & Little, 2010), may influence the quality and effectiveness of data use in these collaborative spaces.

Influence of School Factors on Teacher Data Use

Research shows that school level factors, particularly principals, play a large role in shaping teachers' beliefs, practices, and learning experiences around data use. Principals' personal beliefs and skills around data can impact teachers' experiences, and authentic collaboration with administrators can provide support for teachers as they work together to understand and learn from the data (Barnes et al., 2022; Cosner, 2011; Datnow & Hubbard, 2015). Principals also influence the resources available (e.g., time to engage with data, access to data and technology), the support for learning, and the culture of data use in a school (Datnow & Hubbard, 2015; Schildkamp & Datnow, 2022; Sun et al., 2016). Trusting, collaborative, improvement-oriented environments can provide support for data use, but school cultures that over-emphasize accountability or rigid processes may negatively impact teachers' experiences with data (Abrams et al., 2021; Barnes et al., 2022; Jimerson et al., 2021; Schildkamp & Datnow, 2022). Finally, principals can act as mediators, mitigating the effects and pressures of external influences on teachers' experiences of data use (Lasater et al., 2021).

Influence of Broader Contextual Factors on Teacher Data Use

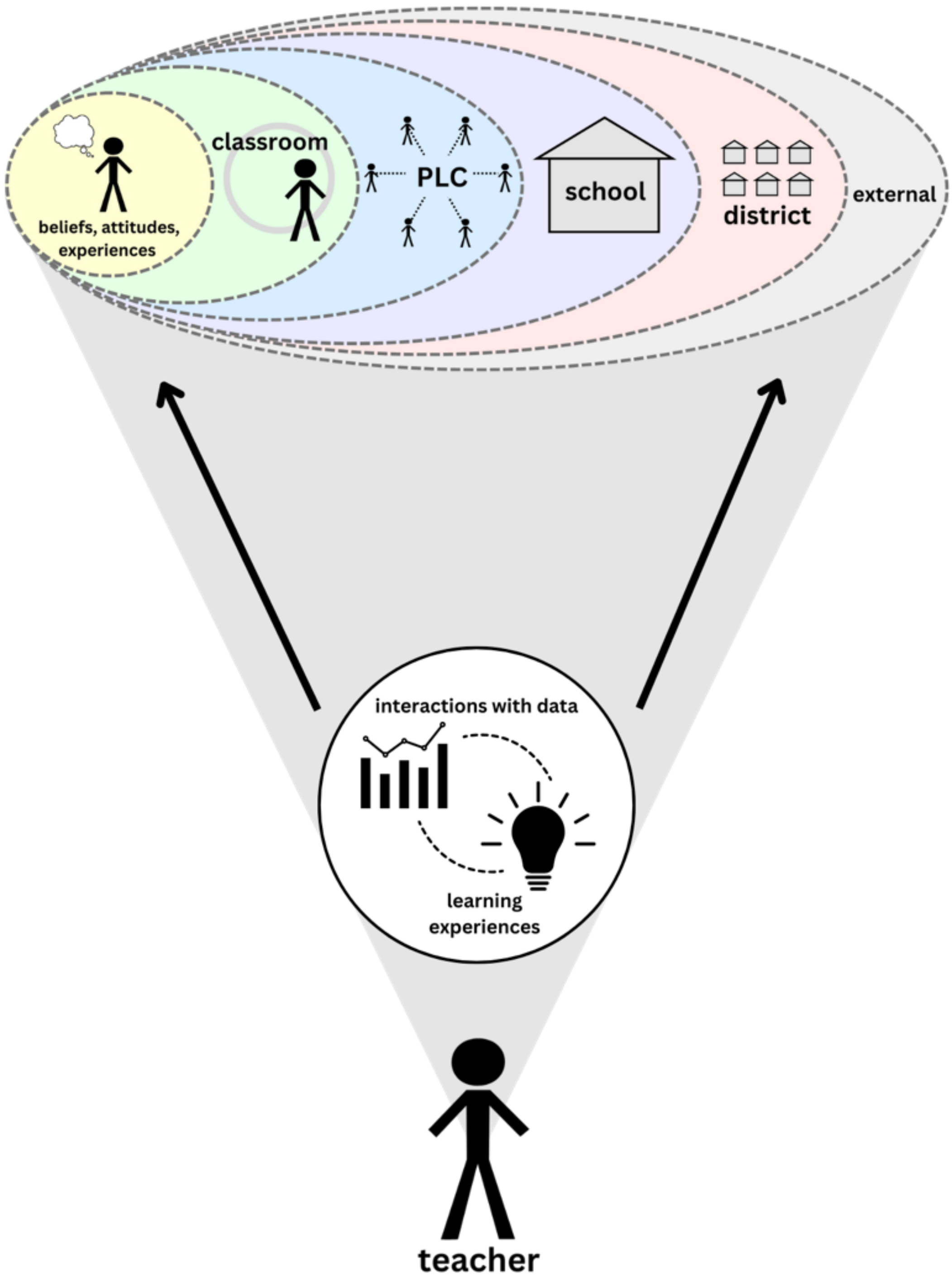
Beyond the school, a range of broader contextual factors impact teachers' learning experiences with data. As with schools, the culture and expectations around data use at the district level can support or hinder the experiences of teachers and principals (Schelling & Rubenstein, 2021). Districts often set the goals and vision for data use, "framing the purpose of data use and setting the direction for data use practices" (Datnow & Hubbard, 2015, p. 17). Numerous studies reference the influence of district, state, and federal policy on teachers' experiences with data (Barnes et al., 2022; Datnow & Hubbard, 2015; Schelling & Rubenstein, 2021; Schildkamp & Datnow, 2022). The pressure of high-stakes accountability policies has a strong impact on data use practices in schools (Datnow & Hubbard, 2015; Gummer, 2021; Schildkamp & Datnow, 2022). Additional factors influencing teachers' experiences with data include parents (Schelling & Rubenstein, 2021), local, state, and national contexts (Jimerson et al., 2021), and societal expectations (e.g., defining proficiency) (Datnow & Hubbard, 2015).

Conceptual Framework

This current study investigated teachers' learning experiences with data use in the context of one elementary school. According to Gummer (2021), "A simple model of teacher inquiry… data collection and interpretation, [and] actions taken based on that interpretation… does not work if we do not take these system issues into account" (p. 4). With this perspective in mind, this research incorporated complexity theory and situated teachers' learning experiences through data use within multiple levels of the educational system. Figure 3.2 presents the conceptual framework for this study.

Figure 3.2

Conceptual Framework for Study #1



This research focused on the experiences of teachers, illustrated by the teacher icon at the bottom of the image. The phenomenon being investigated, teachers' learning experiences through interactions with data, is represented by the circle in the middle of the image. Teachers' learning experiences through interactions with data was defined in two parts. First, through the process of interacting with data (e.g., looking at data, analyzing data, planning responses to data), teachers may develop skills or acquire knowledge about *how to engage with data*, such as data literacy skills. Second, engaging with data may lead to learning *from the data itself*. This could include acquiring information, knowledge, or skills related to the work of teaching and learning mathematics (e.g., learning about students, mathematical content, instructional practices).

From the perspective of the teacher, this study "zooms out" to consider teachers' learning experiences through interactions with data, as well as potential influences on those experiences. The ovals at the top of the image represent some of the nested levels of the educational system which may interact with the phenomenon. The ovals are overlapping, separated by dotted lines. These features are used to imply that these levels are nested with boundaries that are fluid, not rigid. These nested levels are constantly overlapping, interacting, and evolving, and both teachers' learning experiences and their use of data are deeply entwined within and impacted by interactions across nested levels. Note that this representation is limited to a static, two-dimensional illustration, and a more authentic visualization of this system would involve evolving and dynamic elements (McKie et al., 2023).

Research Question

The purpose of this study was to investigate teachers' learning experiences with data use in elementary mathematics in one school. The research question guiding this study was: In one school, how do elementary teachers' learning experiences, in relation to mathematics teaching and learning, take shape through interactions with data in a complex learning system?

Methods

Study Design

This study was conducted as a post-intentional phenomenological study (Vagle, 2018). The phenomenological approach explores the lived experiences of individuals who have all encountered a common phenomenon with the goal of describing the essence of the phenomenon (Creswell & Poth, 2016). Post-intentional phenomenology broadens the traditional phenomenological approach in ways that align with several principles of complexity. First, rather than viewing phenomena as static, post-intentional phenomenology investigates "how phenomena are always appearing and disappearing, and thus partial, multiple, and always in the process of becoming" (Soule & Freeman, 2019, p. 858). This perspective acknowledges the evolving nature of phenomena and attends to emerging aspects. Second, post-intentional phenomenology emphasizes the social relationships and factors embedded in experiences of a phenomenon. As Vagle (2018) explains,

> *"The phenomenon… is not only seen as something an individual experiences, but also as a social apparatus. That is, the post-intentional phenomenon is produced and produces, is provoked and provokes — through social relations in the world." (p. 140)*

Along this same vein, the context of a phenomenon plays an active role in post-intentional phenomenology. A phenomenon is not simply situated in its context; it is actively "shaped, produced, and provoked by context" (Vagle, 2018, p. 145). Complexity theories align with this perspective, acknowledging that complex systems often operate as an ecosystem of dynamic, interconnected interactions (Poth & Bullock, 2023). Finally, the post-intentional approach encourages researchers to integrate other theories within the phenomenological investigation.

Embedding complexity into the phenomenological approach provided space to investigate the many layers, complexities, and nuances of teachers' learning experiences through data use.

Context and Participants

This research took place at Pinecone Elementary School (all names are pseudonyms), a racially diverse, rural elementary school in the southeastern U.S. The school receives Title 1 funding, serves many multilingual learners, and hosts a Spanish dual language program. Several teachers at the school are native Spanish speakers who recently moved to the U.S. to teach at this elementary school. Pinecone Elementary is in a small school district of about 7,000 students across 13 schools, including seven elementary schools in rural and suburban areas.

Acknowledging the complexity of the system, participants were selected to offer multiple perspectives on the phenomenon and represent varying roles within or connected to the school (i.e., school-level, district-level roles) (Ell et al., 2019). At Pinecone Elementary, the principal and one of the two mathematics coaches (Coach Sam) agreed to participate in this research. Two of the grade-level teams that worked with Coach Sam were recruited, one upper grades team and one lower grades team, and seven of the ten teachers agreed to participate in this research. The decision to include a team from the two grade bands (K-2 and 3-5) was intentional to better understand data use in grade levels that do or do not have state-mandated, high-stakes standardized testing. At the district level, two district staff were recruited based on their involvement in and oversight of elementary mathematics at the district level. Participant demographics are presented in Table 3.1.

Table 3.1

Participant Demographics

Pseudonym	*Position*	*Years in PLC*	*Years in Education*
Carmen	2nd grade lead teacher	18	10+
Charlie	2nd grade teacher	2	BT (< 3)
Marybelle	2nd grade teacher	0	5-9
Blake	4th grade lead teacher	4	10+
Riley	4th grade teacher	2	BT (< 3)
Carlos	4th grade teacher	1	10+
Drew	4th grade teacher	0	10+
Pseudonym	*Position*	*Years in Current Role*	*Years in Education*
Coach Sam	Mathematics coach	8	10+
Principal Emory	Principal	2	10+
Jamie	District mathematics leader	8	10+
Carter	District curriculum and instruction leader	4	10+

Data Collection

Based on phenomenological methodology, the primary data source for this study was participant interviews. Initial semi-structured interviews with teachers, the mathematics coach, and the principal were conducted over Zoom between August and November 2023. The interviews were audio- and video-recorded and transcribed. During the interviews, participants described their experiences of data use, mathematics instruction, and professional learning at Pinecone Elementary. Interview protocols are provided in Appendix A. Follow-up interviews were conducted with the teachers and the mathematics coach over Zoom or in person between August and November 2023. In addition, semi-structured interviews were conducted over Zoom with two district staff members between July and October 2022. Because these interviews were conducted the year prior, a follow-up interview (district mathematics leader, December 2023) and an email exchange (district curriculum and instruction leader, March 2024) were used to ask additional questions and member check information from the earlier interviews. Throughout the interview process, memoing was used to document thoughts and reactions.

In line with post-intentional phenomenology (Vagle, 2018) and complexity theory (Ell et al., 2019; Poth & Bullock, 2023), additional data sources emerged during this research. Copies of documents mentioned by participants during their interviews were collected, as well as public documents relevant to data use on the school and district websites. During the interviews, some participants shared copies of student data or demonstrated their process for analyzing student work samples. Videos and photographs of these artifacts were collected. In addition, observations of 17 mathematics PLC meetings and one district professional development session were conducted over eight weeks between August and November 2023. Field notes were taken in each of these meetings, and eleven of the mathematics PLC meetings were audio- and video-recorded. Additional memos were taken during this process and were included as secondary data sources. A list of the primary and secondary data sources is provided in Table 3.2.

Table 3.2

List of Data Sources

Primary Data Source
Interviews
7 teacher participants, Pinecone Elementary
1 mathematics coach, Pinecone Elementary
1 principal, Pinecone Elementary
2 district staff, Garden County Schools
Secondary Data Sources
Artifacts
School documents
District documents
Student work samples
Observations and field notes
17 PLC meetings, Pinecone Elementary
1 district professional development session, Garden County Schools
Memos

Data Analysis

Before engaging with data from the participants, a post-reflexion plan was created. According to Vagle (2018):

> *Post-reflexing is not about setting aside our prior knowledge, assumptions, and beliefs about the phenomenon, but about exploring how they play a part in producing the phenomenon. It asks the post-intentional phenomenologist to try to see what frames their seeing – to try to locate and name their assumptions of what is normal and what surprises them. (p. 153)*

This post-reflexion plan began with writing a post-reflexive statement. Similar to a positionality statement, this text provided a space to document the researcher's own experiences and assumptions around data use in elementary mathematics. A portion of this post-reflexive statement is included at the conclusion of the methods section. Throughout the analysis process, thematic and methodological post-reflexive memos were written (Benade, 2016; Vagle, 2018). Thematic memos were used to engage in conversation with the data, noting thoughts, patterns, and outliers as well as exposing and interrogating the researcher's biases. Methodological memos were used to reflect on and document the analysis process. Example memos are included in Appendix B.

To capture the essence of participants' experiences, a thorough review of the data was conducted and broader themes emerged throughout the analysis. Following the phenomenological method presented by Vagle (2018), data analysis proceeded in a whole-part-whole process (Table 3.3). This whole-part-whole approach referred to transcripts as well as participant groups. This meant that a transcript could be read as a whole and dissected into meaningful parts; it also meant that a new whole could be created as data across teacher participants were recombined to form a new whole. Post-reflexive memos were used to support reflection on emerging themes and analysis processes.

Table 3.3

Data Analysis Process: Whole-Part-Whole

Round 1		*Round 2*		*Round 3*		
Individual participant		Individual teacher participant		Across teacher participants		
Phase 1A	*Phase 1B*	*Phase 2A*	*Phase 2B*	*Phase 3A*	*Phase 3B*	*Phase 3C*
Whole	Part	Whole	Part	Whole	Part	Whole
Holistic reading of transcript	Include all parts relevant to data use	1st line-by-line reading of transcript with notes	Group notes into clusters based on level	Holistic reading of notes for one level	Identify themes across notes	Compile themes into table
Repeated for all participants		Repeated for each teacher participant		Repeated for each level		

Round 4			*Round 5*		
Across administrator participants			Across teacher participants		
Phase 4A	*Phase 4B*	*Phase 4C*	*Phase 5A*	*Phase 5B*	
Whole	Part	Whole	Whole	Part	Whole
Line-by-line reading of transcript with notes	Compare notes from administrator participants to themes	Add notes and new themes to table	2nd reading of transcript with notes	Compile significant statements into new documents	Adjust and collapse themes across participants
Repeated for each administrator participant			Repeated for each teacher participant		

Prior to analysis, data reduction was used to identify parts of a participant's interviews relevant to the research question. All interview questions involving data use were included (see Appendix A for interview protocols). Search terms were used to identify additional sections of the interview related to data use. The initial list of search terms included relevant terms from the literature and specific terms relevant to this district and school, and the list was updated to include relevant terms that emerged from the interviews. The final list of search terms can be found in Table 3.4.

Table 3.4

Search Terms for Data Reduction

General data use terms	*District- and school-specific terms*
Data*	MTSS
Intervention	Tier
Test	Core*
Assess*	Progress*
Protocol	Exit ticket
Evidence	AIMSweb
Benchmark	EOG
Trend	Check*
Need	WIN
	Kid Talk
	Proficien*
	Group*

* Searches for terms labeled with an asterisk included additional word parts or related terms. For example, a search for "assess" included terms such as "assessment" and "assessing". A search for "core" included terms such as "score", and a search for "check" included terms such as "checkpoint" and "check-in".

Following data reduction, each participant's interview was read in its entirety to understand it in a broad sense (*Phase 1A*, Table 3.3). Next, all interview text relevant to the research question was copied to a separate document (*Phase 1B*, Table 3.3). If interview text identified by the search terms did not relate to the research question, the text was eliminated.

The second round of analysis began with a line-by-line reading of the interview transcript for each teacher participant (*Phase 2A*, Table 3.3). Initial descriptive codes, notes, and important quotes were recorded in the transcript margins. The system "level" that a participant was referencing (e.g., individual, classroom, PLC, school, etc.) was noted for each interview response. These codes, notes, and quotes were copied to a new document and reorganized by level so sections referencing the same level were in conversation with one another (*Phase 2B*, Table 3.3).

The third round of analysis examined data across teacher participants. First, data for each level was combined across teacher participants. In other words, the codes, notes, and quotes referencing PLC interactions across all participants were combined in one document. Next, the document was read holistically (*Phase 3A*, Table 3.3), allowing initial themes to emerge across participants (*Phase 3B*, Table 3.3). These themes were compiled into a separate table to illustrate patterns and trends within and across interviews (*Phase 3C*, Table 3.3). This process was repeated for each level of the system (e.g., individual, classroom, PLC, school, etc.).

In Round 4, the interview transcripts for administrator participants were read line-by-line, and codes, notes, and quotes were recorded in the margins (*Phase 4A*, Table 3.3). These descriptive notes were compared to the themes identified previously across teacher participants (*Phase 4B*, Table 3.3). Notes were added to the thematic table to indicate where themes overlapped or manifested differently among administrator participants, and additional themes were included as needed (*Phase 4C*, Table 3.3).

Round 5 began with a second pass through the teacher participant interview transcripts (*Phase 5A*, Table 3.3). “Significant statements” or quotes were identified to characterize themes across participant’s experiences (Creswell & Poth, 2016). These significant statements were copied into new documents and combined across teacher participants for each level (*Phase 5B*, Table 3.3). Memos were recorded, and themes were adjusted and collapsed across participants (*Phase 5C*, Table 3.3).

Additional rounds of data analysis attended to the characteristics and conditions of complex systems (e.g., neighbor interactions, emergence, nestedness) referenced directly or indirectly in participants’ interviews. A priori codes from the literature (Davis & Sumara, 2006; McKie, 2003) were used to code the significant statements in which teachers referenced experiencing or not experiencing learning (Appendix C). Memos were written to note ways these codes surfaced directly or indirectly across the interviews. Memoing was also used to analyze the thematic table, attending to how the characteristics and conditions of complex systems (Appendix C) emerged broadly across all the interviews. Finally, documents, observations, memos, and field notes were examined as secondary data sources. These artifacts were analyzed alongside the emerging themes to support or contradict themes and to offer insight into influences on teachers' experiences.

Trustworthiness

In this study, validity and reliability was established by adhering to the data collection and analysis procedures recommended for post-intentional phenomenological studies. Each of the five components of post-intentional phenomenology described by Vagle (2018; 2019) were applied to this research. This included collecting multiple data sources in a "clear, yet flexible process" and analyzing the data in a "systematic, responsive manner" (Benade, 2016, p. 134). Post-reflexive practices (Vagle, 2018) were incorporated throughout the research process, such as continuously collecting post-reflexive memos and interrogating these memos during the analysis phase. A post-reflexive statement was written to document and explore the researcher's own experiences and biases with the phenomenon, and parts of this statement are included in the following section.

Post-Reflexive Statement

In qualitative research, a researcher's approach to addressing their positionality is guided by the study's methodology (Creswell & Poth, 2016). For post-intentional phenomenology, this begins with a post-reflexive statement, "akin to a subjectivity statement in which the researcher's role, beliefs and perspectives are described, particularly in relation to the phenomenon" (Benade, 2016; p. 139). The researcher revisits the post-reflexive statement throughout the research process to reflect on and add to this statement (Vagle, 2018). A subset of my post-reflexive statement is shared here.

As a former elementary teacher and current researcher and mathematics teacher educator, I bring to this research a background and experiences directly tied to teacher learning and data use in elementary mathematics. During my time as an elementary mathematics teacher, I found data use essential to understanding student thinking and to informing my instruction. It is through the process of analyzing this data that teachers acquire the necessary information about student strengths that can be used to respond to their thinking. While I recognize the power of data for supporting student learning, I am also skeptical of an overreliance on quantitative, learning-outcome-centric data. Such a focus can detract from other essential sources of information, such as a child's experience in the classroom, and can place a higher value on learning mathematical content than on experiencing joy, love, or belonging in the classroom.

While I have had similar experiences to the participants in this study around elementary mathematics education, I acknowledge that we do not all share the same backgrounds. I am a white female, like much of the U.S. teaching force. I am a former elementary mathematics teacher who was trained through a traditional educator preparation program. I am monolingual, and I speak English as my native language. I am also currently an education researcher and a mathematics teacher educator. These experiences have shaped my belief and worldviews in ways that may differ from the participants.

With respect to teachers and teacher learning, I believe that teachers have a wealth of knowledge and expertise around students, mathematics, and data that should be leveraged and nourished. If teachers are expected to engage with data, I believe that they deserve high-quality, job-embedded opportunities for professional learning that center data relevant to their daily work in the classroom. I also believe that teachers' perspectives on their own learning matter and should be highlighted; this was part of my motivation for conducting this research. Finally, I believe that high-quality teacher learning and data use both require a cohesive system of supports across all levels of the complex system.

Findings

Contextual Background

Before addressing the research question guiding this study, background information is shared to help the reader contextualize the educational system in which this study was situated. Attending to the nestedness of the system, this background section focuses on relevant features of the data and teacher learning system at the school, district, and state levels.

At the time of data collection, Pinecone Elementary was focused on integrating data use and small-group instruction into classroom practice. This focus had been identified by Principal Emory and the leadership team as the next step in the school's academic growth. As a result, each PLC was expected to collect common assessment data and record the results on a grade-level spreadsheet. These spreadsheets were shared schoolwide so data was accessible to all staff members. In response, all teachers reported using data and facilitating small groups in their classrooms on a regular basis. In addition to this shared focus on data, the staff at Pinecone Elementary appeared to share a broad conceptualization of data. From the teachers to the mathematics coach to the principal, individuals consistently defined data broadly and referenced a wide range of data sources (e.g., formal assessments, in-class observations) that could be used to gather information about students and their learning experiences.

Another relevant feature of the school learning system included the presence of structures to support teacher learning. These supports included PLCs, coaches, and Data Days. PLCs were organized as grade-level teams, and each grade level in the school had at least one new team member at the start of the school year. Each PLC met weekly with the mathematics coach, Coach Sam, to discuss mathematics instruction and students' progress. Both PLCs elected to meet after school for 60 minutes, as opposed to during their planning period. Coach Sam was available to support their learning outside of PLCs as well through informal check-ins or formal coaching cycles. In addition, PLCs met quarterly in day-long Data Days focused specifically on analyzing the results of external assessments (i.e., diagnostic screeners, interim assessments) for both mathematics and other subject areas. Data from academic and behavioral areas were analyzed throughout the day, with about 45 minutes allotted to discuss data in mathematics. Administrators and other specialists participated in these meetings alongside the grade-level teachers and the coaches. At the time of data collection, there were no formal professional development opportunities available at the school for teachers to learn about data.

In addition to these school-level features, there were relevant contextual features of the broader learning system. There were expectations around the collection and use of data at both the district and the state levels. These expectations included establishing a multi-tiered system of support (MTSS), which is "a school improvement framework that encompasses academic, behavioral, social, and emotional instruction and support" (NCDPI, n.d.). The MTSS framework "employs a systems approach using data-driven problem solving to maximize growth for all" (NCDPI, n.d.). As a part of this framework, teachers were expected to identify students for tiered intervention groups, deliver interventions, and monitor students' progress and growth. A universal screener (AIMSweb) was selected by the district as the assessment tool used to identify students in need of interventions and to measure their growth over time. Other data requirements included district interim assessments and statewide summative assessments in mathematics administered at the end of the year in kindergarten through fifth grade. The statewide assessments were used to measure school progress and to give each school a “school report card grade” (i.e., A, B, C, etc.) based on their students’ proficiency and growth on the end-of-year assessments.

Finally, the district had additional expectations around teacher learning. At the time of data collection, the district was in the process of rolling out an initiative to support teachers’ use of data in PLCs. This initiative involved “relaunching PLCs”, in the words of one district administrator, with a focus on measuring student progress through common formative assessments. School principals were encouraged to establish PLCs to support teacher learning at their schools. Although this PLC initiative was in the works as data was collected for this study, it did not seem to directly influence how teachers interacted with data. However, the administrators, especially the district administrators, did reference this initiative in their interviews.

The contextual information described in this section is intended to help the reader make sense of the findings presented in the following sections. Guided by the research question, this study investigated how teachers’ learning experiences take shape through interactions with data, particularly in the context of a complex system. The findings illustrate how teachers’ learning experiences take shape in relation to characteristics of the data, the nature of the interactions with data, and relevant features of the complex system (Table 3.5). These learning experiences also seemed to emerge in relation to characteristics and conditions of the complex learning system (i.e., nestedness, neighbor interactions, coherence). Findings presented in the first two sections (characteristics of data; nature of interactions with data) emerged primarily from teacher interviews and center teachers' voices and perspectives on their learning experiences. The third section (features of the complex system) incorporates the perspectives of administrators and attends to the broader context impacting teacher learning.

Table 3.5

Teachers' Learning Experiences through Interactions with Data

	No Emergence of Learning	*Emergence of Learning*
Characteristics of Data	Teachers report learning does not take place when data is difficult to interpret or not relevant to their daily work.	Teachers report having learning experiences when data is interpretable and relevant to their work as teachers.
Nature of Interactions with Data	Teachers report learning does not take place when interactions with data are superficial.	Teachers report having learning experiences through meaningful and collaborative interactions with data alongside other teachers in PLCs.
Relevant Features of the Complex System Across Nested Levels		
Coach Sam's Perspective	The mathematics coach's perspectives on the characteristics of and nature of interactions with data were similar to the teachers' perspectives.	
Focus on Data and Small Groups	The school's identified focus for the year was the use of data to inform small-group instruction.	
Conceptualization of Data	There was a broad conceptualization of data schoolwide.	
Structures for Teacher Learning	There were structures established at the school (PLCs, mathematics coach) to support teacher learning.	

Characteristics of Data

When teachers described their interactions with data, they reported different learning experiences depending on characteristics of the data (Table 3.5). The relevance of the data seemed to impact teachers' learning experiences. The interpretability of the data also seemed to matter; teachers noted that they had limited learning experiences when data was hard to interpret. The interpretability of the data seemed to be influenced by the format of the data and the time teachers had available to analyze the data.

Relevance of Data. As teachers described their learning experiences, the relevance of the data seemed to impact those experiences. In this context, the term "relevance" is used to describe how connected a data source was to the teachers' current work with students. Teachers mentioned the importance of having data that provided information about the mathematical content that students were learning in class. The teachers also described the importance of having data that they could clearly respond to in their classrooms.

Teachers reported fewer learning experiences when interacting with data that was disconnected from their daily work with students. If the data provided information that was not relevant to students' current learning, it was less useful for teachers at that time. In contrast, teachers were able to respond to and learn from data that was closely related to classroom instruction. One teacher offered the example of state-mandated end-of-year assessments as a data source that was not connected to her day-to-day interactions with students. She explained:

> *Those higher-stakes testing that are 50 questions long… I sometimes don't dive into that data as much as I would these checkpoints and assessments and classroom-- you know, things that are more what we're learning at the moment.*

High-stakes test results provided information about students, but the information was not as relevant as other data about student learning. This teacher relied more heavily on classroom assessments because classroom data offered information related to mathematical concepts currently being addressed in class. Because the external assessments provided less relevant information about student learning, the teacher explained that she doesn't "dive into" the high-stakes testing data frequently. Data that is less relevant to teachers is used less frequently, limiting the potential for teacher learning.

Teachers described having learning experiences when data provided relevant information about students that they could make use of in their classrooms. The teachers described learning about both students and their instruction from this data. One teacher explained how they conceptualized the differences between data sources:

> *There are different types of data. That's one thing. So the data that is closer to me and that I can understand and do something with the data, that's the data that I work with. But… when we have that data that is very specific and has different numbers, that one is challenging. And sometimes I just stop.*

For this teacher, some data sources were "closer", easier to "understand", and easier to "do something with". These data sources were more connected to the teacher's work. As a result, the teacher more frequently chose to "work with" that data and experienced learning through those interactions. By contrast, there were barriers to understanding other data sources, presumably sources that were farther removed from teachers and their classrooms. It was challenging to make sense of this data, and this teacher sometimes stopped engaging with it. As a result, there were fewer learning experiences for this teacher. It seemed obvious to this teacher that the closer, more meaningful data should be prioritized and used to support student learning, impacting the teacher's experiences of learning as a result.

Interpretability of Data. In addition to the relevance of the data, it seemed that the interpretability of the data impacted the learning experiences available to teachers. The term "interpretability" refers to the degree to which teachers can identify and make sense of useful information in the data. As the teacher mentioned in the paragraph above, some data was easy to "understand" while other data was "challenging". When data was difficult to interpret, teachers' learning experiences were limited. "What does this even mean?" was repeated across several of the interviews. When data was not clearly interpretable, any useful information about students remained locked away until teachers had tools or support to make sense of the data. This was especially true when the data was complex or unfamiliar to the teachers, as in the case of learning from external data. One teacher described the challenge of trying to learn from data that they did not understand:

> *Okay, how do I read this? Because, you know, it's overwhelming. There's so much information. And just like, "Well, what do I do with this?" is essentially what you ask. Okay, I know all this. I got all these numbers. But what does this even mean?... I think sometimes it's very fast when we talk about the data and trying to decide what next.*

There was a sense of overwhelming feelings as this teacher described having an abundance of data and just as many questions about that data. It seemed difficult and frustrating to have "all these numbers" and not know what they meant. The discussions around data and decisions about next steps also seemed to occur at a rapid pace, leaving this teacher little time to make sense of the already confusing data. For this teacher, the format of the data made it difficult to interpret and therefore challenging to learn from.

In contrast, there were other occasions where teachers did find data to be interpretable. On these occasions, teachers were able to easily see and understand the information being communicated by the data, which supported their learning. Oftentimes, the data that teachers found interpretable was collected from assessments that teachers had designed or from teachers' own interactions with students. One teacher explained that she had recently begun collecting her own data in a format that was easy to access and interpret. This experience had changed the way she related to data, making the data clearer and more useful than it was previously. She explained:

> *I have gotten a lot more comfortable with it [data] this year because of how much practice I have had now… Last year I didn't quite get like, what do you mean by collecting data?... But now, it's very clear to me… I've made my own spreadsheet, and I've made my own grade book. And it makes sense to me. So I think that's another big part… the paper that I have to collect my data actually makes sense in my eyes and in my brain. So I can look at it and see right away what I want to, what I'm looking for. So that has been a huge help this year.*

For this teacher, a key shift in her experiences involved seeing data in a format that "makes sense to me". It was not only collecting the data herself that made the difference; this teacher found it beneficial to both collect meaningful data and record it in an interpretable format. This practice supported her interactions with data and helped her grow more comfortable using data. Overall, teachers communicated that data was more meaningful and useful when it was interpretable, which supported the learning experiences available from the data.

Influences on Interpreting Data. Participants described two noteworthy influences on the interpretability of data: the visibility of student thinking in the data and the amount of time required for interpretation. These two influences surfaced across participants.

Related to the first influence, as the teachers considered the interpretability of data sources, they noted the importance of being able to "see" student thinking in the data. It seemed having information about students' thought processes was an important component of interpreting data. One teacher contrasted her experiences with mathematics and reading data to illustrate this point. She explained that reading data was "a lot more ambiguous", and it was difficult to visibly see a student's thinking when answering a reading comprehension question. She described her experiences with math data as a contrast:

> *You can see the thought process out there. In math, I think a lot of times it looks like the strategies that they're using. Well, that'll be important data, important information about the student that you can see there on the paper when they've shown their work… In math… the data feels more meaningful to me because I know how to interpret it.*

For this teacher, it was important to be able to use students' work as data to make sense of student thinking. By having more information about student thinking accessible in the data, this teacher was able to interpret mathematics data more easily, and she found more meaning in mathematics data as a result.

As another example, the teachers sometimes did not have access to assessment questions or student work when analyzing external data. In these cases, student results might be represented in the form of a holistic score or as a score for each standard assessed. Not having access to the assessment or the student work seemed to influence the degree to which teachers could analyze the students' thinking. One teacher explained the challenge of working with data from one external assessment:

> *Sometimes within that data… the question or the problem was a story problem. So you don't really know if they [the students] didn't understand the problem or they actually have a miscalculation problem, because… I don't think we have access to the problems and the answers that they gave. So it is challenging. So we just go by whatever the data is telling us.*

As this teacher described, the lack of information about the external assessment left teachers feeling limited in their ability to interpret the data themselves. In these times, teachers had to rely on interpretations provided by external organizations and "just go by whatever the data [was] telling [them]" because they did not have access to the raw data. This limited their learning experiences, especially the potential for learning about student thinking from the data.

The second noteworthy influence on interpreting data was the amount of time teachers had available. Especially when the data was already presented in an unfamiliar or confusing format, teachers were more likely to understand the data if they had time to sit with the data and make sense of it. The teachers described instances where they had time to ask for help from their PLC or from the mathematics coach because the data was hard to interpret. One teacher described this experience:

> *I think I even took one of our PLCs to be like, "I need someone to explain to me, what am I looking at here?" Because it's different than anything I had seen before… I saw the data, but I was like, "I don't know what this means!" So just having that time to sit down as a team and have them explain it to me, and have a refresher for the other people who may have used it but just reminding us where to find it and what it should look like, and things like that.*

In this example, the teacher was interpreting results from an external assessment and was unfamiliar with the data. This teacher was able to find support from the PLC because the time was available to work through the data together.

On the other hand, time constraints also limited the ways teachers interpreted data, if at all. One teacher described the experience of interacting with the results of an external assessment:

> *I see some bars and I understand, of course, that the red bar is not good. The blue bar is very good… and I understand some of the percentiles. But like there are some things that you just don't get… Sometimes I just also avoid that part of data, you know? I don't have time to really try to understand.*

In this case, it was difficult to make sense of the nuances of the data. The various graphs and percentiles communicated a vast amount of information about students, but this teacher did not have time available to understand what each part of the data meant. At times, this teacher avoided interacting with those data sources entirely, resulting in a lack of learning experiences from the data.

Nature of Interactions with Data

Teachers described many interactions with data. These interactions differed in nature, and some supported learning while others did not (Table 3.5). When asked about their learning experiences with data, the teachers overwhelmingly described interactions with other teachers in PLCs. Teachers explained that superficial interactions with data did not support their learning. In contrast, teachers described learning experiences that emerged through meaningful and collaborative interactions with data alongside other teachers in PLCs.

Superficial Interactions with Data. Teachers reported that superficial engagement with data limited their learning. The term “superficial” refers to surface-level discussions, analyses, or responses to data. When asked to describe moments that did not lead to learning, two teachers described interactions with data in PLCs that felt procedural, more like checking boxes than trying to learn from data and respond to it at a deep level. One teacher described:

> *It's a little more housekeeping stuff... [or] maintenance type of thing rather than like, “Oh, we can go into a deeper discussion about the task, or about the work, or about the students, or about the data.” ...That wasn't helping me feel more confident or better about my lessons next week.*

In this example, “housekeeping” or “maintenance” tasks are contrasted with “deeper discussions” about students, data, and instruction. The housekeeping tasks that teachers mentioned included sorting students into intervention groups and describing grade-level trends in a broad, proficient-versus-not-proficient manner. The teachers acknowledged the importance of these tasks but also explained that they did not lead to teacher learning. A second teacher explained:

> *I know it's still necessary. But it's still frustrating because you want to get to the part that affects your kids. When we're grouping kids, like these kids need to be together for this intervention or this small group, those procedural things, that feels frustrating sometimes.*

According to this teacher, some tasks were “necessary” to complete even though they did not provide the best learning experiences. By “necessary”, she may have meant that the tasks were required by the principal, the district, or the state, as in the case of grouping students for MTSS intervention groups. Both teachers also noted ways in which superficial interactions with data seemed disconnected from essential aspects of teaching. The first teacher explained that the “maintenance” tasks did not support instruction, and the second indicated that these interactions utilized data in ways that did not “affect” students. These descriptions suggested that superficial interactions with data limited meaningful connections that teachers could make with the data, thus restricting their learning.

Time also showed up as a limiting factor as teachers described superficial interactions with data. There was not always time to thoroughly unpack data in PLCs, which resulted in discussions that remained surface-level. The second teacher explained:

> *I like that we come back and talk about our data after we've given an assessment. But… I wish there was more time… to analyze the work that kids did as opposed to just the numbers.*

While this teacher appreciated interacting with data, she found it more useful to analyze student work than "just the numbers" (i.e., proficiency, student scores). Learning did not necessarily take place without engaging in deeper discussions about student mathematical thinking. However, those discussions were sometimes restricted because of time limitations in PLCs.

Meaningful Interactions with Data in PLCs. In contrast to these superficial moments, the teachers described meaningful and collaborative interactions with data in PLCs that did support their learning. The term "meaningful" describes in-depth interactions with data that served a purpose for teachers, and "collaborative" indicates that individuals were working together. Teachers described learning experiences that emerged in PLCs as they collaboratively shared, analyzed, and responded to data in meaningful ways.

When teachers described their learning experiences with data, interacting with colleagues seemed to be a key part of the experiences. Teachers almost exclusively mentioned learning experiences that involved interactions with other teachers and Coach Sam in PLCs (neighbor interactions; Davis & Sumara, 2006). One teacher indicated a preference for individual learning ("I'm the type of person that I just figure things out on my own") but also shared several examples of learning though interactions with other teachers in PLCs. Across the board, teachers expressed that working through data with colleagues helped them make sense of data and discover useful ways of responding to their students' needs. The following examples illustrate how collaboration seemed to support teacher learning through meaningful interactions with data.

Example 1: Sharing Data as a Team. When describing their experiences of learning, the teachers frequently mentioned the importance of sharing and discussing data collectively. As a team, teachers were expected to develop common assessments, establishing coherence (Davis & Sumara, 2006) and ensuring that teachers could discuss the results together. Common assessment data included exit tickets (simple formative assessments given at the end of a lesson to assess student understanding of a specific topic) and unit assessments, and this data was shared on the grade-level spreadsheet. Sharing data during a PLC meeting was a typical practice for these teachers, one they perceived to be useful. One teacher stated, "Last week, for example, we brought our assessments that we had given so that we could discuss data, which was helpful." Another teacher explained:

> *We have that spreadsheet where we input our results from checkpoints and assessments, pre-assessments, post-assessments and we discuss those… I think that that's meaningful in terms of, well, we are saying things are happening in all the classes.*

By bringing student work samples or looking at the shared spreadsheet together, teachers were able to engage in meaningful interactions with data that connected the work in their own classrooms to their work at the grade level. Having the results of common assessments accessible to everyone also created a common starting point upon which to build discussions of data.

Example 2: Analyzing Data Collectively. Sharing data in the PLC shifted data use from an individual exercise to a social one. This opening allowed learning through social interactions to emerge. Teachers typically began analyzing data from their class independently, looking through their own data prior to meeting as a PLC. In PLCs, teachers continued this analysis process by discussing and interpreting data together. This included noticing common strategies, errors, or responses across the grade level. Analyzing data collectively offered teachers the chance to learn how their students were progressing and how they were making sense of the mathematical content.

There were times when teachers evaluated student learning and scored assessments together in PLCs. When teachers shifted to grading assessments collectively in the PLC, there was the potential for learning as teachers interpreted the data in community. A teacher described this experience:

> *When we are looking at it [data] item by item on an assessment, sometimes it opens up conversations about how we're interpreting what kids understand across the grade level. Especially if one of us or multiple of us have scored an item one way or viewed it one way versus another way, like what we're seeing as students demonstrating proficiency or not proficiency or misunderstandings, or – There could be varying levels of that.*

According to this teacher, collaborative grading created moments for teachers to discuss "how we're interpreting what kids understand" about the mathematics. The teachers sometimes had differing interpretations of what constituted proficiency or partial understanding, and these interpretations impacted the resulting data. These diverse perspectives may not have been revealed if teachers were examining data independently. Once teachers noticed these differences, it sparked conversations around what it meant to demonstrate proficiency, allowing teachers to articulate and adapt their understandings in response to others' views. The conversations around proficiency helped the PLC develop an aligned vision of what mastery of a standard looked like, which likely supported teachers' mathematical knowledge for teaching (Ball et al., 2008). In this way, analyzing data collectively as a PLC seemed to support the emergence of teacher learning.

Example 3: Using Data to Support Instruction. Teachers seemed to view interactions with data as meaningful when the data was used to guide their instruction in support of student learning. Teachers reported having learning experiences as they connected data to instruction with other teachers. Several teachers explained that they frequently used data to gauge student learning and evaluate the effectiveness of their instruction. One teacher shared how the PLC asked questions about instruction based on the data:

> *We checked the data, like, are your kids getting it? Can we keep going? Or do we need to slow down?... Is it [the instruction] working? Is it not effective? How do we change it?*

This focus on how students were responding to instruction allowed teachers to critique their instruction in a safe place. It prompted discussions of best teaching practices in mathematics and provided opportunities for teachers to learn whether their instruction was working and how to make changes in response to their students' demonstrated needs.

Because the teachers were working with common assessment data, teachers often compared the results of an assessment across classes. Teachers identified trends across the grade level and noted instances where one class outperformed the others. One teacher explained:

> *Sometimes when there's something that is only happening in one class that works or is helpful, then the other teachers plus Coach Sam are going to give ideas or take strategies so you can actually help your kids.*

Another teacher shared a similar example:

> *We put them [the data] all on the same spreadsheet too to see who might be doing a better job than we are, so then we can steal something from them.*

In these cases, the differences in class performance served as a perturbation for the teachers. They wanted to know what caused the difference in students' progress. In the hopes of learning more, the teachers asked questions and "dug a little deeper to find out if instruction was different." If instruction was different in that classroom, the other teachers viewed the interaction as an opportunity to learn an instructional strategy that could potentially be more effective in their own classrooms. The teachers described these moments as experiences of learning how to adapt and improve their instruction.

As noted in the quotes above, other teachers played an important role in supporting learning as teachers determined how to respond to data. PLCs provided space for teachers to collectively discuss and share resources, suggestions, and ideas for responding to data. This was especially important for teachers who were new to the school or to teaching. A beginning teacher explained:

> *I like hearing from more experienced educators about how you fix that… What do you do when this thing is happen[ing]? What do you do in this circumstance?*

The "experienced educators" in the room offered a wealth of knowledge and experience that other teachers could draw upon and learn from. As teachers were exposed to new or challenging trends in the class data, they could rely on the diverse experiences of teachers in the PLC (internal diversity; Davis & Sumara, 2006) to inform their conversations about responding to the data. Working alongside teachers provided support for teachers as they brainstormed solutions and possible responses, allowing learning experiences to emerge in the process.

Example 4: Unpacking Student Thinking. The final example illustrates a finding not widely represented across the interviews. Almost all teachers gave examples of unpacking student thinking in the data, but only two teachers specifically described this as a learning process. These teachers communicated the importance of collectively investigating student thinking in depth. One teacher pointed to aspects of interactions with data that tended to support or hinder learning experiences in the PLC.

> *I like to know where we're all at, like, "This classroom has this many kids that are proficient in this." I like to see that bigger picture. But sometimes I'm not sure if that is helping. It's giving me a sense of… what's happening across the grade level. But from a learning perspective, I feel like I need to go a little deeper sometimes. Like looking at student work maybe, or student examples… And I know at some point you do have to be like, okay, this is what the data says, but the better learning would be to take that and peel back the layers of what's really happening there.*

This teacher described two ways of interacting with data in the PLC. Discussions around data sometimes revolved around identifying the number of students proficient at a skill in each class. In contrast, there were other times when the teachers closely examined student work, analyzing data with the goal of understanding student thinking. For this teacher, the first approach was not as effective for learning as the second. While she acknowledged that it was useful information to have “that bigger picture” of how students were doing across the grade level, there were better ways to support her learning. This teacher explained that she needed “to go a little deeper” and “peel back the layers” of the data to really understand what students were thinking and how to “move them to that next level of thinking”. Unpacking student data with other teachers provided better learning experiences.

Across these examples, teachers described meaningful, collaborative interactions that supported their learning in the context of a PLC. Having the opportunity to work alongside other teachers provided learning experiences for these teachers as engaged with data purposefully in ways that directly supported their work with students. Through these interactions, teachers learned about mathematical content, their students, and teaching practices to best support students’ mathematical development.

Relevant Features of the Complex Learning System

The characteristics of data and the nature of interactions with data seemed to influence teachers’ learning experiences, and these experiences took shape within a complex educational system. Learning experiences seemed to emerge, in part, through interactions with noteworthy features of the learning system across nested levels. While some features of the learning system were introduced earlier as part of the contextual background, this section presents findings on how those features interacted with and subsequently shaped teachers’ learning experiences (Table 3.5).

In addition to the teachers, four administrators were interviewed (mathematics coach, principal, district mathematics specialist, district director of curriculum and instruction). These administrators offered additional perspectives on teacher learning through interactions with data.

Perhaps not surprisingly, the mathematics coach shared the most thorough perspectives on teacher learning and expressed views quite similar to the teachers. The other three administrators offered perspectives that reflected their role and expertise. As such, the perspective of the mathematics coach is presented first to place it in conversation with the teachers' views. The sections that follow incorporate the views of the other administrators and expand on ways that relevant features of the complex system (Table 3.5) interacted with teachers' data use and their learning experiences with data.

Coach Sam's Perspectives on Data and Teacher Learning. Like the teachers, Coach Sam noted how the characteristics of data afforded different learning experiences for teachers. She particularly attended to the format of the data, describing how data that presented group characteristics offered little information about student thinking. Coach Sam explained:

> *So when we are looking at our check-in data, or our K-2 takes an end-of-year summative, or AIMSweb or mClass, we're not looking at individual student responses. We're looking at, "This is how many students scored in the 25th to 50th percentile," which doesn't tell us much about the student and what we need. Like, what did the student do well? Why did the student not answer these questions about subtraction? In PLCs, I feel like if we're looking at student work, the work is in front of us. It's not about who's correct or not correct. It's like, what did the student do?*

In contrasting data in the format of numerical, group reports with student work samples, Coach Sam made a few key points. One, data presented in a group format provides useful summary information about a group, but it provides little information about "individual student responses". Two, these group reports could be used to communicate grade level trends, but they could not explain a student's thought process. Three, the numerical data was useful for identifying responses as correct or incorrect but not for identifying a student's strengths and what they did well. Coach Sam explained that these characteristics of data impacted the learning experiences available to teachers. In addition, Coach Sam contrasted teachers' experiences with classroom data and external data. Coach Sam shared that external data was limited in its ability to support teacher learning:

> *I don't feel like looking at big data, like universal screeners-- we look at that too much for what it is. That doesn't lead to learning for anyone. You don't learn about students. You don't learn about math content. You don't learn about instruction.*

In her opinion, “big data” did not offer teachers’ engagement with student thinking, mathematical content, or the impact of instruction on students. She explained that, on the other hand, classroom data was going to be “more impactful” and meaningful for teachers, thus offering the potential for teacher learning.

Coach Sam also noted how aspects of teachers’ interactions with data supported or hindered their learning. Overall, Coach Sam led the PLC with an open, inviting leadership style that offered teachers agency and encouraged active participation. However, she reflected on moments when her leadership style limited the learning experiences available to teachers. For instance, she explained how there were moments when Data Days felt scripted and did not lead to learning:

> *So when I think about Data Days, they're supposed to be learning opportunities, but I think it becomes more coach-led…. In Data Days, we look at… larger data. And it's a lot of like, what do you notice? What do you wonder? Why is this happening? What do we need to do with our core? But we prepare those questions… and I knew that's what was going to come out of the data, which is taking away the opportunity for others to make that connection and that learning.*

Coach Sam noted that when the discussion in PLC was more “coach-led”, there were fewer opportunities for teacher learning. In this moment, the PLC was operating with less decentralized control, which limited the opportunities for teachers to make organic connections to the data. As a contrast, Coach Sam described how learning seemed to emerge when there were embedded opportunities to interact with other teachers and student work in PLCs:

> *In PLCs we look at student work… I think that's a learning opportunity. I think when they hear like, “Oh, my students… started their number line at zero instead of from one of the*

> *addends," and somebody else is like, "Yeah, I have a group like that." So those can be learning opportunities because we learn about math content, I think, when we're doing that with them.*

In this example, Coach Sam illustrated how neighbor interactions allowed teachers to connect their own data with data from another classroom. These interactions provided learning experiences because the teachers were able to grow in their understanding of student thinking and the mathematical content.

Conceptualizations of Data at Pinecone Elementary. An important part of teachers' experiences with data involved their definitions of data in elementary mathematics education and their beliefs about what counted as data. Across the school, there appeared to be a broad conceptualization of data. Teachers mentioned a wide range of data sources in their interviews, with a focus on data about students and their mathematical learning. As one teacher phrased it:

> *Data is information that you gather about students. It could be numerical, like based on an assessment that you give. It could be anecdotal. You know observations that you're doing. Anything that's going to inform my teaching or inform me about my students.*

Teachers often relied on assessments to provide information about student learning. These included classroom assessments (evaluations of current student learning intended for classroom use by teachers) and external assessments (district, state, or national assessments not developed by teachers). In the realm of elementary mathematics, teachers pointed to student work and student strategies as informative evidence of student thinking. Teachers used student work samples, often in the form of classwork or exit tickets, to help them understand student thinking. As they analyzed these data sources, teachers attended to the different strategies students were using, helping them assess student strengths and learning. For most teachers, it was important to combine the perspectives offered by multiple data sources to form a "more well-rounded picture of students".

Teachers also pointed to observations of students as a way of gathering information about their students' learning or other experiences. Every teacher mentioned student observations as an important data source during the interview. The teachers explained that observations provided information about student thinking, affect, mathematical habits, and even mathematical identity. Teachers relied on this real-time information to make sense of students' experiences in the mathematics classroom. One teacher explained:

> *Everything that you do basically is giving you all the time information. Of course, there are things that are more measurable, like an exit ticket, or a screener, or a checkpoint, or a post assessment. But I think that observation is also key. You can see their faces when they are struggling, and you can see their faces when they are making progress.*

This information helped teachers better connect with and understand their students, ultimately allowing them to respond in the moment to student needs. Observational data in small groups provided real-time feedback to help this teacher adjust their instruction. Finally, observations supplemented other data sources and served as an additional perspective to support, contradict, or explain other data points.

The administrators' perspectives on data were aligned with the teachers' perspectives. Like teachers, the administrators tended to define data in broad terms while focusing on information about student learning. They mentioned the importance of formal and informal assessments in mathematics as well as observations. Principal Emory emphasized that, in her eyes, "Everything is data. Even the absence of data is data." She shared her view that data was "any form of expression where we can potentially get an understanding of what the child understands or doesn't," including students' conversations, words, and actions. It is possible that the teachers' perceptions of data were influenced by Principal Emory's broad definition of student learning data, or vice versa. Together, the teachers' and administrators' conceptualizations of data emphasized a broad view of data at Pinecone Elementary, one that primarily emphasized gathering data about student learning. This broad conceptualization also extended across the district administrators, particularly the district mathematics leader. This broad view of data impacted teachers' learning experiences. Teachers had opportunities to gather information about student learning broadly by engaging with aggregated group data or through a focused lens by examining student work samples. Teachers could interpret student learning by integrating information across multiple data sources, rather than relying on just one data point. Interacting with a diverse range of data sources provided teachers with a wealth of potential learning experiences.

While there seemed to be schoolwide alignment around a broad conceptualization of data, one teacher drew attention to an area of misalignment. This teacher was currently teaching in Spanish as a part of the school's dual-language program. Students in the dual-language program learned mathematics in Spanish for half of the time and in English for the other half and, as a result, classroom assessments included questions in both languages. However, all external data in mathematics was collected in English. The decision to collect external data in English was likely made across multiple levels (i.e., district, state), and it was likely influenced by the statewide, end-of-year assessments in mathematics administered only in English. From the perspective of this dual-language teacher, the school was missing essential data by only measuring students' progress on external assessments in English. She expressed her frustrations:

> *Every time that we use the data, they have to do a test or an evaluation in English… I spend the entire time teaching them math in Spanish. But then you are telling me that, 'Oh, but to evaluate that, you have to do it in English.' And it's like, 'Hmm! ... That doesn't help me to see what I'm doing as a teacher.'*

This teacher struggled with the prioritization of students' mathematical learning in English over their learning in Spanish. The absence of external mathematics data collected in Spanish limited her ability to measure students' mathematical progress in Spanish and to evaluate the effectiveness of her instruction. As a result, this teacher indicated that she had few experiences of learning from the data. She explained further:

> *I don't know what they expect from me when I go to every data meeting, and we are analyzing the data but in the English side… Of course, that I participate… I can say, like, 'Yeah, I noticed the same in Spanish… the kid… is not getting it, it's not working, he cannot do that in Spanish too.' But most of the time… I cannot participate as much as I want. Because… how can I talk about this if I notice different things in my side?*

Not only did this teacher have access to less data that she could learn from, the absence of data in Spanish also limited her ability to participate substantially in data meetings. This teacher's perspective demonstrates how teachers valued data in English versus Spanish differently depending on their role in the school. It also illustrates how decisions made across multiple levels of the system could limit teachers' learning experiences by influencing their interactions with data and with PLCs.

Schoolwide Focus on Data and Small Groups. Across the interviews, it was clear that the school's focus at the time of data collection for this study was on integrating data use and small-group instruction into classroom practice. The teachers consistently mentioned that their school's focus for the current year was data and small groups. When asked about the school culture, one teacher explained, "We are *all* about the data. Our focus this year is data and small groups… So, data is definitely a huge thing in the building this year." The teachers explicitly acknowledged that this was a top-down initiative and described how administrators set expectations at the beginning of the school year. In her interview, Principal Emory clearly stated her expectations for Pinecone Elementary: "This year our focus is on small groups and data." This quote mirrored those from the teachers, suggesting that communication was consistent from Principal Emory to teachers. The consistency across interviews suggested that there was coherence among the staff in terms of what their focus was to be for the school year.

This vision was set by school administrators and the school leadership team in response to the school report card grade as measured by the state based on the end-of-year assessments. Principal Emory described how her concerns about the school's performance first inspired the work of school improvement, and for the preview year the school had focused on re-engagement with teachers and students, particularly in response to the effects of the COVID-19 pandemic. Once the school began making growth, the administrators shifted the school focus towards improving classroom instruction. In reference to school report card grades, Principal Emory explained:

> *Moving students from C to A is way different and way more focused on teaching, learning, data, and proficiency. So that's why… we are now hyper-focused on instruction, which means we have to hyper-focus on, "How do we know what kids know?"*

The schoolwide focus on data was intended to emphasize student learning. Principal Emory's goal was for teachers to consistently gather information about "what kids know" and use that information to develop targeted instructional responses.

The decision to focus on data and small groups at Pinecone Elementary had a clear impact on teachers' interactions with data. Teachers noted that the administrators' expectations filtered down into PLCs and classroom practices. While many teachers were already collecting classroom data to inform small-group instruction, teachers across the school began doing this with intentionality. PLCs shifted to focus more on discussing shared classroom data. This was a step in the evolution of the school's orientation towards data. One teacher explained:

> *It [data] is one of our goals this year, so it's a bigger focus than I feel like it has been maybe in the past. Data-- I feel like it's kind of evolved more down to the classroom level… In the last couple of years, it has been really just that big school data, formal data like EOGs, checkpoints. And I feel like we're at a place where we've moved towards looking at exit tickets and our assessment data to reflect or to inform our instruction at the PLC level… There always hasn't been space for that… Maybe we've put the scores in a spreadsheet. But there hasn't been space to talk about it as a team.*

While Pinecone Elementary had initially focused on “big school data”, the focus had shifted over time and moved closer to teachers’ classroom practice. This teacher attributed the shift towards data use at the classroom and PLC levels to the school’s identified focus on data this year. The intentional discussions about classroom data in PLCs and the resulting instructional shifts may have supported teachers’ learning experiences. Another teacher described how her personal data practices evolved in response to the school focus on data and small-group instruction. She explained that she had recently begun collecting and using classroom data to guide small-group instruction, and she attributed this change to the schoolwide data focus. She stated:

> *Since Principal Emory this year in the staff meetings was telling us, “We are focusing on data this year,” I was kind of like, “Okay, then I should probably start looking at data.”*

The explicit schoolwide focus on data use motivated this teacher to engage with data in new ways. As this example indicates, school-level decisions about data practices can shape teachers’ interactions with data, both individually and in PLCs.

Structures to Support Teacher Learning at Pinecone Elementary. As described in the earlier sections, PLCs served as important spaces for teachers to interact with data. A key feature of these PLCs was the safe, open environment that was provided for teacher learning. Teachers referred to the PLC as a “safe space” and a “judgment-free zone” in which to share data, and they described interactions with other teachers as “supportive”. In PLCs, Coach Sam served as the facilitator, setting a tentative agenda for a meeting and guiding conversation from one topic to the next. However, teachers were also active agents within the PLCs (decentralized control; Davis & Sumara, 2006). Teachers introduced topics and ideas, asked questions, and shared problems of practice in the PLCs (randomness; Davis & Sumara, 2006). At times, this altered the entire course of the PLC as the group responded to the needs of its members. One teacher described a PLC meeting where she expressed concerns that her students were “lost” and needed more time to learn about place value. In response, the remainder of the PLC meeting was spent brainstorming suggestions for how she could shift instruction to support the students and their learning. These PLCs were inviting, collaborative spaces where ownership was distributed among the members, supporting interactions and allowing learning experiences to emerge.

The mathematics coach seemed to play an important role in supporting teacher learning around data both within and outside the PLC. Coach Sam often facilitated teachers' interactions with data in PLC, supporting them as they analyzed, interpreted, and brainstormed ways to respond to data. Especially when it came to interpreting external data, Coach Sam provided much needed information to help teachers make sense of the format or the meaning of the data. Several teachers described how Coach Sam took time to answer their questions or explain aspects of the data to them. One teacher explained, "I think Coach Sam is very good at breaking down data which I love because I need data to be broken down for me just another step or two." This teacher and others described how Coach Sam supported their learning by acting as an intermediary between them and the data. Coach Sam provided information and tools to unpack the data alongside teachers, helping the teachers learn to interpret the data. In addition, Coach Sam supported teacher learning by sharing a different perspective on the data. As one teacher phrased it:

> *There's times where I feel like the coaches have the bigger picture… They might be able to look at data and see something different than what we see cause… they kind of look at the grade level as a whole.*

Because of her role, Coach Sam was able to interpret data through a different lens than the teachers. She offered insight into the data that teachers may not be aware of or attending to, particularly in the realm of grade-level or schoolwide trends. As she shared these thoughts, Coach Sam helped the teachers widen their own perspectives and understand the data from a different angle.

While experiences in the PLCs and with Coach Sam supported teacher learning, there were no schoolwide, formal professional development sessions available for teachers at Pinecone Elementary at the time of data collection. Although they reported experiencing learning in their PLCs, teachers consistently explained that they had not participated in any professional development (PD) on data through the school. The quotes below are representative of the teachers' responses:

> *I don't feel like I've had formal data professional development here at Pinecone. Maybe I have. But I can't recollect anything that stands out to me as like, that was PD about data.*

> *I don't know if we-- I haven't done any PD for sure about it. I think that probably would be the area that we needed.*

Some teachers noted that they felt the need for more PD around data. Given that the push for data use was a school-driven initiative that was new for many teachers, it is not surprising that this was a schoolwide area of need. As Pinecone Elementary pushed to become more "data-driven" in practice, the lack of PD and support around data impacted how teachers did their jobs. A teacher shared:

> *I don't remember having an email or something saying, "Let's, all of you, you can have this PD about data." And sometimes that's something that, of course, affects your performance as a professional when things become data-driven, because you just don't understand what the data is showing you.*

In addition to these shared concerns, however, this teacher also communicated another reality: teachers were stretched thin for time. The teacher explained:

> *The point is that we have a lot already. So even if there was something that was offered, maybe I wouldn't take it right now. Just because of time and life. I already have lots of time devoted to the school.*

In this teacher's experience, offering additional PD – especially outside school hours – would not necessarily be helpful. Teachers were already spending many hours supporting their students and the school. While professional learning opportunities around data were needed, the effort required to seek out and take advantage of additional support, on top of everything else teachers were responsible for, seemed daunting.

The school administrators acknowledged that teachers had not been provided with formal professional learning opportunities around data, especially in mathematics. This was due in part to a statewide literacy initiative that had encompassed all of teachers' professional learning time for the past two years. Coach Sam noted that discussions in PLCs and Data Days could support teacher learning but explained that this support was not "intentional targeted professional development." The school administrators suggested that teachers needed additional professional learning around data and that Pinecone Elementary needed space to develop alignment around data. "Even amongst our leadership team, we don't have a common view of what pieces of data are useful. And I think that's just because of our different lenses that we come to the table with." In response to these needs, Principal Emory explained that she intended to incorporate professional learning into staff meetings. Her plan was to incorporate "some data-based PD and understanding" into upcoming staff meetings throughout the school year as a way of providing additional learning opportunities for teachers.

Discussion

The findings presented here capture ways that teachers' learning experiences are shaped through interactions with data in a complex system. The characteristics of data, the nature of teachers' interactions with data, and the nested levels in which those interactions occur all seemed to influence the emergence of teacher learning. These themes communicate an important point: teachers' learning experiences differ across interactions with data, and these differences emerge within a web of complex, evolving features that make up the learning system. The characteristics and conditions of this complex learning system (neighbor interactions, internal diversity, nestedness, coherence, emergence) that surfaced most often in the data are discussed below.

From the teachers' perspectives, it appeared that learning was primarily supported by *neighbor interactions* (Davis & Sumara, 2006) with data alongside other teachers in PLCs. Teachers consistently emphasized experiences of learning that emerged through interactions with other teachers. This finding is consistent with prior research that points to collaboration as a support for data use (Sun et al., 2016) and a key component of teacher learning (Darling-Hammond et al., 2017), particularly in job-embedded settings (Kazemi et al., 2018). As teachers analyzed and responded to data as a PLC, they had opportunities to move through multiple stages of data use collectively. This process seemed to promote teacher engagement with and use of data, and teachers pointed to these collaborative interactions with data as learning experiences. Other studies have pointed to PLCs as a support for teacher learning with data (e.g., Brodie, 2014; Datnow et al., 2021), but few studies have investigated how teachers' learning experiences take shape through interactions with data in mathematics PLCs (e.g., Horn et al., 2015). This study contributes to the literature by noting that teachers can experience learning in PLCs as they work with relevant, interpretable data in meaningful ways. These findings suggest that the potential for data to support teacher learning may be mediated by teachers' perspectives on the data. PLCs may benefit from prioritizing interactions with data sources that are closely connected to teachers' work. In addition, the visibility of student thinking seemed to impact the discussions teachers could have and the conclusions they could make in both mathematics and reading. Teachers reported that when student thinking was visible, it was easier to interpret the data and gather information about students' understandings. Teachers shared that examining student work helped them gain insight into student thinking, which was difficult when working with an aggregated group report or an overall test score. PLCs in multiple subject areas should consider what a data source reveals about student thinking and how much teachers can learn about students by analyzing the data. This examination of teachers' learning experiences intentionally relied on interviews as a primary data source, and self-report data may present an incomplete view of teacher learning. To address this, additional perspectives and data sources were incorporated (e.g., administrator interviews, documents). In addition, future research could extend this study with in-depth investigations of teachers' interactions with data in their classrooms or in PLCs (see Chapter 4).

Within this learning system, *internal diversity* (Davis & Sumara, 2006) seemed present in the wide range of personal feelings, beliefs, and experiences that teachers had with both data and with teaching. Teachers' backgrounds contributed to the diversity of perspectives shared in PLCs, and differences between teachers often sparked learning experiences when interacting with data. For example, beginning teachers reported learning from their more experienced colleagues through discussions of problems of practice and potential ways to respond to students' needs. This finding aligns with other research (McKie et al., 2023) which suggests that diversity may be an important component of teacher learning. However, the literature is clear that diversity within a group should be balanced by commonalities (redundancy) between individuals (Davis & Sumara, 2006; McKie et al., 2023). The experiences of the dual-language teacher pointed to this reality; the diverse perspectives limited this teacher's learning because there was misalignment between the data practices and her role. PLCs and administrators could learn from this finding by honoring the diverse perspectives teachers contribute when making sense of data, while also acknowledging and being mindful of how that diversity may change the learning experiences of each teacher.

Teachers' interactions with data and the emerging learning existed within a system of *nested levels* (Davis & Sumara, 2006), and these levels interacted in ways that impacted teachers' learning experiences. For example, statewide school report card grades motivated the leadership at Pinecone Elementary to emphasize the use of data to guide instruction. This schoolwide focus pushed teachers to engage with classroom data more consistently on their own and in PLCs, offering the potential for learning experiences. As another example, PLCs were established structures at Pinecone Elementary, existing formally as a result of expectations at the school and district levels. PLCs operated as hubs for teacher learning nested within the larger school, offering consistent spaces for teachers to interact and learn. However, the nestedness of the system also impacted teachers' interactions with data in ways that restricted their learning. For example, policy decisions at the state and district mandated the collection of certain data sources (e.g., high-stakes standardized tests, universal screeners to monitor students for MTSS). School-level decisions required teachers to engage with this external data in specific ways (e.g., grouping students for MTSS interventions, analyzing standardized assessment data during Data Days). Teachers reported that these interactions with data did not consistently provide experiences of learning, especially if the external data was difficult to understand or if teachers considered the interactions with data to be superficial, as in the case of assigning students to intervention groups. While there may have been potential for fruitful learning in these interactions, time constraints limited the learning experiences available to teachers. The fact that teachers were operating within a system of nested levels had implications for how they interacted with data, and these interactions with data in turn afforded or constrained learning experiences from the data. This finding contributes to a growing literature base that emphasizes the importance of examining both data use (Gummer, 2021; Mandinach & Schildkamp, 2021a) and teacher learning (Strom & Viesca, 2021) from a systems-level perspective. Because this study provided an in-depth examination of one learning system, the findings are integrally connected to this context. The findings may not generalize to a different context that, for instance, does not host a dual-language program or does not have PLCs that meet regularly to support teacher learning. Conducting similar studies in other contexts could further investigate the characteristics and conditions that support positive interactions with data, possibly supporting, contradicting, or expanding the findings presented here.

Coherence (Davis & Sumara, 2006) was present across the nested levels as teachers were expected to engage with certain data sources in specific ways. There seemed to be a shared conceptualization of data across levels of the system as district leaders, school leaders, and teachers had a broad definition of data that included many different types. This shared conceptualization points to coherence across the system, a foundation for providing systematic support for teacher learning (Cobb et al., 2020). Other schools and districts may benefit from developing a shared, broad definition of data that emerges from the views of both teachers and administrators. Within the PLCs, coherence seemed to support learning by aligning the teachers around common data sources. By collecting data in a similar format and displaying the results in a shared space, teachers had opportunities to compare the results and make connections across the grade level. This coherence seemed to support teachers' understanding of their students and instruction as they noticed similarities and differences in student thinking between classrooms. These findings connect with the literature on PLCs (DuFour & Reeves, 2016), which emphasizes the importance of using common formative assessments to ground the work of a PLC around discussions of student learning. At a time when misalignment around data use is prevalent

(Mandinach & Schildkamp, 2021b), it appears that coherence across multiple levels of this system may have supported teachers' learning experiences through data use.

Within this complex system, teacher learning experiences seemed to *emerge* (Davis & Sumara, 2006) through (some) interactions with data. As teachers made sense of relevant data alongside their colleagues, meaningful interactions took place and learning experiences emerged. As in other studies, teachers described the emergence of learning about students and their mathematical thinking (see Chapter 4; Datnow et al., 2021), about the mathematical content (Brodie, 2014), and about their past and future instruction (see Chapter 4; Cosner, 2011). Teachers also described moments where learning did not emerge, noting how confusing, disconnected data and superficial interactions restricted the potential for learning. For example, focusing attention only on student proficiency limited what teachers could learn about the mathematical content or about student mathematical thinking through the interaction. Time constraints often interfered with the emergence of learning in these cases. Because teacher learning is a complex, evolving phenomenon, it is important to attend to how learning emerges over time (Ell et al., 2019). In this study, initial and follow-up interviews were conducted with participants to investigate their perspectives at two points in time. Additional data sources (e.g., documents, interview responses describing past experiences) provided insight into the evolution of the phenomenon in this system. However, the field could benefit from future research that utilizes longitudinal designs to capture the emergence of teacher learning at different points in a school year and in tandem with evolutions in the system.

Finally, it is worth addressing the influence of time on teachers' interactions with data and their learning experiences. Time is an incredibly valuable resource in schools, one that is important to both teacher learning (Merritt, 2016) and data use (Marsh, 2012; Marsh et al., 2006;

Means et al., 2010). Like other research (e.g., Horn et al., 2015), the results of this study pointed to ways that limited time can influence teachers' interactions with data. Teachers struggled to make sense of confusing data and to engage with data in deep, meaningful ways when pressed for time, resulting in fewer learning experiences. However, this study also demonstrated ways that time could be provided for teachers to discuss data in collaborative spaces such as PLCs. Teachers reported having learning experiences when they had time in PLCs to examine relevant data in ways that connected meaningfully to the work of teaching. Providing time for collaborative, job-embedded professional learning through the use of data seems to support teacher learning, and other schools could benefit from providing teachers with ample, dedicated time on a regular basis (i.e., weekly mathematics PLCs) to engage with data in these collaborative spaces.

Overall, this study amplifies teacher voices by sharing teachers' perspectives on their own learning experiences with data, while also acknowledging the complex factors that influence teacher learning through data use across a system. While there are mixed findings and perspectives on data use in schools (Mandinach & Schildkamp, 2021b), this study showcases one school where teachers report that they are indeed learning from their interactions with data. Consequently, much can be learned from the findings, both to inform other practitioners and to guide future research.

CHAPTER 4: STUDY #2

Zooming In: Examining Teachers' Opportunities for Learning through Interactions with Data in PLCs

Data-based decision making (DBDM) is a widely acclaimed practice in educational settings that holds potential for supporting student learning (Barnes et al., 2022; Marsh et al., 2006). DBDM is based on the theory that educators can collect information – data – about students' current understandings and use the information to design instructional responses. Despite its acclaim, research suggests that data use in schools is a complex practice that can be difficult to implement and that does not consistently lead to improvements in student learning (Schildkamp & Datnow, 2022; Staman et al., 2017).

In elementary mathematics education, noticing and responding to student thinking is another widely cited practice that also has potential to foster students' mathematical growth (Carpenter et al., 1989; Jacobs et al., 2007; NCTM, 2014). Teachers elicit and probe student thinking to gather information about the students' current mathematical strategies and reasoning, then draw on that information to guide their instruction (Leatham et al., 2015). Despite the parallels between data use and attending to student mathematical thinking, there is not much discussion in the literature about the overlap between these two practices. A focus on student mathematical thinking in data discussions appears to be a promising practice that has the potential to make DBDM meaningful for teachers and to support learning for students and teachers alike (Datnow et al., 2021).

The skills needed to investigate and respond to student mathematical thinking and student data in a rich, timely, and effective manner are complex, and research suggests that teachers develop these skills given time and support (Datnow et al., 2021; Jacobs et al., 2010).

Professional learning communities (PLCs) are collective spaces designed to foster teacher inquiry around teaching practices and student learning, and these communities may offer the necessary support required for teacher learning. Mathematics PLCs provide an ideal space for teachers to collectively examine data with a lens towards student mathematical thinking. Focusing discussions of data around student mathematical thinking in PLCs may provide teachers with rich opportunities for learning about their students, their instruction, and the mathematical content (Brodie, 2013; Kazemi & Franke, 2004; van Es & Sherin, 2008). However, much of the research on student thinking in elementary mathematics PLCs involves an intervention or professional development program (e.g., Kazemi & Franke, 2004; van Es & Sherin, 2008). There is limited research on teachers' interactions with student data and student thinking "in the wild", especially in elementary mathematics PLCs. There is also a lack of research on the extent to which those interactions offer opportunities for teacher learning. This study addresses these gaps by exploring the extent to which teachers examine student mathematical thinking during interactions with student data in elementary mathematics PLCs and investigating opportunities for teacher learning afforded by those interactions. Consequently, this study bridges the research areas of data use, student mathematical thinking, and teacher learning by examining their intersection.

Literature Review

PLCs as a Context for Teacher Learning

Teacher learning is a multidimensional phenomenon, emerging across a range of settings and interactions as part of a complex, evolving system. Professional learning communities, sometimes known as professional learning teams or teacher workgroups, are one space in which teacher learning may occur. The term professional learning community (PLC) refers to a group of educators working together towards a common goal while simultaneously learning from the material and from each other (DuFour, 2004). The concept of a PLC is grounded in sociocultural learning theories and socioconstructivism, emphasizing that learning is constructed socially through interactions (Hord, 1997; Stoll et al., 2006; Wenger, 1998). The goal of a PLC is to serve as a collaborative team through which the practice and art of teaching can be explored and improved, providing teachers with opportunities for job-embedded professional learning. PLCs can also counteract the isolation often experienced when teachers are siloed in their own classrooms (Hord, 1997).

PLCs hold promise as a mechanism to cultivate teacher learning because they incorporate several features of effective professional learning identified in prior work (e.g., Darling-Hammond et al., 2017; Desimone, 2009). PLCs involve groups of teachers working and reflecting collaboratively on aspects of the instructional cycle (collective participation; active learning) throughout the school year (duration) (DuFour, 2004; Hord, 1997). They can target a particular subject area (content focus), grade level, or both. The work of PLCs ideally centers around teachers' daily interactions in the classroom and, when implemented effectively, can offer space to experiment with content from other learning experiences (coherence) (Stoll et al., 2006). These features suggest that PLCs may offer teachers opportunities for on-the-job learning.

Research on teacher learning opportunities in PLCs has focused on ways that learning emerges through "patterns of social interaction" (Van Lare, 2016, p. 761), including interactions between teachers, resources, ideas, and representations. Using observations of teacher workgroups, Horn and colleagues (2017) developed a taxonomy to distinguish between the depth of learning opportunities supported through different conversational processes. High-depth meetings were dialogical in nature; teachers engaged in collective interpretation, which allowed them to develop their understanding of teaching concepts and connect to future work. Popp and Goldman (2016) also investigated learning opportunities in PLCs by examining teacher discourse. The authors used discourse moves associated with knowledge building to analyze PLC conversations, and they found that knowledge building indicators were more prevalent in PLC meetings that focused on assessments than meetings centered around instruction. Finally, the work of Horn and Little (2010) suggests that learning opportunities in PLCs emerge as teachers engage in discussion of problems of practice, often using replays and rehearsals to represent past or future classroom interactions. These moments allowed teachers to wrestle with current, relevant dilemmas from their classrooms and, through conversational routines, examine and problem solve through these dilemmas with peers.

Within mathematics PLCs, teachers engage in many activities through which learning may occur. These activities could include the discussion of instructional pacing or logistics, collaborative planning of lessons, or the sharing of resources and materials (Farley-Ripple & Buttram, 2014; Horn et al., 2017). In addition, teachers in mathematics PLCs may also interact with student data and investigate student thinking (Harvey & Teledahl, 2022).

Data Use in the Context of Mathematics PLCs

Teachers often use student data to support their work, and opportunities to interact with student data can occur in mathematics PLCs (Farley-Ripple & Buttram, 2014; Harvey & Teledahl, 2022). Teachers refer to multiple student data sources in PLCs, including student learning data, behavioral data, or demographic data (Datnow et al., 2018; Farley Ripple & Buttram, 2014). The goal of examining student data in PLCs is often to make instructional adjustments and improve student learning outcomes (Vescio et al., 2008); as a result, teachers typically focus on student learning data in PLCs. Data about students' current learning is often gathered through mathematics classroom assessments (i.e., unit tests) or external assessments (i.e., standardized state tests, interim assessments) (Farley-Ripple & Buttram, 2014; Horn et al., 2015).

Research suggests that using data to effectively support student learning is a difficult and complex process (Gummer, 2021), and PLCs may provide a supportive environment for teachers to collectively analyze and respond to data (Sun et al., 2016; Datnow & Hubbard, 2015). In some cases, teachers analyze data collectively with a focus on student proficiency. Teachers may determine whether students are meeting proficiency as measured by an assessment or group students into levels based on their scores (i.e., “high”, “average”, “low”, etc.) (Datnow et al., 2018). This information may be used to identify students in need of remediation or extension, either holistically or for specific mathematical skills. Interventions may be planned in PLCs in response to the identified student needs (Farley-Ripple & Buttram, 2014; Horn et al., 2015). At other times, PLCs dive deeper into student learning data. Teachers identify grade-level trends, attending to commonly missed questions, or examine student mathematical thinking around specific standards (Horn et al., 2015). This information can be used to plan instructional responses, such as reteaching mathematical concepts that have not been mastered or changing the format of future instruction (i.e., meeting with small groups, incorporating stations) (Van Lare, 2016). PLCs can serve as a space for teachers to share instructional ideas and discuss ways to respond to trends in student data (Farley-Ripple & Buttram, 2014; Van Lare, 2016). In addition, mathematics PLCs may use student data to adjust curricular pacing or evaluate the effectiveness of instruction (Farley-Ripple & Buttram, 2014).

Opportunities for Learning through Interactions with Data in PLCs. The ability to analyze and utilize data substantially requires teachers to examine data for evidence of student learning, to reflect on the efficacy of past instruction, and to make appropriate changes to the method and delivery of instruction in response. Developing these skills has been shown to be a complex process, one that requires learning over time (Cosner, 2011; Ikemoto and Marsh, 2007). If teachers are expected to analyze and respond to data effectively, they need multiple, job-embedded opportunities to learn these skills. PLCs can provide support for teachers as they make sense of data, especially given the fact that interpreting data can be a complex process.

Research suggests that teachers may have opportunities to learn from data in PLCs (Horn et al., 2015), especially when investigating evidence of student mathematical thinking (Datnow et al., 2021). Several studies of professional learning experiences provide evidence of teacher learning through interactions with data in PLCs. Schildkamp and colleagues (2016) developed the “data team procedure”, a professional development intervention (PDI) that supports data teams in schools. The data team procedure was implemented with four secondary data teams in the Netherlands, and qualitative analyses indicated that three of the four teams developed new knowledge about the data, their students, and instruction through the process of engaging with data. Quantitative analyses of a similar PDI, implemented across nine Dutch secondary schools (Ebbeler et al., 2017), indicated that participants’ data literacy skills increased as measured by pre- and post-assessments. Another PDI, implemented with elementary mathematics PLCs, demonstrated teacher learning through self-report data and through observations of instruction (Supovitz & Sirinaides, 2018). Result of a randomized control trial showed that teacher learning increased on both measures, and teachers reported opportunities to learn about mathematics instruction and about student thinking. The literature suggests that teachers have opportunities to learn new information and new skills through interactions with data, but this is primarily researched in the context of PDIs. There are limited studies that investigate how interactions with data offer opportunities for learning in mathematics PLCs, specifically outside the context of a PDI. One important study, conducted by Horn et al. (2015), examined the teacher learning opportunities that emerged naturally through interactions with data in two middle school mathematics PLCs. The nature of conversations and interactions with data differed across the two PLCs, resulting in different opportunities for learning. One PLC spent time analyzing missed test questions and had opportunities to learn about student thinking and re-teaching strategies; the other PLC focused on identifying students for intervention groups and had opportunities to learn about resources for intervention and strategies to support student motivation. This study contributed to the field's understanding of teacher learning through data use in naturally occurring settings, but more information is needed about elementary mathematics PLCs and the extent to which learning opportunities emerge through interactions with data "in the wild".

Student Thinking Literature in Elementary Mathematics

A related body of work involves discussions and investigations of student thinking in mathematics PLCs (Harvey & Teledahl, 2022; Kazemi et al., 2018). The term "student mathematical thinking" encompasses students' mathematical ideas, strategies, and reasoning, and it can apply to specific student thinking or broader trends in strategies generally used by students. Investigating student mathematical thinking can provide teachers with information about how students approach and reason about mathematical content, often in ways that are different than adults (Leatham et al., 2015). PLCs may engage with general examples of student thinking, possibly anticipating students' responses to a task or unpacking typical strategies for a particular skill and age group (Brodie & Chimhande, 2020; McKie et al., 2017). Teachers may also use evidence of their own students' thinking to prompt discussion in PLCs (Kazemi & Franke, 2004;

Kazemi et al., 2018). Typical examples of this evidence for student mathematical thinking includes work samples, observations, and student interviews.

Opportunities for Learning through Interactions with Student Thinking in PLCs. Attending to student mathematical thinking, particularly from current students, is a challenging task. Teachers must elicit, notice, interpret, and respond to the thinking of an entire classroom of students. To do so, teachers rely on professional noticing of children's mathematical thinking, defined as "a set of three interrelated skills: attending to children's strategies, interpreting children's understandings and deciding how to respond on the basis of children's understandings" (Jacobs et al., 2010, p. 172). Research has pointed to the importance of noticing student mathematical thinking "in-the-moment" during classroom interactions (Jacobs et al., 2010) and in PLCs by examining students' work samples or classroom videos (Kazemi & Franke, 2004; van Es & Sherin, 2008). Professional noticing is a skill that teachers can develop, and PLCs can provide one space for teachers to learn to notice student mathematical thinking. PLCs may support teachers in attending to, interpreting, and responding to student thinking.

As teachers learn to attend to student mathematical thinking in PLCs, they gain insight into students' strategies and mathematical strengths, as well as the pedagogical conditions surrounding students' responses (Franke & Kazemi, 2001; Kazemi & Franke, 2004). Teachers can use this information to develop intentional responses that leverage and extend students' existing strategies and mathematical understanding (Kazemi & Franke, 2004). Investigating current student thinking in PLCs can also build teachers' own mathematical understandings and help them recognize their own areas for growth as mathematical learners and teachers (Brodie, 2013; Kazemi & Franke, 2004).

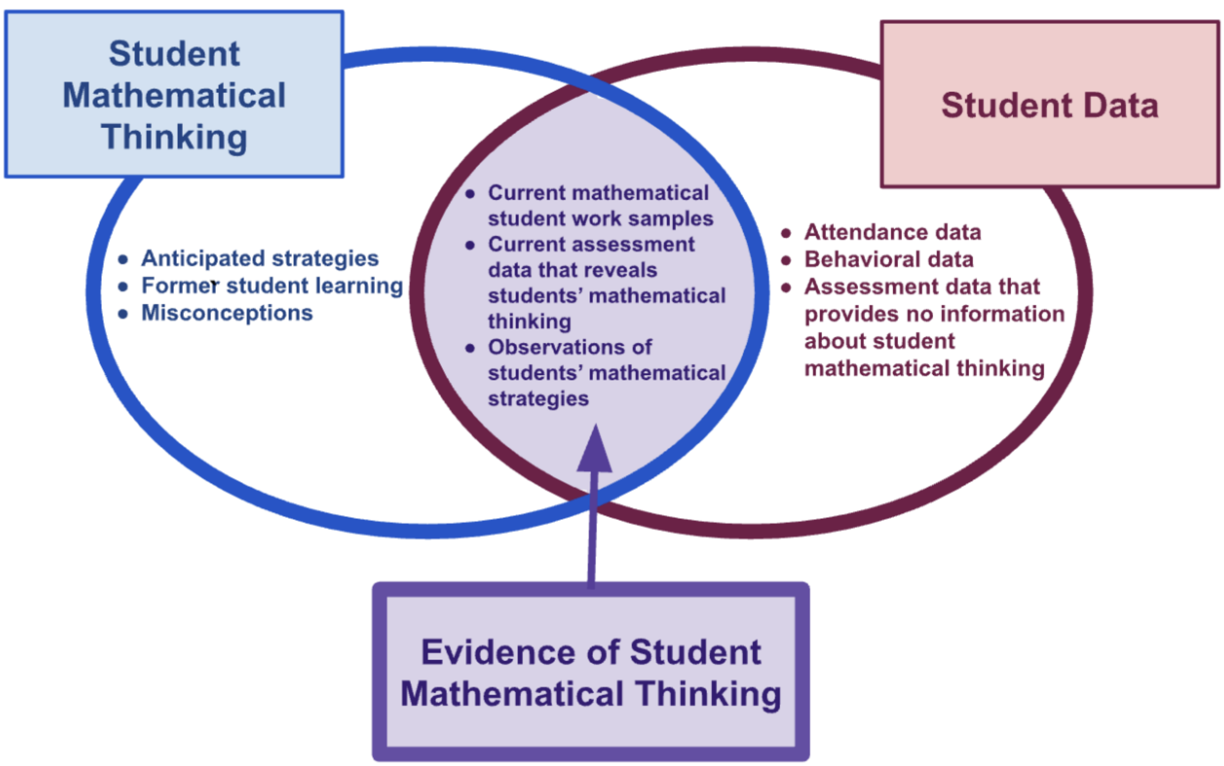
Attending to Student Thinking in Interactions with Data

There are many similarities between the use of data and the use of student thinking to guide instruction. In both cases teachers collect information from students, use that information to make sense of students' learning, and respond accordingly. Nevertheless, the literature on teachers' investigations of student thinking in mathematics is often discussed separately from the data literature. "Although commonly examined in the instructional improvement realm and central to many teachers' work, student thinking is a form of evidence not typically defined as "data" in the data use literature" (Datnow et al., 2021, p. 1). Despite this disconnect, some work has drawn attention to the overlap between these fields in mathematics education, noting that many sources used to examine student thinking could be considered data and emphasizing the importance of examining student thinking within traditional data sources (Brodie, 2014; Datnow et al., 2021; Garner & Horn, 2018). In their study of middle school mathematics PLCs, Datnow and colleagues (2021) adopted a broad definition of data to investigate teacher capacity building through interactions with data. As part of a multi-year instructional improvement effort, an instructional coach supported PLCs to collaboratively examine "evidence on student thinking" (e.g., student work) as an embedded part of instructional planning. Through this process, teachers learned to integrate data use into the instructional cycle and used reflection to consistently interrogate and improve their teaching practices. The authors point to "ongoing data use… embedded in instructional planning" and "an expansive conception of data" as two critical components that supported capacity building among the teachers (Datnow et al., 2021, p. 8). It appears that merging investigations of data and student thinking may provide teachers with meaningful, job-embedded opportunities for learning.

Figure 4.1 conceptualizes the intersection between student data and student mathematical thinking. As noted by the white portions of each circle, student mathematical thinking can be discussed without incorporating evidence from current students (data), and not all data sources provide information about mathematical thinking. Evidence of student mathematical thinking, represented by the overlapping section in the center, encompasses information (i.e., data) gathered from current students about their mathematical knowledge, reasoning, or strategies (Datnow et al., 2021).

Figure 4.1

Evidence of Student Mathematical Thinking: The Intersection of Student Data and Student Mathematical Thinking



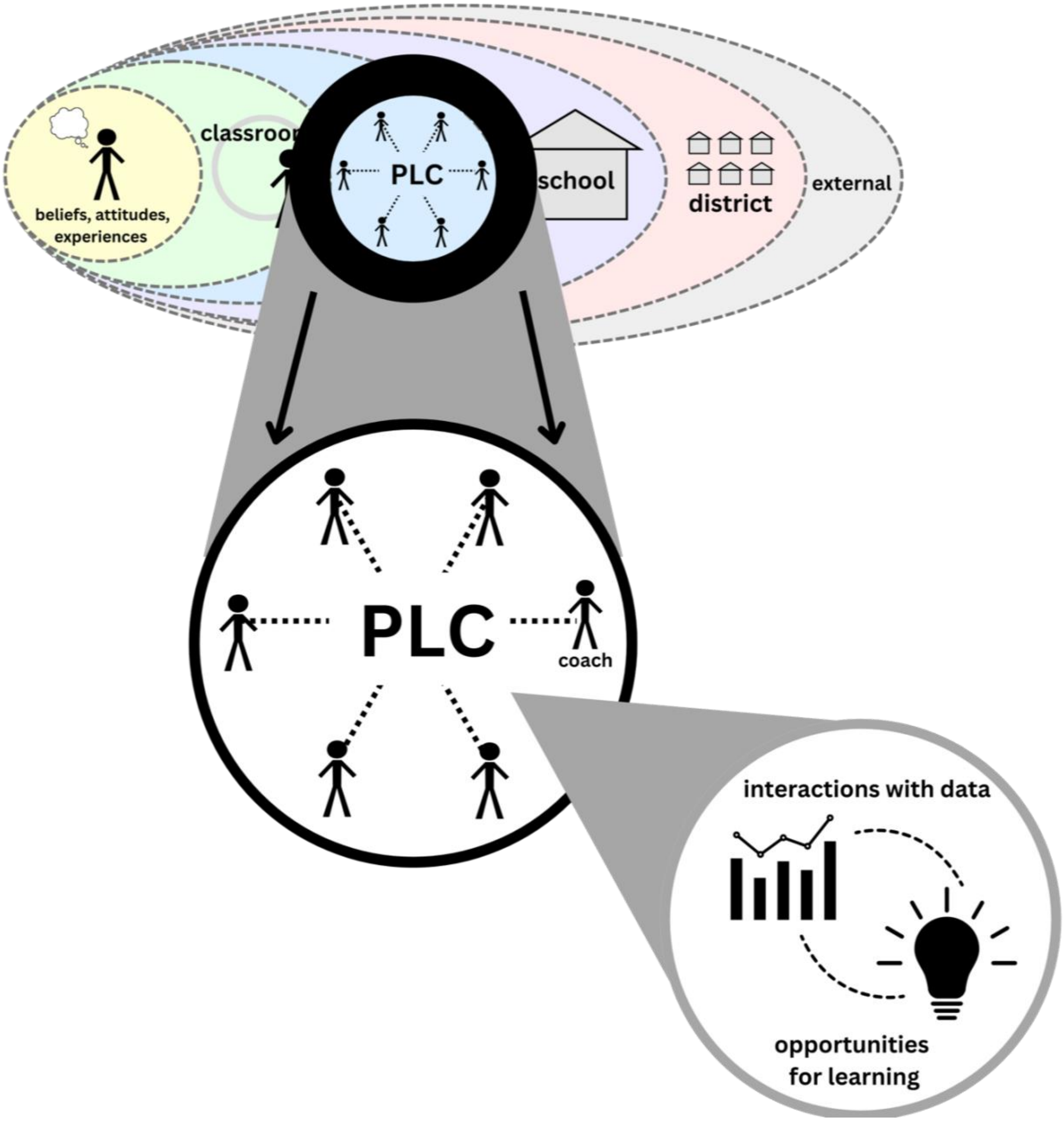
Examining evidence of student mathematical thinking in PLCs is ideal for teachers because they can gain real-time information about the specific mathematical content their own students are wrestling with (Datnow et al., 2021; Kazemi & Franke, 2004). According to Datnow et al. (2021), "a focus on student thinking may help to provide a more tangible connection between data and instruction and can promote student and teacher learning" (p. 2). This type of data is both timely and content-focused, offering teachers the potential of developing relevant instructional responses. This current study investigates teachers' interactions with data, attending to ways teachers discuss evidence of student mathematical thinking and the opportunities available for teacher learning.

Conceptual Framework

The conceptual framework for this study is depicted in Figure 4.2. While situated in a broader educational system, this study "zooms in" on teachers' interactions in elementary mathematics PLCs. In the context of these PLC interactions, the study investigates teachers' interactions with data and the opportunities for learning afforded by those interactions. Following the lead of other researchers (Datnow et al., 2021; Lai & Schildkamp, 2013), this study defined data broadly as "information that is collected and organized to represent some aspect of schools" (Lai & Schildkamp, 2013, p.10). Because this study focused on teachers' interactions in collaborative spaces, "opportunities for teacher learning" were operationalized as observable oral interactions between an individual or group and other people, ideas, resources, or representations.

Figure 4.2

Conceptual Framework for Study #2



Research Questions

The purpose of this study was to investigate teachers' interactions with data in elementary mathematics PLCs and to examine how those interactions may provide opportunities for learning. The research questions guiding this study were:

1) In what activities do teachers engage during elementary mathematics PLC meetings?
2) In elementary mathematics PLCs, (a) for how much time and (b) during what activities do teachers engage with student data?
3) In elementary mathematics PLCs, what are the characteristics of teachers' interactions with student data, including their attention to student mathematical thinking?
4) In elementary mathematics PLCs, what are the characteristics of rich opportunities for learning around student data?

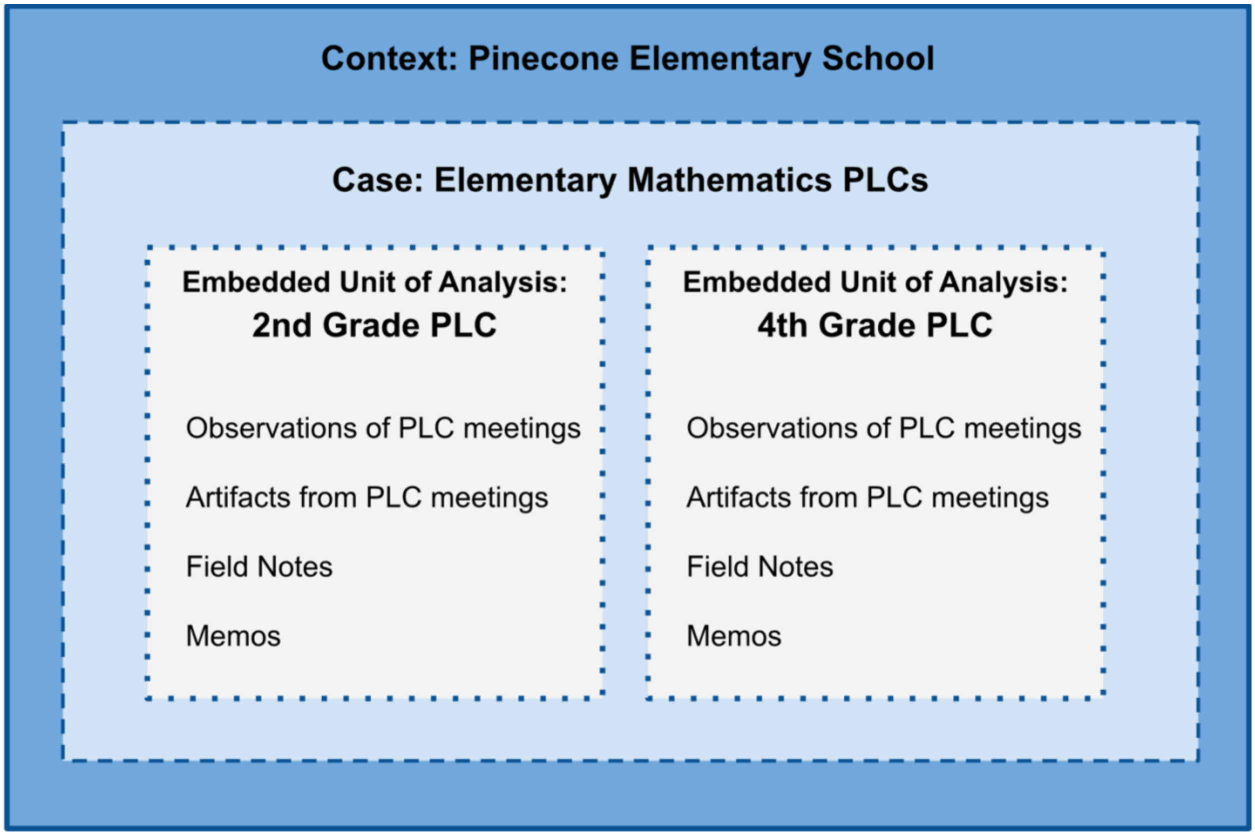
Methods

Study Design

To understand teachers' interactions with student data, a qualitative case study methodology was selected. According to Yin (2018), "a case study is an empirical method that investigates a contemporary phenomenon ("the case") in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident" (p. 15). Case study methodology was chosen for this research because understanding teachers' interactions with data and opportunities for learning requires an in-depth study of a contemporary phenomenon. An embedded single-case design (Figure 4.3) was utilized to investigate a "common case", intended "to capture the circumstances and conditions of an everyday situation" (Yin, 2018, p. 50). In this study, the case was defined as elementary mathematics PLCs at Pinecone Elementary. The case was bound by the mathematics PLC members and by the set PLC meeting times in the fall of 2023. Within the single-case, two embedded units of analysis (second-grade PLC; fourth-grade PLC) were included.

Figure 4.3

Embedded Single-Case Study Design



Following the recommendations of Little (2012), this study examined the practice of teachers' data use through a microprocess study. Teachers' interactions with data were observed "in the wild", as teachers "interact[ed] with data in the course of their ongoing work in the situated context of their workplaces" (Coburn & Turner, 2012, p. 99-100). Microprocess studies consider data use to be an interactive phenomenon (Little, 2012), aligned with the socioconstructivist framing of teacher learning (Adams, 2006).

Context and Participants

Participants for this study were selected using purposeful criterion sampling. Among those individuals who could provide in-depth information about teachers' learning opportunities, participants were selected based on relevant, predetermined criteria (Palinkas et al., 2015). From the seven elementary schools in this district, one school was selected based on the following criteria: the school had mathematics PLCs that meet consistently, the principal gave permission for research to be conducted at the school, and the school employed a mathematics coach who agreed to participate. Based on this criteria, Pinecone Elementary School was selected as the school site (all names are pseudonyms). Pinecone Elementary is a racially diverse, rural, Title I elementary school with approximately 600 students and a large population of multilingual learners. The school employs two mathematics coaches. In the school year prior to this study, the mathematics coaches at this school joined elementary and middle school mathematics coaches across the district for professional learning opportunities through a partnership with a local university. This experience focused primarily on one-on-one coaching in mathematics. At the start of the previous school year, this district also participated in professional development for improving PLCs through an external organization.

Within the school, two PLCs were selected based on the following criteria: a majority of the PLC members had worked together for at least one year, all PLC members agreed to participate in the research, and the PLCs worked with the same mathematics coach. Keeping the mathematics coach and the school context consistent between PLCs was an attempt to limit the amount of contextual variation. Through this process, one upper grades PLC team (five teachers) and one lower grades PLC team (five teachers) agreed to participate, along with one mathematics coach and the principal. Participant demographics are presented in Table 4.1. Because the school had recently experienced significant teacher turnover, the principal had reorganized grade-level teams at the start of the school year. Therefore, each PLC in the school had at least one team member new to the grade-level team. The teachers in both PLCs brought a wealth of resources to the team; however, there were notable differences in the two PLCs. The second-grade team had spent more years working together as a PLC (*Median Years in PLC*, Table 4.1), while the teachers on the fourth-grade team had more years of teaching experience on average (*Mean Years of Teaching Experience*, Table 4.1).

Table 4.1

Participant Demographics

Pseudonym	*Position*	*Years in PLC*	*Years in Education*
Carmen	2nd grade lead teacher	18	10+
Lucy	2nd grade teacher	4	5-9
Emma	2nd grade teacher	4	5-9
Charlie	2nd grade teacher	2	BT (< 3)
Marybelle	2nd grade teacher	0	5-9
Blake	4th grade lead teacher	4	10+
Riley	4th grade teacher	2	BT (< 3)
Carlos	4th grade teacher	1	10+
Maria	4th grade teacher	0	10+
Drew	4th grade teacher	0	10+
Coach Sam	Mathematics coach	8	10+
Principal Emory	Principal	2	10+

Grade Level	*Mean Years of Teaching Experience*	*Median Years in PLC*
2nd Grade PLC	8.2	4
4th Grade PLC	14.2	1

Data Collection

Data collection took place during the fall semester of the 2023-2024 school year. One feature of case study methodology is the use of multiple data sources to triangulate findings (Yin, 2018). The following data sources were collected in this study: observations and recordings of PLC meetings, artifacts from PLC meetings, field notes, and memos.

Weekly mathematics PLC meetings for both grade levels were observed for five consecutive weeks in September and October 2023 (Table 4.2). These meetings took place after school and were scheduled for 60 minutes. Meetings were attended by the grade-level teachers, the mathematics coach, and occasionally by the academically gifted teacher and the special education teacher. In the second week of observations, each grade level participated in a "Data Day", an additional data-specific PLC meeting scheduled during the school day. Approximately 45 minutes of the meeting was allocated to discussing data in mathematics. In addition to the teachers and the mathematics coach, this meeting was attended by administrators and specialist teachers (i.e., student support coach, multilingual learner specialist).

Table 4.2

Summary of PLC Meeting Observations

Grade Level	Date	Total Recorded Meeting Time
2nd	9/21/23	56:19
	9/27/23 (Data Day)	47:51
	9/28/23	38:21
	10/5/23	Canceled
	10/12/23	46:31
	10/29/23	59:03
4th	9/20/23	1:05:28
	9/27/23	58:19
	9/29/23 (Data Day)	42:50
	10/4/23	58:38
	10/11/23	1:04:19
	10/18/23	1:02:49

Summary Information	*2nd Grade*	*4th Grade*
Total Number of PLC Meetings Recorded	5 meetings	6 meetings
Total Recording Time (PLC Meetings)	4:08:05	5:52:23
Range of Recording Time (PLC Meetings)	38:21 – 59:03	42:50 – 1:05:28
Mean Recording Time (PLC Meetings)	49:37	58:44

The PLC meetings were audio- and video-recorded. During the meetings, the researcher collected field notes, including a copy of the meeting agenda before and after the meeting (to reflect any notes taken by the team). Photographs and digital copies of artifacts referenced during the PLC meeting (e.g., student work samples, planning documents, assessment data) were also collected. After observing each meeting, the video files were downloaded to a secure platform and organized, along with the artifacts and field notes. The files were organized in folders by grade level and PLC meeting date. Memoing was used after each PLC meeting to reflect on the research questions and to note comments, patterns, and preliminary themes from the data.

Data Analysis

The analysis methods were aligned with the case study approach and aimed to provide an in-depth understanding of teachers' interactions with student data (Creswell & Poth, 2016). The analysis occurred in four phases, each analyzing a separate research question (Table 4.3).

Table 4.3

Phases of Data Analysis

Phase 1: Identify PLC Activities	
Research Question 1: In what activities do teachers engage during elementary mathematics PLC meetings?	
Steps	Data Sources
- Develop codes to categorize PLC activities - Identify duration of PLC activities	Recordings of PLC meetings, artifacts from PLC meetings, and field notes

Phase 2: Identify Data Episodes	
Research Question 2: In elementary mathematics PLCs, (a) for how much time and (b) during what activities do teachers engage with student data?	
Steps	Data Sources
- Use data reduction to identify sections of PLC meetings focused on data ("data episodes") - Categorize and transcribe all data episodes - Identify all relevant artifacts	Recordings of PLC meetings, artifacts, field notes, and memos

Phase 3: Characterize Data Episodes	
Research Question 3: In elementary mathematics PLCs, what are the characteristics of teachers' interactions with student data, including their attention to student mathematical thinking?	
Steps	Data Sources
- Code data source in student data episodes - Code episodes to characterize teachers' interactions with student data	Transcripts of data episodes, artifacts, field notes, and memos

Phase 4: Characterize Rich Learning Opportunities	
Research Question 4: In elementary mathematics PLCs, what are the characteristics of rich opportunities for learning around student data?	
Steps	Data Sources
- Identify richest episodes based on criteria - Use descriptive memos to capture characteristics of learning opportunities	Transcripts of data episodes, artifacts, field notes, and memos

Phase 1: Identify PLC Activities (RQ 1). The first phase of analysis explored the activities in which teachers engage during elementary mathematics PLC meetings. "PLC activity" was defined broadly as the focal topic or task for a segment of the PLC meeting. Although teachers may discuss multiple topics during a given segment, the purpose of this analysis was to identify the primary, overarching topic of that segment. Therefore, codes were mutually exclusive. Initial inductive codes emerged from the meeting agendas. These initial codes were compared to meeting recordings and field notes and refined as needed. The codes were then collapsed and adjusted, resulting in a final list of six PLC activities across three categories (Table 4.4). The final codes were applied to each meeting segment. Starting and ending times for the segment were marked based on recordings and field notes and were used to calculate the duration of each PLC activity. A sample representation of the PLC activities in one meeting is provided in Figure 4.4.

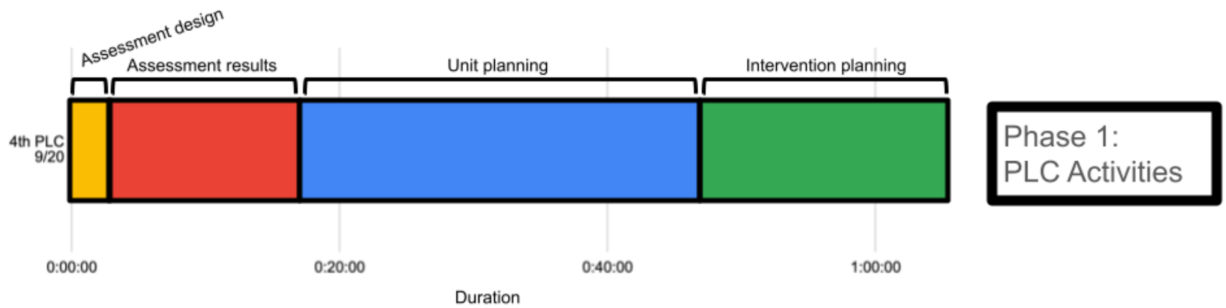
Table 4.4

List of PLC Activities

Category	**PLC Activity**	**Definition**
Instruction	Unit Planning	Discussing content, format, pacing, and delivery of upcoming mathematics instruction
	Intervention Planning	Discussing content, format, delivery, and assessment of mathematics interventions
Assessment	Assessment Design	Discussing content, format, timing, and delivery of upcoming mathematics assessments
	Assessment Results	Discussing results of formal mathematics assessments for students
Other	Teacher Observations	Discussing past and upcoming observations of teachers' instruction
	Other	Discussing other topics; examples include parent newsletters and reflecting on goals of PLC

Figure 4.4

Sample Representation of Phase 1 (Identify PLC Activities)

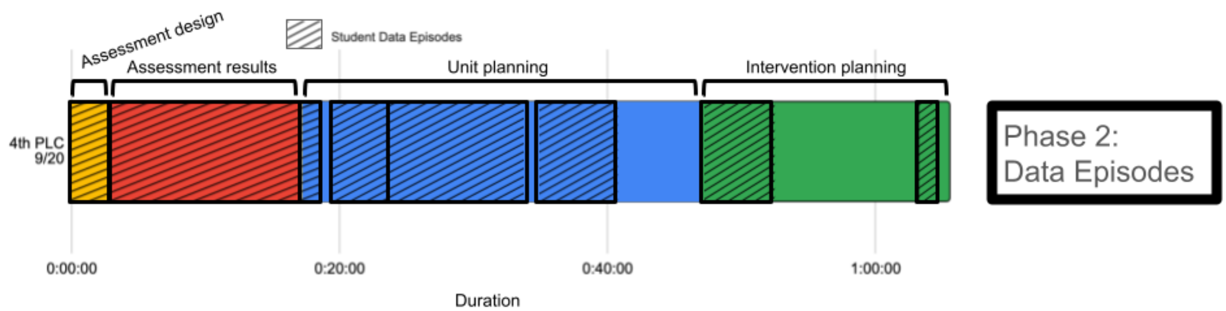


Phase 2: Identify Student Data Episodes (RQ 2). The second phase focused on identifying episodes within the PLC meetings in which teachers interacted with student data in mathematics. Student data in mathematics was defined as a reference to information collected about current students' mathematical knowledge, either through formal or informal means. This definition included formal assessment data, such as unit tests, as well as informal data, such as observations. Data reduction was used to identify moments within the PLC meetings in which teachers engage with student data. First, the video recording for each PLC meeting was rewatched. A copy of the field notes was created, and additional notes were added to the new document during the rewatch (references to students or student data, connections between student data and plans for instruction), including approximate timestamps of these instances. Notes were also taken when a moment was potentially referencing current students or student data, but the reference was unclear. Artifacts and field notes were referenced to interpret the meeting recordings.

Next, a codebook was developed to document initial definitions of codes. Using field notes, memos, and the codebook, “student data episodes” were identified within each PLC meeting (Figure 4.5). Student data episodes were defined as sections of the PLC meeting that referenced information about current students’ mathematical knowledge. Episodes began when student data was referenced, included all analysis of the data and discussions of instructional responses to the data, and ended when the topic of conversation shifted away from student data. The starting and ending times for each episode were identified, and the episodes were transcribed either by the researcher or an external transcription service. The transcripts for each episode, along with any relevant artifacts, were saved and organized on the secure platform. Information about the student data episodes was organized in a spreadsheet.

Figure 4.5

Sample Representation of Phase 2 (Identify Student Data Episodes)



Phase 3: Characterize Student Data Episodes (RQ 3). The third phase of analysis focused on characterizing teachers' interactions with student data. A total of 51 student data episodes, 18 from second grade and 33 from fourth grade, were analyzed.

First, the data source in each student data episode was identified using PLC recordings, field notes, and artifacts. Initial codes were added to the codebook. If more than one data source was referenced during the episode, both data sources were coded. The initial codes were collapsed into broader categories that indicated the type of student data (*Assessment Type*, Table 4.5). (For context, an exit ticket is a simple formative assessment given at the end of a lesson to assess student understanding of a specific topic.) Each episode was coded according to the "assessment type" codes; any episodes referencing both classroom and external assessments received both codes. The data sources were then coded a second time based on whether artifacts displaying student work were present during the episode (*Presence of Student Work*, Table 4.5). The codes for the presence or absence of student work samples ("student work sample present" and "formal data representations, without student work sample present" codes) were mutually exclusive; however, the "observation" code could be applied to an episode along with either of the "student work sample" codes. As such, some episodes received two codes.

Table 4.5

Codes for Student Data Source

Code	Definition	Examples
Assessment Type		
Classroom data	Formative or summative assessment intended for use in the classroom by teachers; could be developed by teachers or curriculum designers; also includes informal assessments such as observations	Pre-assessment, post-assessment, exit ticket, interview, observation
External data	School, district, state, or national assessment; not developed by teachers	Diagnostic screener, state standardized assessment
Presence of Student Work		
Student work sample present	Artifacts showing student mathematical thinking or student strategies, physically or digitally displayed in front of the teachers during the discussion	Exit tickets, classwork, short answer questions, etc. physically present during discussion
Formal data representations, without student work sample present	There is nothing present during the discussion that shows student mathematical thinking or student strategies.	Spreadsheets, graphs present during discussion
Observation	Information about current students gathered by noticing actions, words, strategies, etc.	Noticing student strategies during a lesson

Next, codes were developed to characterize specific aspects of teachers' interactions with student data. The episodes were coded across five categories: episode length, discourse type, student thinking, mathematical content, and connecting student thinking and mathematical content. Within each category, codes were developed through an iterative process. First, a priori codes (e.g., knowledge building indicators (Popp & Goldman, 2016); monologic and dialogic discourse (Horn et al., 2017); interactions with data (Farley-Ripple & Buttram, 2014; Farley-Ripple et al., 2019), identified from the literature, were used to code a subset of the student data episodes. Memoing was used to describe the coding process and to note additional emerging codes. After an initial pass through a subset of the data, the codes were adjusted and collapsed into broader codes and defined in the codebook (Table 4.6). All student data episodes were coded using the refined codes. Because coding was applied at the episode level, episodes with multiple references to the same category (e.g., multiple discussions of mathematical content) received the highest numerical code based on those references.

Table 4.6

Characterizing Teachers' Interactions with Student Data

Category	Code	Criteria	Quote
Episode Length	1	Episode duration less than 4 minutes.	-----
	2	Episode duration between 4 and 10 minutes.	-----
	3	Episode duration more than 10 minutes.	-----
Discourse Type	Monologic	Only one person contributes to the discussion.	-----
	Dialogic	More than one person contributes to the discussion. Contributions are connected and build on one another.	-----
Attention to Evidence of Student Mathematical Thinking			
Category	Code	Criteria	Quote
Discussion of Mathematical Content	1	Vague discussion of mathematical content. Unclear what mathematical content is being discussed OR no discussion of mathematical content.	"I would like to say that every one of my students got it correct today."
	2	Specific discussion of mathematical content. Mathematical content is named only.	"We gave them the standard form and then they wrote expanded and word, but we never went back the other way… All of our practice pages, they didn't have to go from word to standard or from expanded to standard."
	3	Specific discussion of mathematical content. Mathematical content is named and described.	[Describing one way to solve 9 + 6] "Because in your head you're going to think nine plus one is ten but five more is fifteen."

Table 4.6 (continued)

Characterizing Teachers' Interactions with Student Data

Discussion of Student Thinking	1	Vague discussion of student thinking. Unclear what or how students are thinking OR no discussion of student thinking.	"Even kids who are proficient have these random pockets... there's a lot of kids who are red but they have a lot of yellow in here."
	2	Specific discussion of student thinking. Discussion of *what* students were thinking.	"For some of the friends, they're using removal at a time that… is way harder."
	3	Specific discussion of student thinking. Discussion of *what* and *how* students were thinking.	"Oh it's says five minus three, two.... I wonder if the student's thinking of it like a comparison problem, if you were comparing."
Connecting Mathematical Content and Student Thinking	1	No overlap in mathematical content and student thinking codes.	"This tells us that we have 64% of our students who are totally ready to access grade level."
	2	Overlap: mathematical content and student thinking discussed in same quote. Connection is not clear or is not central to the discussion.	"Thinking intentionally of my learners in my classroom, they love a split everything up moment."
	3	Overlap: mathematical content and student thinking discussed in same quote. Connection is central to the discussion OR multiple connections are mentioned throughout the discussion. Connection is clear. Discussion of student thinking and mathematical content each scored at 3.	"Basically, the main strategy all of them are using is skip counting, but when their numbers are high, they just get lost in their additions."

Phase 4: Characterize Rich Learning Opportunities (RQ 4). The fourth and final phase analyzed characteristics of rich learning opportunities with student data. Using findings from phase 3, the student data episodes were filtered to identify episodes with the richest opportunities for learning. Because opportunities for learning were operationalized as "observable oral interactions between an individual or group and other people, ideas, resources, or representations", this process sought to identify the richest moments of discussion as teachers engaged with data. The following criteria were selected to identify the richest learning opportunities (refer to Tables 4.6 for descriptions of codes): 2 or 3 for length, dialogic, 3 for student thinking, 3 for math content, and 3 for connecting mathematical content and student thinking. (See Figure 4.6 for a depiction of this process.) Eight episodes (two episodes from second grade and six episodes from fourth grade) met these criteria.

Figure 4.6

Identifying Richest Student Data Episodes

DATE	NAME	Length	Discourse Type	Student Thinking	Math Content	Math + Student Thinking
9/20	checkpoint 1 - multiples	1	dialogic	3	2	2
9/20	multiplicative comparison exit ticket	3	dialogic	3	3	3
9/20	legislative - planning	3	dialogic	1	2	2
9/20	T/F - planning	2	dialogic	1	2	2
9/20	checkpoint 1 - factors	2	dialogic	3	3	3
9/20	WIN plan for EC kids	1	dialogic	2	1	1
9/20	WIN groups	2	dialogic	2	2	1
9/20	x interview spreadsheet	1	dialogic	3	2	3
9/27	reflect on unit 1 screener	1	monologic	1	2	1
9/27	PR WIN groups	1	dialogic	1	3	1
9/27	planning # corner	1	monologic	2	3	2

A descriptive memo was written for each of the selected episodes, detailing with a rich description how teachers were interacting with the student data and with one another. The template for the descriptive memos is shown in Table 4.7. A sample descriptive memo is included in Appendix D. Field notes and artifacts were referenced to provide context and add insight to the descriptive memos. These memos were used to identify patterns and themes in learning opportunities within and across episodes. The data from these memos was combined and analyzed collectively across the entire case, rather than by unit of analysis, to identify characteristics of rich learning opportunities across all episodes. Multiple rounds of coding were used to develop assertions about opportunities for learning that are supported by data across the PLC meetings.

Table 4.7

Descriptive Memo Template

Grade Level — PLC Meeting Date
Episode name

DATE / TIME

>>>>>>>>>>> DESCRIPTIVE MEMO <<<<<<<<<<<<

Section 1: Thick description

Background context:

Describe in a paragraph what happened. Include quotes as needed.

//

Section 2: Commentary

Data: Note what data informed this episode. What is the format of the data? Who collects and shares the data?

Note how teachers are interacting with data. How does the data drive the discussion?

Student thinking: Note *how* teachers are interacting with student thinking.

Participation: Who is talking? Who is not talking? Who starts the conversation? Who adds on, and to what degree? What's the level of specificity? Does it extend the conversation?

Math content: *How* is math content is centered in this episode?

Connections to instruction: Note *what* connections to instruction are made and *how* those take place.

Learning opportunities: What opportunities might teachers have for learning in this episode? What characteristics of the interactions or other factors may support these opportunities for learning? What am I (the researcher) inferring here?

Other: What makes this a rich episode? What other information is needed to understand this episode? What questions are lingering?

Trustworthiness

In the case study approach, trustworthiness is established through construct validity, external validity, and reliability (Yin, 2018). Construct validity, ensuring that constructs are appropriately operationalized, was addressed by utilizing multiple data sources and creating a chain of evidence (Yin, 2018). To establish external validity, theory was used to demonstrate the extent that findings of this case study generalize to other PLCs (Yin, 2018). In order for future studies to replicate these procedures (reliability), the case study protocol was utilized during the data collection and analysis phases, forming a chain of evidence and developing a case study database (Yin, 2018). Finally, I acknowledge my positionality in this research.

Positionality

As a qualitative researcher, I acknowledge my own positionality with respect to the study at hand (Creswell & Poth, 2016). My personal experiences as an elementary teacher, researcher, and mathematics teacher educator led me to this research. As a teacher, my best opportunities for learning occurred in collaboration with colleagues formally and informally, and I bring that perspective to this research. However, it was in part due to a lack of space for learning as a teacher and a desire for additional learning opportunities that I pursued graduate studies. As a researcher, I am interested in investigating and supporting teacher professional learning for several reasons, two of which are important here. One, I believe there is the potential to leverage teachers' daily interactions with students, colleagues, resources, and ideas to support teacher learning. Two, I believe that teachers are a critical lever in the work of developing positive experiences for students in schools, especially around learning, and I believe teachers can continuously improve their practice by engaging in professional learning.

With respect to data use, my background in mathematics education emphasized the importance of learning from students. I therefore place a high value on gathering data that reveals information about student mathematical thinking, not just summary scores. I see the value of data use in schools, but I also recognize its complexity. Finally, I approach this research on elementary mathematics teaching and learning from the perspective that both students and teachers deserve access to high-quality learning experiences that are grounded in deep understanding of mathematical concepts.

Findings

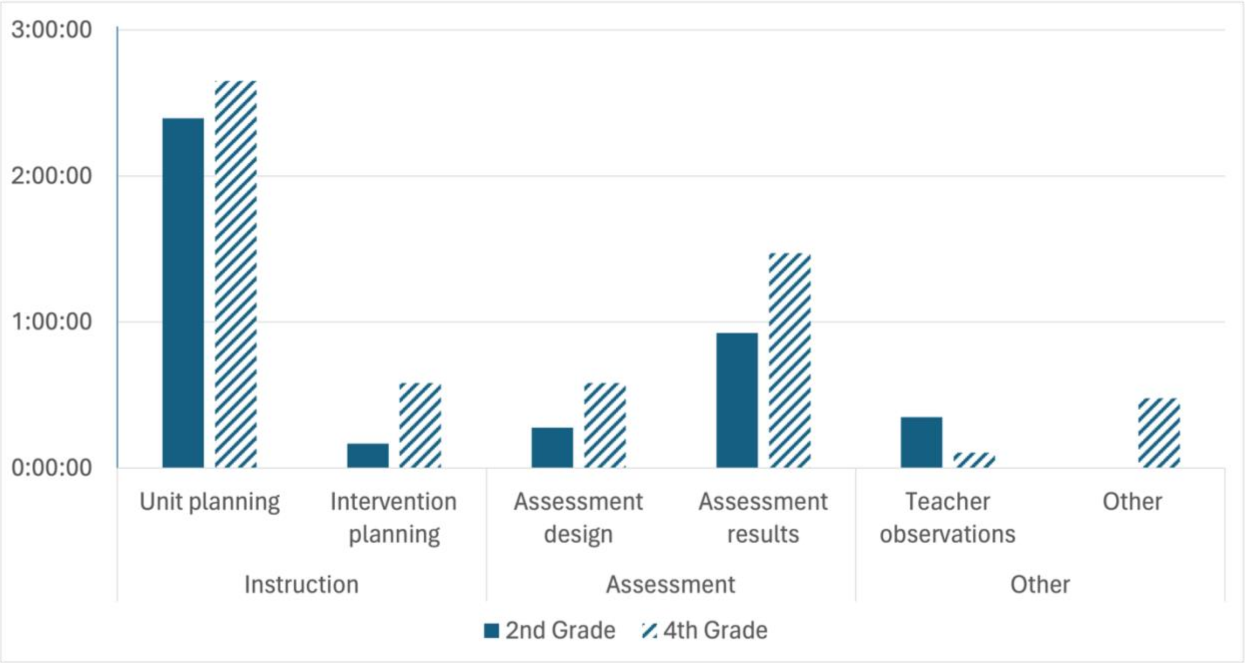
The findings presented below are organized into four sections, corresponding to the four research questions.

Finding 1: PLC Activities

The first research question investigated the activities in which teachers engage during mathematics PLC meetings. The PLC activities fell into three broad categories: instruction, which included planning for upcoming units and interventions; assessment, which included designing assessments and discussing the results of assessments; and other. (See Table 4.4 in methods for definitions.) Both grade levels engaged in these activities, and the total amount of time that each grade level spent on the activities over five weeks is illustrated in Figure 4.7.

Figure 4.7

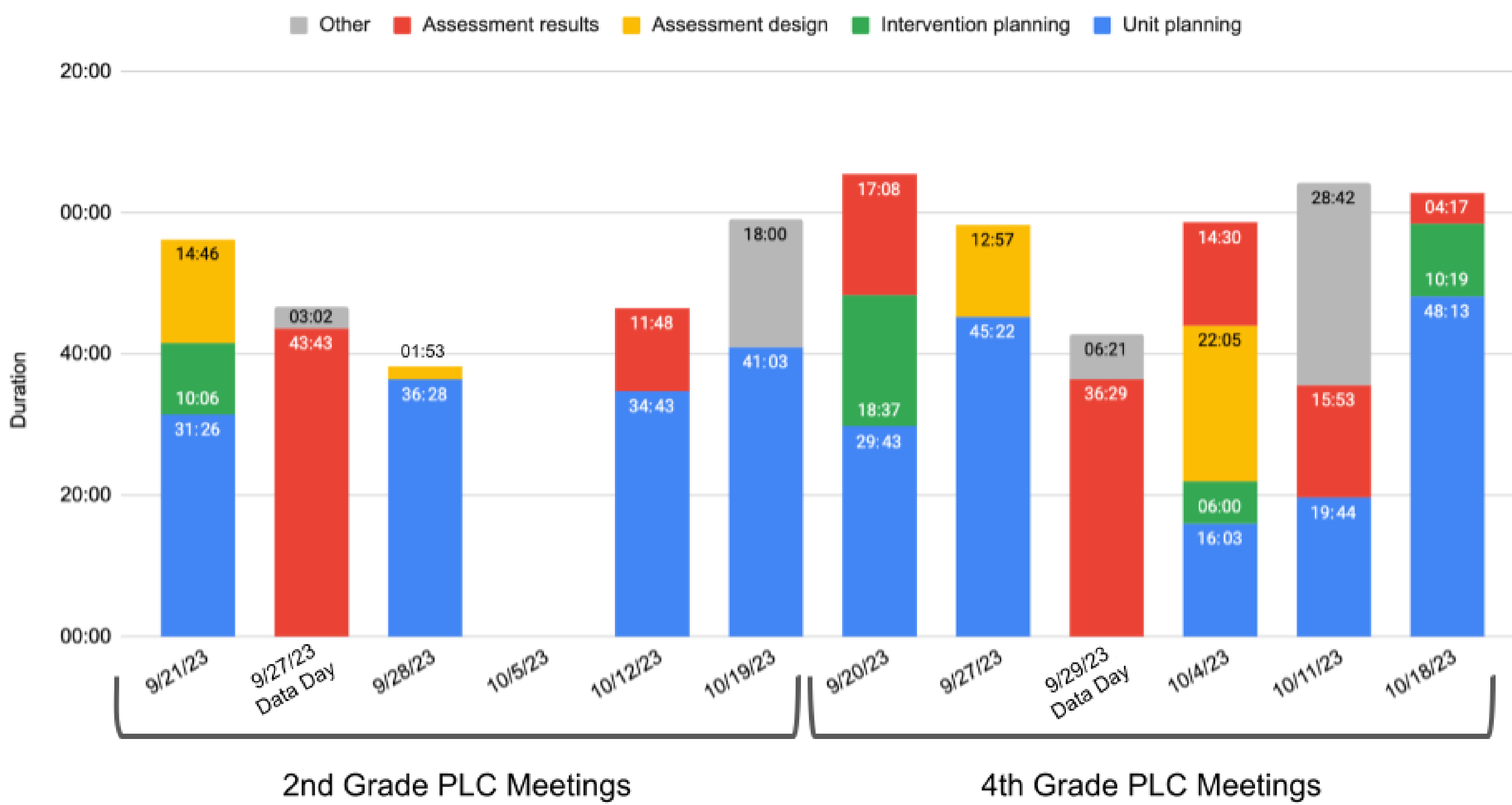
Total Time Spent on PLC Activities by Grade Level



Considering all the recorded meetings collectively (Figure 4.7), more time was spent on unit planning than any other activity. Unit planning was a key part of almost every PLC meeting (Figure 4.8). The primary exception to this was the "Data Day", during which most time was spent discussing assessment results. The activities in which PLCs engaged typically matched the topics listed on the meeting agendas. The agenda for each meeting was set by the mathematics coach, and the agenda was shared with teachers prior to the meeting. Teachers were encouraged to add topics to the agenda as needed. While the agenda was set before the meeting, topics occasionally came up organically during the meeting, and the focus of the meeting shifted in response to teachers' needs. There were no set activities or meeting protocols set by the administrators at this school. However, the emphasis at the school for this academic year was on "data and small groups", which may have influenced the activities within the PLCs (see Chapter 3).

Figure 4.8

Time Spent on PLC Activities Across All PLC Meetings



Finding 2: Occurrence of Student Data Episodes

The second research question examined the episodes, across all PLC activities, where teachers discussed student data. As a reminder, a "student data episode" was defined as a portion of a PLC meeting that references information about current students' mathematical knowledge. A student data episode could occur at any point during the PLC meeting, not only when teachers were discussing assessments. (See Figure 4.5 for an example.)

A summary of the student data episodes can be found in Table 4.8, and the distribution of student data episodes across PLC meetings is shown in Figure 4.9. The student data episodes occurred across all PLC meetings and ranged widely in length. A reminder to the reader that the purpose of presenting these statistics is to paint a contextual picture of how student data discussions are represented within these PLC meetings. The goal is not to suggest that more data episodes or longer data episodes are necessarily better for PLCs. As suggested by the data in Table 4.8, there was variation between the second- and fourth-grade PLCs in the duration of student data episodes. There is a notable difference in the total number of student data episodes, with the fourth-grade PLC engaging in almost twice as many student data episodes as the second-grade PLC. This difference is due in part to the difference in total recording time (see Table 4.2).

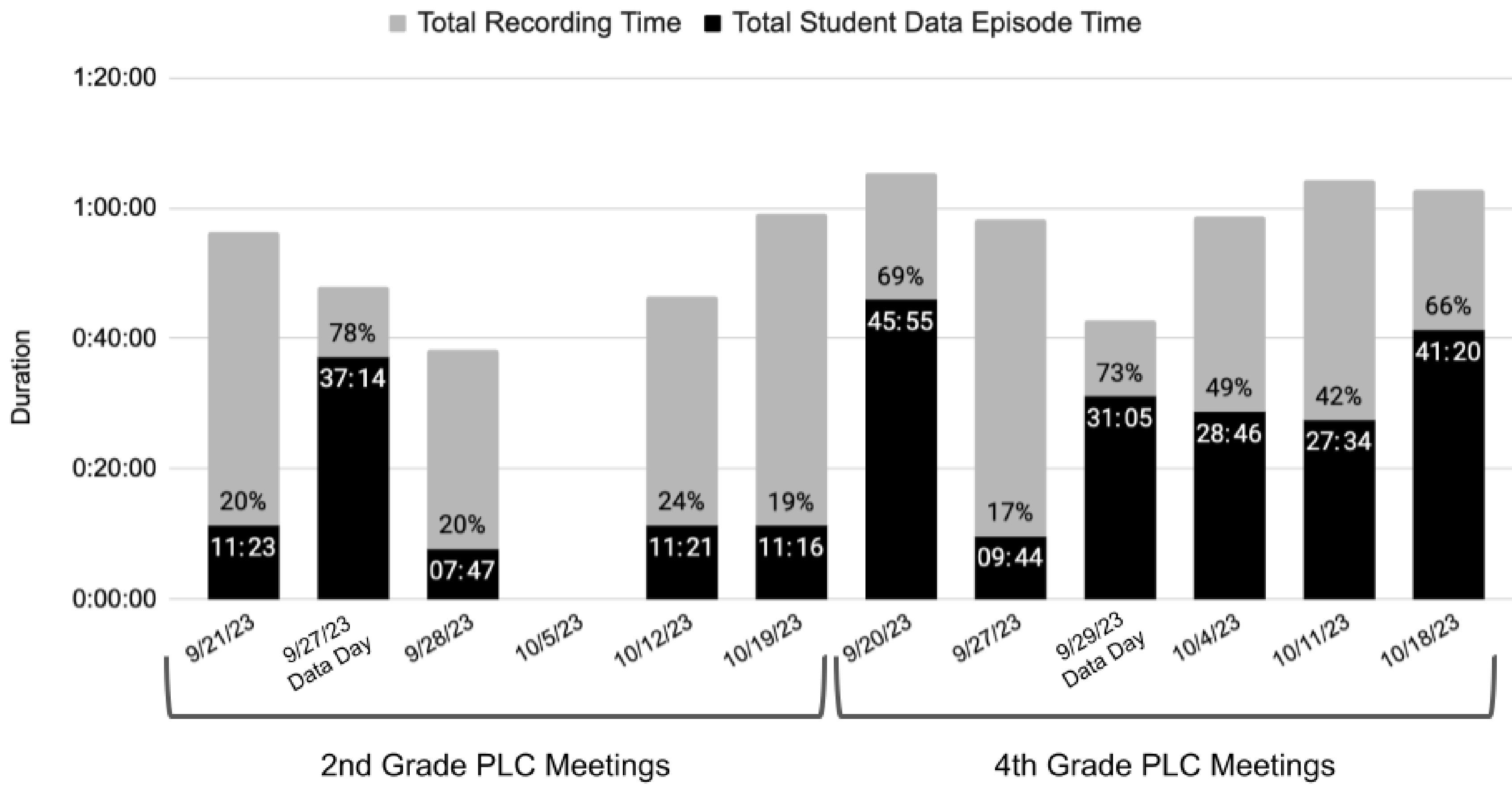
Table 4.8

Summary of Student Data Episodes

Student Data Episodes		
Total Number of Episodes	18 episodes	33 episodes
Mean Episodes per Meeting	3.6 episodes	5.5 episodes
Range of Episodes per Meeting	3 – 4 episodes	2 – 8 episodes
Mean Episode Length	03:30	05:23
Median Episode Length	01:15	04:39
Range of Episode Length	00:10 – 15:28	00:26 – 14:49

Figure 4.9

Total Time in Student Data Episodes Across PLC Meetings

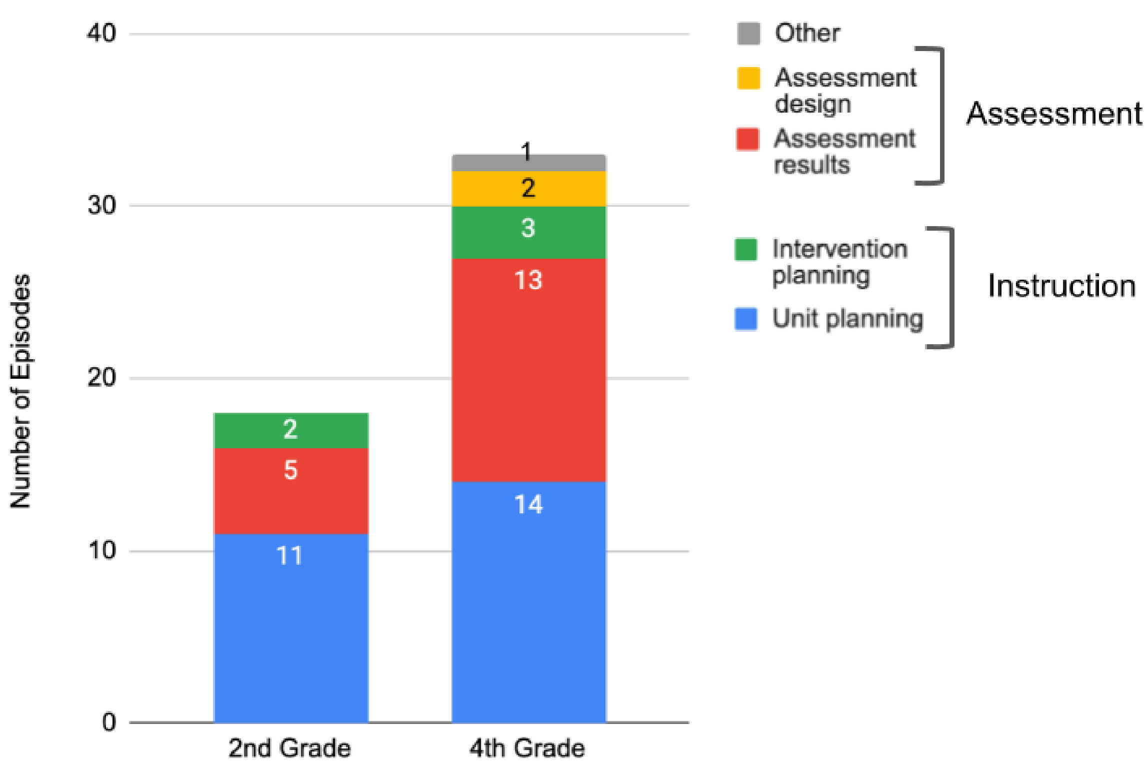


Note: The percentage refers to the percent of the total meeting time that was included as student data episodes.

In addition to variation in length, there was variation in the activities during which the student data episodes occurred in the PLC meetings (Figure 4.10). Not surprisingly, teachers spent time engaging with student data when discussing assessment results. However, student data was also a topic of conversation as teachers planned instruction, assessment, and intervention. When teachers were not explicitly discussing assessments results, student data was typically brought into the conversation organically. For example, a teacher would reference an observation of her students during the math lesson that day to support decision-making when the team was planning lessons for the following week. Overall, student data was most frequently referenced as teachers planned upcoming units and, not surprisingly, discussed assessment results. As a reminder, these two activities also occupied the most time during the PLC meetings (Figure 4.7).

Figure 4.10

Distribution of Data Episodes Across PLC Activities



Finding 3: Characteristics of Student Data Episodes

To answer research question 3, “In elementary mathematics PLCs, what are the characteristics of teachers’ interactions with student data, including their attention to student mathematical thinking?”, the student data episodes were characterized across the following categories: data source, discourse type, length, and discussion of student thinking and mathematics. The characterizations for data source are shown in Table 4.5, and the remaining characterizations are shown in Table 4.6.

Data Source. Each episode referred to one or more data sources to spur conversations about student data. These data sources were classified in two separate ways: type of assessment, and presence of student work samples (refer to Table 4.5 in the methods section). As illustrated in Table 4.9, both PLCs primarily relied on classroom assessments in conversations about student data. These classroom assessments included formal assessments like unit tests and informal assessments like observations. The fourth-grade PLC relied more heavily on classroom assessments, particularly observations, in discussions of student data. While both grade levels referenced multiple data sources at times, only the fourth-grade PLC discussed their own classroom assessments with data from external assessments simultaneously. Of all the student data episodes, there were only a few episodes where teachers referenced student work samples physically or digitally in front of them (Figure 4.11). In the other cases, teachers looked at spreadsheets or graphs of assessment results, and/or they described classroom observations of students.

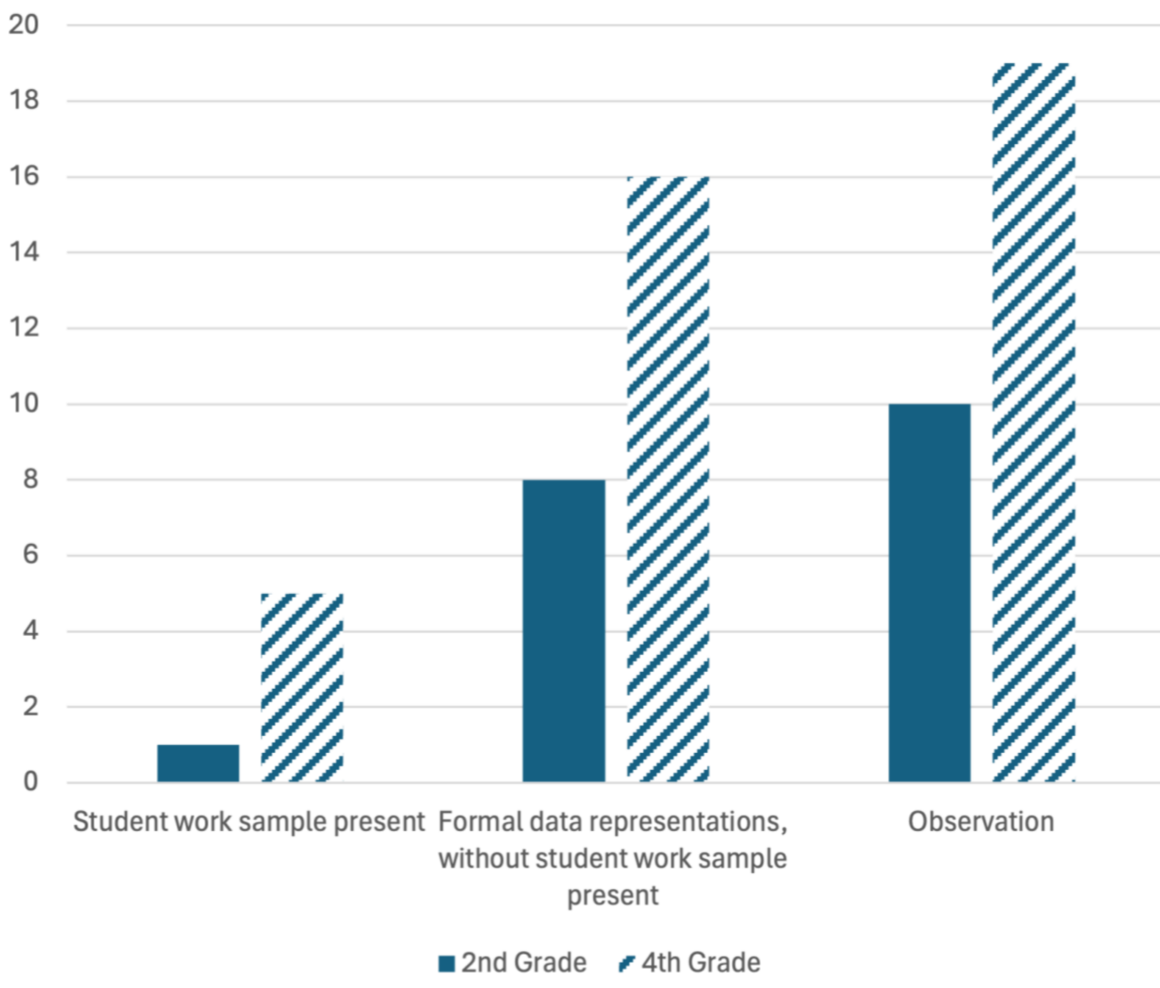
Table 4.9

Data Sources Referenced in Episodes

	Number of Episodes		
	2nd (n=18)	4th (n=33)	Examples
Classroom data	12	25	Post-assessments, observations, exit tickets
External data	6	5	State assessment, diagnostic screener
Both types of data included	0	3	Both classroom and external assessments mentioned

Figure 4.11

Presence of Student Work Samples Across Data Episodes



Discourse Type. Almost all the student data episodes were dialogical in nature, meaning that two or more PLC members engaged in dialogue. The coach typically initiated more formal conversations about student data (i.e., transitioning to "data analysis" activities), while both teachers and the coach initiated the informal conversations that took place across PLC activities (e.g., referencing exit ticket data when planning upcoming instruction).

Characterizing Discussions of Mathematical Content. Teachers' discussions of mathematical content in student data episodes were organized into three clusters based on characteristics of the discussion (refer to Table 4.6). There were some moments where mathematical content was discussed vaguely or not at all. For example, one teacher described her students in the following way: *"I know that some students I'm thinking of, they need repeated practice with the skill that they keep getting pulled out for or they need practice time. They don't get a lot of practice time because they're always with the teacher."* The teacher is describing the current needs of her students in mathematics, but there are no specific references to mathematical concepts or which skills students need to practice.

In the second cluster, teachers named mathematical content but did not offer any further description. For instance, the statement, *"I was really, really happy with even and odd compared to last year and the ability to write an equation with two equal addends,"* referenced specific mathematical concepts covered in the second-grade standards. However, the mathematics was mentioned in name only; there was no description of what it meant to *"write an equation with two equal addends"* at the second-grade level.

In the third cluster, teachers named and described specific mathematical content. Rather than saying they wanted to work *"in small groups… [on] more place value stuff,"* teachers described which aspects of place value they want to address, such as *"talking about like, the* *value of the six is sixty… [and] the six is in the tens place…"* in the number 62. This description offered a clearer and fuller depiction of the mathematical content being referenced.

Characterizing Discussions of Student Thinking. Teachers' interactions with student thinking were classified in three clusters (refer to Table 4.6). In the first cluster, teachers either talked about student thinking in vague ways or did not reference student thinking at all in their discussions of student data. For example, *"I would like to look at my place value checkpoints again, because there were definitely some areas we need to build a lot more there, so maybe using next week as a lot of small group time to have-- like catch up on things that we need."* This statement has much potential because the teacher notices areas for growth based on the assessment results and begins to develop a response to that data. However, her description is too vague to learn anything about the students' thinking.

The second cluster characterized moments where teachers mention something about *what* students were thinking but did not elaborate further. This cluster was similar to the second cluster of "mathematical content" where moments were specific but not descriptive. For instance, a teacher shared about her students' progress by saying, *"But they did it well, they can locate the decades now."* This statement provides some information about the "what" of the students' thinking; it indicates what skill the students are working on and their ability to demonstrate understanding of that skill. However, this statement is missing information about *how* students are thinking about the task.

The third cluster included moments where teachers described both *what* students were thinking and *how* they were thinking about it. In these moments, teachers tended to indicate the strategies students were using, describe students' process for solving a task, or point out specific steps in student work. For example, Coach Sam described the interactions she had with students during one of her fourth-grade classroom visits. *"These kids know how to compose and decompose numbers like nobody's business. The thinking that I just heard blew me away… what he was doing was making new groups of hundreds, like decomposing numbers to make a new hundred and decomposing to make a new 10. 'Well, that's a hundred. That would make a new hundred and then I'd have 20 left over.' And I'm like, 'Yes, that's great. Now let's just work on how you show this thing.' It was pretty amazing today. I really enjoyed it. It's the highlight of my day."* Here, the coach provides a description to communicate information about how the student composed and decomposed numbers.

Characterizing Connections between Mathematical Content and Student Thinking. The final way that student data episodes were characterized examined the connections between mathematical content and student thinking (refer to Table 4.6). In this category, the first cluster included all episodes where discussions of mathematical content and student thinking did not overlap. A common trend in this cluster involved references to student data in vague ways that mentioned scores or groupings (i.e., colors, levels) that were devoid of mathematical content or student thinking. For instance, *"[Student A] obviously all has the 1s, but going horizontal is where I'm seeing more patterns. I see a majority of threes for mine, which I love, but a lot of the kids, they're either green with maybe one or two red and yellows, or they're red, or yellow."* This discussion centered around student data in mathematics, but there was no mention of the mathematical content or the student thinking, let alone a connection between them.

The second cluster of episodes in this category included at least one mention of student thinking about mathematical content. However, this mention was either vague or not a central component of the episode. For example, during a discussion of a unit assessment, a second-grade teacher shared, *"A lot of them just decided, I'm going to count up how many beads there already* *are and tell you that."* This comment was not taken up by the group and not a central part of the episode.

The third cluster of episodes included clear references to student mathematical thinking that were central to the discussions in the episode. Both the student thinking and the mathematical content were described clearly in these moments. The example below provides an illustration of this cluster.

Lucy: *When we did that lesson last Thursday where they made the three largest numbers possible…. [the digits were] a nine and a five and a three, so majority of them were like, "Oh 953." And then we're like, "Okay now make the second largest number you can." They were like—*

Emma: *"593."*

Lucy: *593. So they didn't realize they could have kept the digit nine in the hundred's place, and I was like, "Whoa, why'd you do that?" And so that prompted--*

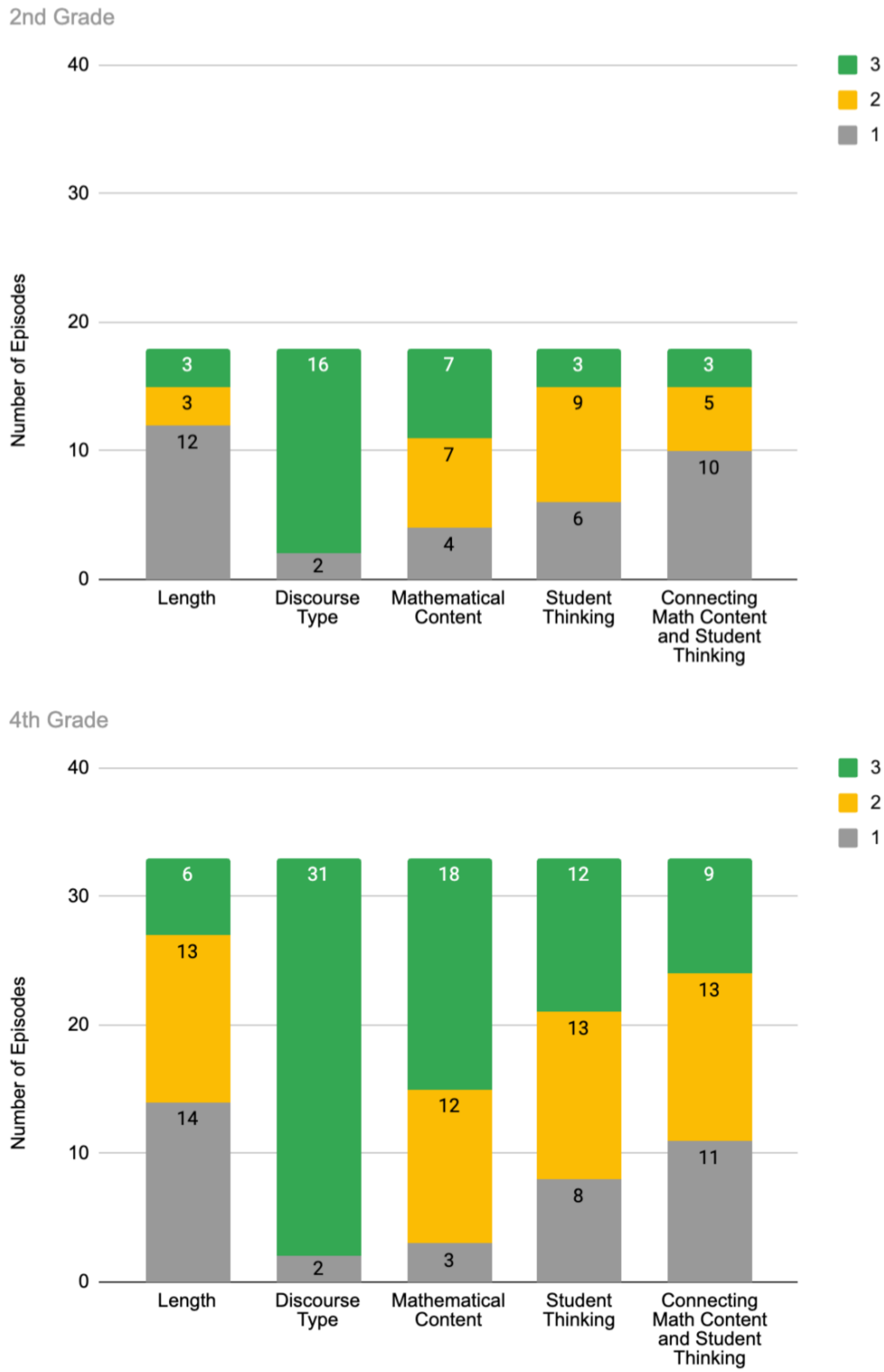
Emma: *So I would show them, I would build 935 and be like, "Oh, so where would you put this number in your lineup?" And they'd be like, "Oh, as number two."*

In this moment, Lucy and Emma share an example that includes a clear, specific description of student mathematical thinking. There is enough information provided here for others to understand the mathematical content and the ways students were thinking about that content.

Distribution of Characterizations Across Data Episodes. As demonstrated in Figure 4.12, there was variation in how teachers discussed student thinking and mathematics across the data episodes. Mathematical content was typically mentioned with specificity at some point in the episode, but it was not always described. The discussion of student thinking was distributed relatively evenly across the episodes in fourth grade, but there were fewer episodes that specifically discussed how students were thinking in second grade (three episodes). In those three episodes, however, the discussion was clearly focused on student mathematical thinking. More than half of the data episodes in fourth grade included some discussion of student mathematical thinking.

Figure 4.12

Distribution of Characterizations Across Data Episodes



There was also variation in when these types of discussions took place. Figures 4.13 and 4.14 illustrate how the classifications for “connecting mathematics and student thinking” were distributed across data sources. Putting these three figures in conversation, the richest discussions of student mathematical thinking occurred when teachers were discussing classroom assessments, most often either observations or with student work samples present. There were no rich discussions of student mathematical thinking during the designated “Data Days”, during which the conversation focused on external assessments with no student work samples present.

Figure 4.13

Discussions of Student Mathematical Thinking based on Assessment Type

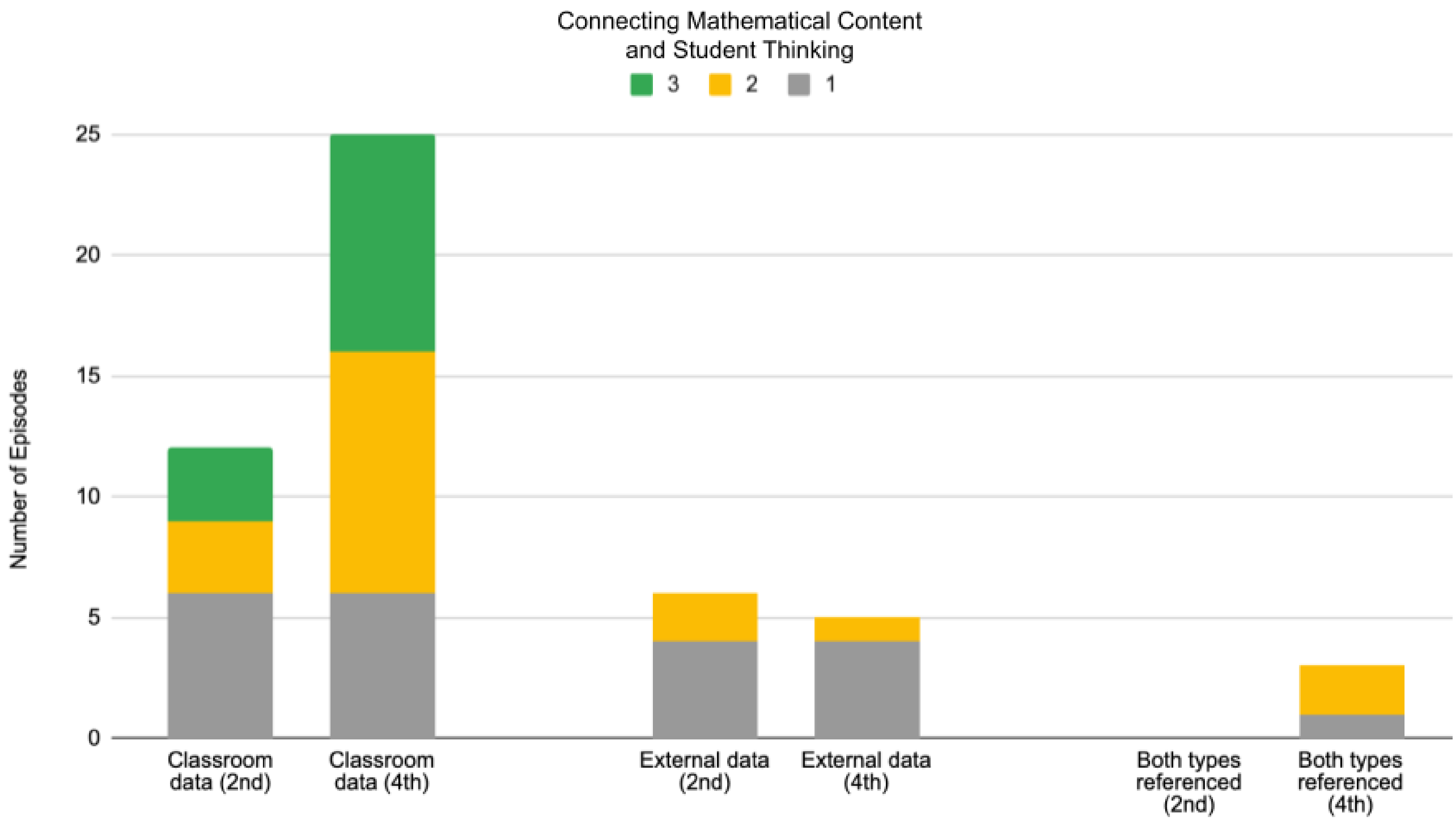
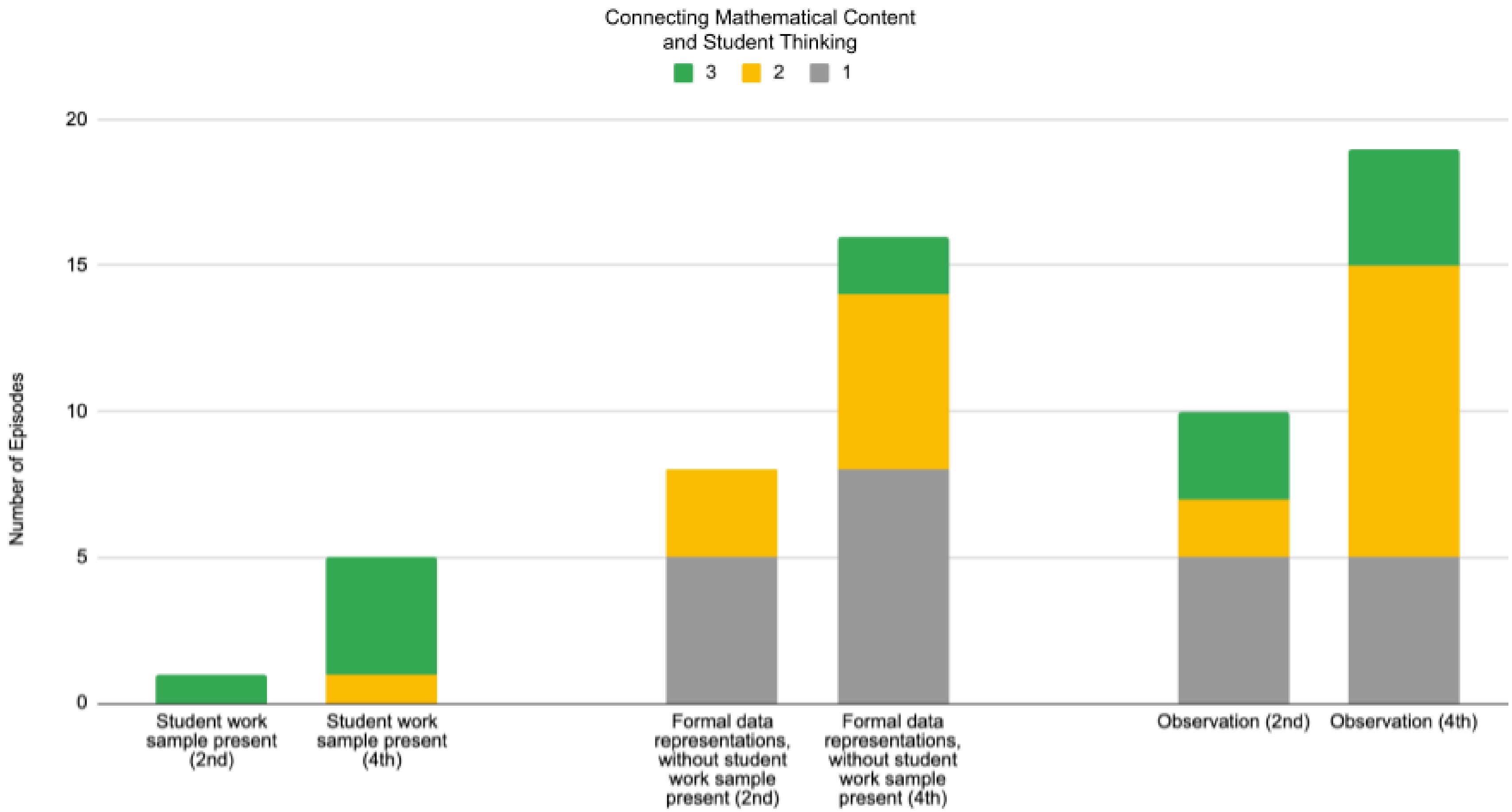


Figure 4.14

Discussion of Student Mathematical Thinking with Student Work Samples



Finding 4: Rich Opportunities for Learning with Student Data

The fourth and final research question investigated the characteristics of rich learning opportunities with student data. As a reminder, the criteria for being a rich learning opportunity with student data is as follows: student data episode, at least four minutes long; dialogic discourse, and 3 for the following codes: "discussion of mathematical content", "discussion of student thinking", and "connecting mathematical content and student thinking". Five characteristics emerged through the analysis of the rich learning opportunities (Table 4.10). Each characteristic is paired with an assertion about the characteristic and is described in further detail in the following sections.

Table 4.10

Characteristics of Rich Opportunities for Learning with Evidence of Student Mathematical Thinking

Characteristic	*Assertion*
(1) Partial understanding	Teachers examined students' partial understanding of mathematical concepts.
(2) Uncertainty	Teachers leaned into uncertainty and asked questions about student thinking.
(3) Replays	Teachers used replays (Horn 2005; 2010) to offer others a window into their practice.
(4) Inviting participation	Teachers invited other teachers to participate in the conversation.
(5) Connecting data to instruction	Teachers offered suggestions and made plans for how to respond instructionally to student data.

(1) Partial Understanding. In the richest episodes, teachers examined students' partial understanding of concepts as they analyzed student data. This meant that teachers moved beyond looking at students' responses as simply correct or incorrect and noticed when students were demonstrating some understanding of a concept that was not fully mastered. Teachers pointed out specific errors that students made, noticed trends in students' mistakes, and attended to inefficient strategies, all with the goal of building on student understanding to reach mastery. These are potential learning opportunities because teachers can grow in understanding of specific student needs, investigate the development of mathematical understanding in nuanced ways, and view student learning from an asset-based lens. Two examples are provided below to illustrate this characteristic.

Example 1A: Number forms exit tickets (4^{th} grade). In this first example, the fourth-grade teachers are looking through exit tickets that students had completed earlier that day. The exit ticket (Figure 4.15) assessed students' understanding of number forms, specifically standard, expanded, and word form. Initially, the conversation is about whether students have answered the exit ticket correctly. Partway through the discussion, however, the teachers begin to notice more nuanced aspects of the student work.

Figure 4.15

Standard, Expanded, and Written Form Exit Ticket

Name_______________________________ I can write numbers in standard, expanded, and written form.

1. Complete the chart.

standard	
expanded	90,000 + 9,000 + 400 + 3
written	

2. Complete the chart.

standard	
expanded	
written	eighty-three thousand, fifty-two

Drew: *This is where I dive into a little bit more though because my other four [students], the mistake that they made was that they put the 9,000 as 900.*

Riley: *Mmmhmm. I had one do that as well.*

Drew: *And so then, the second number was correct. And so I kind of put them in a group, because that's more, I kind of need to go and*---

Coach Sam: *I have two who did that. (holding up two exit tickets)*

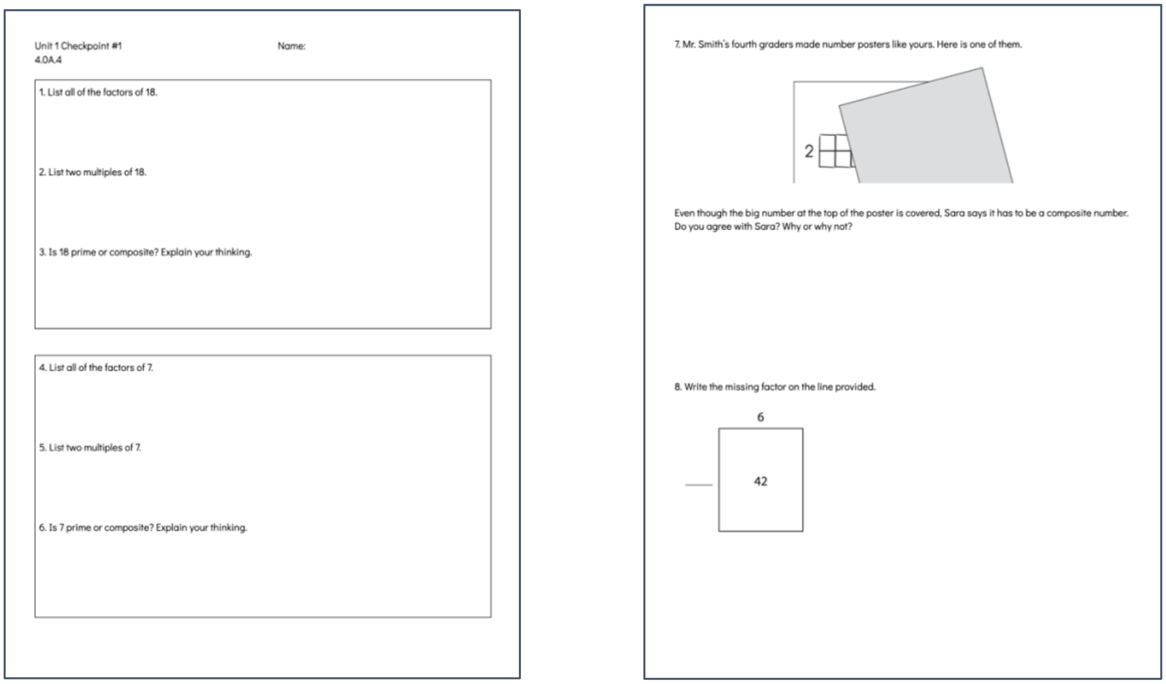
Riley: *Or like most of the time they got at least one of the forms correct. Like they knew how to write the number in standard form, but maybe they missed the 99,000, they missed the nine or they wrote like 90,000, 9,000, you know or like... So for me, my ones who got it wrong, it wasn't like nothing was there, it was just like, oh, we need some little push in the right direction.*

In this moment, Drew shifts her focus beyond accuracy to students' partial understanding. Rather than just saying the responses were "incorrect", Drew describes how she "dives into a little bit more" of the student thinking. She examines students' responses to see what specific mistakes students are making, then groups the responses based on patterns she notices. A few lines later, Riley continues this emphasis on partial understanding. Riley explains that some students have demonstrated understanding with one skill, such as "writ[ing] the number in standard form," but may not have demonstrated mastery of all the skills assessed on this exit ticket.

Example 1B: Students' understanding of factors (4th grade). In this second example, Coach Sam is engaging teachers in a conversation about students' progress based on a recent mid-unit assessment (Figure 4.16) and exit tickets (Figure 4.17). This episode begins with Coach Sam asking teachers whether students demonstrated their understanding of factors on the assessments.

Figure 4.16

Mid-Unit Assessment (Factors, Multiples, Prime and Composite Numbers)


Unit 1 Checkpoint #1 Name:
4.OA.4

1. List all of the factors of 18.

2. List two multiples of 18.

3. Is 18 prime or composite? Explain your thinking.

4. List all of the factors of 7.

5. List two multiples of 7.

6. Is 7 prime or composite? Explain your thinking.

7. Mr. Smith's fourth graders made number posters like yours. Here is one of them.

Even though the big number at the top of the poster is covered, Sara says it has to be a composite number. Do you agree with Sara? Why or why not?

8. Write the missing factor on the line provided.

Figure 4.17

Factors Exit Ticket

Exit Ticket Name:

Which list includes all of the **factors** of the number 24?

A. 1, 2, 4, 6, 12, 24

B. 1, 2, 3, 4, 6, 7, 12, 24

C. 1, 2, 12, 24

D. 1, 2, 3, 4, 6, 8, 12, 24

Coach Sam: *How did we do on factors?*

Riley: *Pretty much everybody had... At least with my folks, pretty much everybody had a strategy or was able to find some factors. Were they able* *to find all of the factors? Not necessarily. So that I think is what my friends need practice with.*

Coach Sam: So Blake's kids were having trouble with that…

Blake: Oh yes. They did an exit ticket for their morning work…

Coach Sam: And there was a huge chunk that missed the three times eight…

In this exchange, the teachers notice trends across their classes. Most students could identify some factors of a number, but not everyone could identify all the factors. This perspective emphasizes students' partial understanding. Rather than just labeling responses as "incorrect" when students left off some of the factors, the teachers look more closely at the work to see what students *do* understand. Riley notices that students are using strategies and points out that by identifying some of the factors, students are demonstrating partial understanding of the concept. Coach Sam recaps a similar trend from Blake's class and points out specifically which factors the students missed (three and eight). By noticing this developing understanding among her students, Blake was able to adjust her instruction and model strategies that could help students systematically identify all the factors of a number. (For a full description of Blake's instructional response, see Example 5A.)

In Examples 1A and 1B, there were more opportunities for learning about student data than would come from just looking at correct or incorrect responses. The teachers noticed specific aspects of student work. This has the potential to offer more insight into student thinking, both how students are thinking and why they made specific choices. There are numerous ways students could obtain a correct or incorrect response, and noticing partial understanding provides information about their process – information that teachers could leverage – that is hidden when responses are just marked as "incorrect". Uncovering this information could support teachers in developing intentional instructional responses based on student thinking, such as Blake's response in Example 5A.

(2) Uncertainty. Teachers leaned into uncertainty which showed up in a few ways: wondering about the data, asking questions about the data, and showing professional vulnerability. When discussing student data, the teachers wondered aloud about how students were thinking rather than jumping to conclusions about student thinking. The teachers asked questions, especially "why" questions, about the student data. The teachers showed professional vulnerability, admitting that they did not know something in front of their peers. These are potential learning opportunities because the admission of uncertainty opened the floor for discussion and allowed other people to share their thoughts. It also normalized "wondering" as a process of considering multiple possible answers and weighing the validity or benefit of each. This theme is illustrated through the examples that follow.

Example 2A: Open number line (2nd grade). In this episode, the teachers are planning for small-group instruction the following week. Carmen mentions that her class has been working with open number lines as a strategy for addition and subtraction. She has noticed that the students consistently move from left to right on the open number line, even when they are subtracting. This spurs a discussion about why the students are thinking about an open number line this way.

Coach Sam builds off Carmen's thinking by describing her own experiences working with younger students on *"the forward counting and backward number sequence"*. She gives the example of a first-grade student who easily counts forward but struggles to identify the previous number in the counting sequence. Coach Sam pulls out a plastic mat with a linear series of counting numbers, places it on the floor, and demonstrates how students use the number mat to count forward and backward.

Coach Sam: *I was thinking about the transition to the open number line. My first grader uses a number path and actually has to hop backwards on it. (demonstration with number path) … I'm just wondering, if they're unsure about the open number line and which direction it goes, if they still need that number line mat that comes with [our curriculum] or something that's more tangible.*

In this moment, Coach Sam wonders aloud about why the students are struggling with this concept of direction on a number line. She brings the conversation deeper by connecting to foundational counting concepts, implying that teachers may need to consider students' underlying conceptual understanding of the counting sequence alongside their understanding of number lines. She demonstrates how her wondering leads her to consider potential instructional responses, such as working with a number line mat. Coach Sam's comment opens space later in the episode for several more ideas to emerge, each considering how to develop students' understanding of adding and subtracting on an open number line. This encourages the teachers to consider multiple possible responses to student data before selecting one. The present exchange continues with Coach Sam offering an alternative to her initial suggestion.

Coach Sam: *The other thing you could do is have them do the number line and just let them go the wrong way. And then pull out your number line to 20 and be like, "Okay, now let's show it on this. What's different? Why is it different? Oh, okay." Instead of having to say over and over, maybe them making the error and checking it themselves and realizing it would make them more*

> *aware. I don't know. I've just been trying to think about that since we talked about, why do kids have such a hard time thinking about which direction going on the number line?*

At the end of her comment, Coach Sam makes several important points. First, she demonstrates and normalizes professional vulnerability by saying "I don't know." This could encourage professional vulnerability from others in the PLC, knowing that it is acceptable to admit when you are still wondering and do not have an answer. Next, Coach Sam poses a specific question to the teachers, wondering why students have a hard time thinking about direction on a number line. She highlights the importance of considering not just what students are doing but why they are doing it. When she presents this question, Coach Sam explains that she has been thinking about this question over time. She demonstrates that she takes time to ponder questions, setting the expectation that questions do not need to be answered immediately. Finally, Coach Sam leaves her question unanswered, posing it to the teachers instead. This sets the expectation that she as a coach does not have all the answers and invites the teachers to participate in the conversation.

Example 2B: Multiplicative comparison exit ticket (4th grade). This episode takes place as the fourth-grade team is sharing the results of an exit ticket on multiplicative comparison (Figure 4.18). The teachers have the exit tickets displayed in front of them. The episode begins with Coach Sam asking Maria to share the results from her class.

Figure 4.18

Multiplicative Comparison Exit Ticket

Exit Ticket 1 Name:

Sergio has 5 stickers. His older brother has 3 times the number of stickers as Sergio has. How many stickers does his older brother have?

A. 25
B. 15
C. 2
D. 8

Coach Sam: How about you, Maria?

Maria: Most of them were right. Two of them picked 8. One, 25. The other one C, two.

Blake: What is that work they have there? (Maria holds up exit ticket for the student who selected C.) Oh, it says five minus three, two.

Coach Sam: Yeah, I mean she even wrote the equation.

Blake: She did.

Maria: Mmmhmm. (pause) Surprise.

Blake: I wonder if the student's thinking of it like a comparison problem, like if you were comparing...

Drew: Like how many more.

Blake: That kind of problem, yeah.

Coach Sam: How many stickers....

Blake: I'm trying to think what might've triggered that thinking in the problem. Not sure.

Coach Sam: Sergio has five times...

Drew: *It'd be interesting to go back and ask like, "Why did you subtract? What words in here made you think you should subtract?"*

In this exchange, the teachers dive in deeply to investigate one student's response. The student had selected C on the exit ticket (Figure 4.17). Blake, the fourth-grade lead teacher, immediately looks more closely at the student work and shares her noticing with the others. The student had written an equation to show her thinking (5 – 3 = 2), indicating that she had solved the problem by subtracting. Given that this is all the teachers have to work with, they begin to wonder aloud about the student's thinking. In doing so, the teachers open the space to a host of potential learning opportunities.

First, Blake considers the possibility that the student viewed this as an additive comparison question. ("Sergio has 5 stickers. His older brother has 3 stickers. How many more stickers does Sergio have?") This draws the other teachers' awareness to a common student misunderstanding, potentially supporting their understanding of how students conceptualize additive and multiplicative comparisons. Next, Blake makes her thought process explicit. "I'm trying to think what might've triggered that thinking in the problem." She emphasizes to the others that it is important to unpack how the student was thinking about this problem to make sense of their answer. This not only normalizes the process of wondering about student thinking, but it unveils an otherwise invisible thought process (replay of data analysis, see Example 3A) and suggests that there is something important to be learned about students' in-progress learning (see Section 1, Partial Understanding). Blake ends her comment with the phrase, "Not sure," suggesting that it is normal to not have an immediate explanation when examining student thinking. Finally, Drew articulates questions that she would like to ask the student about her thought process. Drew's comment emphasizes the importance of asking why questions about student thinking and understanding student sense-making.

Across Examples 2A and 2B, there were multiple occurrences of teachers leaning into uncertainty. Teachers displayed professional vulnerability, asked questions, and wondered about student mathematical thinking. In each of these cases, space was opened to allow for learning. Rather than shutting down conversations with certainty or unasked questions, these practices allowed more ideas to flow, offering potential learning opportunities. There was a distribution of power as the coach and lead teachers admitted when they did not have the answer, inviting other teachers to share their ideas or uncertainties as well. By asking questions about student thinking, these teachers unpacked the student data at a deeper level that offered more opportunities for learning about student mathematical thinking than would have been revealed if the analysis had stayed at a surface level.

(3) Replays. Teachers used replays to offer others a window into their practice (Horn 2005; 2010). This showed up in two ways. One, teachers described in detail how they thought about data analysis. Two, teachers described moments from their classrooms, either their teaching practices or their interactions with students, in detail. These are potential learning opportunities because other teachers gained access to practices that would otherwise have remained hidden. The added detail could allow teachers to learn from and replicate these practices themselves. The following examples illustrate this theme.

Example 3A: Replay of data analysis (4th grade). The episode begins with Coach Sam inviting Drew to lead the group's discussion of the number form exit tickets (see Example 1A above). In the exchanges that follow, Drew walks the other teachers through her thought process for data analysis.

Drew: *Okay, so my exit tickets here I'm looking at-- (flips through exit tickets, holds up four) I only have four kids that they've got it correct. Right? (other teachers flip through exit tickets as well) ... So that to me says that's not a tier issue. That's now a core issue.*

Blake: *It is.*

First, Drew explains that she sorts through the data to determine the number of students who answered the exit ticket correctly. Only having four of her eleven students successfully complete the exit ticket alerts her to the fact that revisiting this content is a pervasive need across the class, or a “core” need. She makes this first step in her analysis process clear for other teachers so they can do the same. Next, Drew describes how she is going to use that information.

Drew: *But also we need to keep going with our curriculum somewhat. So I was saying, I'm now going to be more intentional about reteaching this stuff in small groups. And it's just an added planning…*

While Drew acknowledges that her data indicates that revisiting this content is a “core issue”, she quickly contrasts that with the fact that the team needs to continue moving through the curriculum. The need to “keep going with the curriculum” is a reference to the constant pressures of timing and pacing in in today’s classrooms. As a result, Drew explains that she made the decision to address number forms again in small groups and continue with the curriculum at the normal pace for whole class instruction. She offers the others a window into her decision-making, offering them information about how she balanced meeting students’ needs with covering all the fourth-grade content.

After this, Drew describes her next phase of analysis.

Drew: *This is where I dive into a little bit more though because my other four [students], the mistake that they made was that they put the 9,000 as 900.*

Riley: *Mmmhmm. I had one do that as well.*

Drew: *And so then, the second number was correct. And so I kind of put them in a group…*

Here, Drew explains how she looks more closely at the student work. Once she knows which students have answered the question correctly or incorrectly, she examines their responses to identify the specific mistakes that students are making. Then, she makes groups of students based on similar response patterns. By describing this process aloud, Drew helps other teachers understand her thinking. They can see how she looks closely at the student responses and notices trends across the class. Drew also explains that she uses this information to form small groups, implying that she could develop a small group instructional plan to meet the specific learning needs of students with that response pattern.

Across this episode, Drew is intentional about "thinking aloud" about her data analysis practices. She has been charged with leading this part of the PLC, and she describes her thinking out loud to show the other teachers the steps in her process. This results in a potential learning opportunity for the other teachers. They can now "see" Drew's thinking (which would otherwise be invisible), potentially try out her data analysis practices on their own, or offer Drew suggestions for how to modify or improve her process.

Example 3B: Replay of classroom interactions (2nd grade). In this episode, the second-grade team is partway through a unit on place value and measurement. The students have been using trains of colored Unifix cubes to measure the perimeter of paper rectangles. Through class discussions, the teachers have been showcasing student strategies that capitalize on place value knowledge (i.e., building trains of five or ten cubes to support counting) and properties of rectangles (i.e., opposite sides of a rectangle are congruent).

Coach Sam begins by transitioning the second-grade team to lesson planning for the upcoming week. Marybelle immediately speaks up and suggests that the team includes time during the upcoming week for students to continue practicing the skills from the previous week (i.e., counting by fives and tens, and measuring rectangles). In the quote that follows, Marybelle provides a description of what has been taking place in her classroom over the past few days.

Marybelle: *... For some others, what's not as clear as I wanted [is how] to use the counting by fives and by tens to measure. And some of them have spent a lot of time trying to figure out what to do… I think that they also need to continue working on that. Because maybe for us, we assume that they're going to figure it out that, "Oh, in a square, four sides equal. In a rectangle these two sides (gestures with hands to show left and right sides of a rectangle) are the same as these two sides (gestures with hands to show top and bottom of a rectangle)." For us it's clear, but for some of them, no. And I have to spend a lot of time showing them with the concrete material that, "Oh look, I put here 40 [cubes] (gestures with hands to top of rectangle), do you think that I need to put another 40 here (gestures to bottom)?" And they were like, "Yes. Yes." So I have to show them that I put here 40 [cubes] (gestures to top), and here 40 [cubes] (gestures to bottom), so 40 and 40 (gestures to top and bottom), 80. And after that, I said like, "Okay, now with this side (gestures to left), and what about this side (gestures to right)?" And after that I explained that this side (gestures*

> *to top) and this side (gestures to the bottom) is the same… [but] they still need me to show it, that this (gestures to left) and this side (gestures to right) with cubes, so they take a lot of time to do that.*

Marybelle’s description offers her colleagues a window into her classroom interactions. In this moment, Marybelle indicates that her students are still developing strategies to measure the perimeter of a rectangle. She describes some of her interactions with students, demonstrating how she explained and modeled concepts with the students. It is clear in Marybelle’s descriptions that the students are still wrestling with some of the mathematical concepts, such as understanding the properties of rectangles and applying those properties to measure perimeter. The students “have spent a lot of time trying to figure out what to do,” suggesting that there is (potentially productive) struggle taking place in the classroom.

By providing this rich description, Marybelle offers her colleagues access to her otherwise invisible classroom interactions. Teaching practices and interactions with students are typically only witnessed by the classroom teacher and her students, and this can limit the opportunities for collaborative learning alongside other teachers. Replays (Horn 2005; 2010) of classroom events are one avenue that teachers can use to “invite” others into their classrooms and spark conversations that support on-going reflection and learning. In this episode, Marybelle shares information with the PLC to help the others understand what she and the students are struggling with. Her colleagues can now use this information to extend the learning opportunity even further. They could ask probing questions to gain more information about the students’ thinking, offer suggestions for how to shift the instruction, or validate Marybelle’s experience and her decision to allow students more time to practice. Each of these responses could lead to additional learning opportunities for Marybelle and the rest of the second-grade PLC.

Examples 3A and 3B each illustrate how teachers utilized replays to share with their colleagues otherwise hidden aspects of their practice. Whether they were describing their process for data analysis or their interactions with students, the descriptions were detailed, walking others through the replay step-by-step. By presenting these rich descriptions, the teachers created opportunities for learning for their colleagues.

(4) Inviting Participation. In rich episodes, teachers tended to invite others to participate in the conversations. There were three variations of this theme: (A) all teachers were encouraged to share data or answer a question; (B) teachers asked other teachers questions to generate their ideas or experiences; and (C) the mathematics coach pushed teachers to share their thoughts and ideas, rather than sharing her own. These variations, described below, are potential learning opportunities because teachers were invited to make contributions that others could learn from or build upon.

Example 4A: All teachers were encouraged to share data or answer a question. There were several interactions where all teachers were encouraged to participate in the conversation explicitly. Often, this involved teachers sharing data from their classroom. For example, when the fourth-grade team brought exit tickets to a PLC meeting, the mathematics coach asked each teacher to share a summary of their data with the rest of the PLC. Each teacher contributed information about the unique learners in their classroom, information that other teachers could potentially relate to, investigate further, and learn from. The practice of inviting all teachers to contribute distributed the opportunities for participation and for learning across all the team members.

Example 4B: Teachers posed questions to other teachers to generate their ideas or experiences. Throughout the richest episodes, teachers often asked their colleagues questions about their ideas or experiences. Rather than relying on the mathematics coach to drive the conversation, the teachers took ownership of the PLC and elicited information from one another. For example, when discussing the recent place value assessments, Charlie asked the other second-grade teachers about a trend she noticed among her students, wondering if it was also represented in their classes. “Did you have a lot of kids that were like meaning to write 122, but wrote 1022?” By asking this question, Charlie offered information about her students’ thinking to the other teachers, while also inviting them to bring relevant information about their students into the conversation. This moment offers potential for the teachers to learn about Charlie’s students and could lead to additional learning opportunities as they identify patterns or anomalies in student thinking across the grade level.

Example 4C: The mathematics coach pushed teachers to share their thoughts and ideas, rather than sharing her own. Across PLC meetings, the mathematics coach used her position as facilitator to elicit information from the classroom teachers. Coach Sam is an expert educator and coach who has a wealth of knowledge and perspective to contribute to the PLC. Rather than trying to provide all the answers herself though, Coach Sam invited the teachers to be active participants in the PLC. In the process, she opened the potential for numerous learning opportunities for all the PLC members, herself included. During a discussion of student data, for instance, the fourth-grade team noticed that many students were not attending to precision in their work. Coach Sam’s response to this discussion places responsibility on the teachers to come up with solutions, rather than providing them with answers herself. As the teachers finish sharing sample student responses, Coach Sam replies, “Any ideas for that? Because that is going to keep coming up, right?” She acknowledges that this skill, attending to precision, will “keep coming up” for students. She could have immediately offered a solution here, but doing so would have only helped teachers work through this moment. Instead, Coach Sam pushed the thinking back onto the teachers themselves. She positions them as expert educators and encourages them to wrestle through their own ideas for possible instructional responses. Coach Sam provides space for the teachers to develop the skills they need to continue identifying student needs and designing instructional responses beyond this current moment.

In each of these three variations, members of the PLC made an effort to invite others to join the conversation. These actions created potential learning opportunities both in the moment and afterwards. Teachers sometimes shared information that others can learn from in the questions they ask. Other times, the act of inviting others into the conversation created space for future learning opportunities to emerge. The members of these PLCs possess deep knowledge of mathematical content and teaching practices, as well as a unique understanding of the students in their own classrooms. Drawing on this expertise by asking questions about their ideas or classroom experiences created the potential for learning opportunities in the PLC.

(5) Connecting data to instruction. In the richest episodes, teachers offered suggestions and made plans for how to respond instructionally to student data. Typically, the episode began with a discussion of student mathematical thinking, then transitioned to a discussion of how the teachers might address any student needs that surfaced. Two characteristics surfaced across the episodes that seemed to enhance the potential for teacher learning. First, teachers planned targeted instructional responses to address specific aspects of student thinking. Second, teachers provided rationales for their instructional suggestions. These are potential learning opportunities because teachers can share ideas with one another, wrestling with how these ideas might be implemented and how they may or may not support student learning. This opportunity for learning could support their instruction moving forward.

Example 5A: Targeted instructional responses (4th grade). This episode (also featured in Example 1B) begins as the teachers are discussing students' understanding of factors as demonstrated on recent assessments. Here, Blake and Coach Sam recap how Blake noticed and responded to the trend in the exit ticket data (Figure 4.19).

Figure 4.19

Factors Exit Ticket

Exit Ticket Name:

Which list includes all of the **factors** of the number 24?

A. 1, 2, 4, 6, 12, 24

B. 1, 2, 3, 4, 6, 7, 12, 24

C. 1, 2, 12, 24

D. 1, 2, 3, 4, 6, 8, 12, 24

Coach Sam: So, Blake's kids were having trouble [finding all the factors of 24]. So she did a little different mini lesson last week with finding all the factors…

Blake: Oh yes. They did an exit ticket for their morning work…

Coach Sam: And there was a huge chunk that missed the three times eight…

During this first exchange, Coach Sam and Blake share with the other teachers the trend they noticed in the exit ticket data. Students were able to identify some of the factors of 24, but many students did not include three and eight as factors. Next, Blake describes her response to this data analysis.

Blake: So… I went back to that same problem… And I showed them, you have two strategies. You can do this T chart, and we modeled how systematically, we're not just picking random numbers. We're going one *and this number, two and this number. And I explicitly said, "A lot of students always skip three. You can't just stop at three and skip it because you don't know." And then I also modeled how that would look like with the rainbow strategy.*

Coach Sam: *And you talked a little bit about strategies. Like how do-- If I don't know threes-- You gave them some time to figure it out. You told them, "Three is a factor. Figure it out."*

Blake: *"So what can you do? If you don't know three times whatever in your head, what can you do?" And they're like, "Well, we can skip count." "Great." "You could do repeated addition." "Great. But your paper should not be blank. You should be trying something."*

Here, Blake describes two specific responses to her student data. First, she realized students may need support systematically identify all factors of a number. To address this, Blake modeled a systematic method for checking factors sequentially using both a "T chart" and the "rainbow strategy". Second, Blake inferred – both based on this data and her previous teaching experiences – that students may need strategies to help them identify three as a factor. She responded by asking students to name multiplication strategies that they felt confident using, then giving them time to use those strategies in this problem. After this, the teachers shared more strategies to support students with identifying all the factors of a number.

Drew: *I felt like my kids did a lot better too, once I did the T chart and showed them. And like that question, "How do I know when I'm done?" I talked to them about how when your numbers are close together... "If we're doing 12, three and four, there are no other numbers in between them, so you're* *done." So explicitly teaching them, "How do I know when I've hit that bottom?"*

Blake: *And the other one I think to explicitly teach them. If it's an even number, you know two is a factor. What's the other factor that goes with two? If that's an even number, you should know there's something else there.*

Coach Sam: *We could [try] another Marvelous Mistake… where a kid makes a factor chart or a rainbow and it's like, "I found all the factors. Do you agree or disagree?"*

In each of these cases, a teacher suggests a strategy that could support students as they check to see if they identified all the factors of a number. Coach Sam even suggests creating a "Marvelous Mistake" (an error analysis for students) to specifically assess students' ability to identify all factors of a number. These teachers share multiple suggestions for how to respond instructionally to a specific, identified student need. This practice offers learning opportunities for teachers as ideas are shared that they could use in their classrooms tomorrow to support students' understanding of factors. The sharing of these instructional ideas also provides opportunities for learning more generally. By sharing this example, Blake offered the fourth-grade PLC the opportunity to learn how to identify and target a specific student need in the future. The episode concludes with Coach Sam commending Blake's instructional response.

Coach Sam: *I took a picture of Blake doing that. Cause I was like, "What a great way to respond to your data." … This was where you were going to go but then your data said, no you need to go here first. And I was like, "That's a really great way of responding."*

Coach Sam acknowledges that Blake had a plan for her lesson that day, but she adjusted her plan in response to the student data. She positions Blake's decision as "a great way to respond to your data," communicating to the others that intentionally responding to student data is an important skill to learn and practice. In addition to the learning opportunities described in the previous paragraphs, it is worth noting that this episode includes replays of Blake and Drew's classroom experiences. The in-depth descriptions of data analysis, teaching practices, and interactions and dialogue with students offers additional opportunities for learning for the teachers in this PLC.

Example 5B: Offering rationales for instructional suggestions (2nd and 4th grade). The two episodes presented here illustrate how rationales can be utilized to justify suggestions about future instruction. In the first episode, also featured in Example 2A, the second-grade teachers are discussing students' use of an open number line. Some students tend to move from left to right when subtracting on the open number line, which is the opposite direction of a conventional number line. The teachers have already proposed a few ways to address this trend in their classrooms. In this moment, Coach Sam offers a clear instructional response while also providing a rationale for her suggestion.

Coach Sam: The other thing you could do is have them do the number line and just let them go the wrong way. And then pull out your number line to 20 and be like, "Okay, now let's show it on this. What's different? Why is it different? Oh, okay." Instead of having to say over and over, maybe them making the error and checking it themselves and realizing it would make them more aware.

Coach Sam's suggestion here is to allow students to make errors, then use those errors to build student sense-making. Students could solve the same task on an open number line and a standard number line. Students could reason about direction on number lines by comparing their own work using these two different strategies. To explain her reasoning, Coach Sam offers a rationale for the instructional suggestion. "Instead of having to say over and over, maybe them making the error and checking it themselves and realizing it would make them more aware." Instead of constantly repeating directions to students, it may be possible to use student errors to engage students in the thought process. Providing opportunities for students to check and make sense of their own work may increase students' self-awareness and support a deeper understanding of the mathematical concepts.

By justifying her instructional suggestion with a rationale, Coach Sam exposes her reasoning to the other teachers. They have an opportunity to learn where Coach Sam is coming from and how she arrived at this possible instructional response. This also opens the door for future learning, either by discussing and questioning Coach Sam's reasoning or by considering how this logic could be applied to current and future instructional decisions.

The second episode provided here takes place during a fourth-grade PLC meeting. The team is planning a lesson on metric measurement of length. Earlier in the year the team had taught a lesson that involved measuring with rulers, and they had noticed that students were not lining objects up at the edge of the ruler when measuring. Carlos described how his students were measuring objects inaccurately using the middle of the ruler, and he suggested that "it would be beneficial to have a lesson on how to use the ruler." Coach Sam invites the team to share ideas for addressing this concern and introducing metric measurement of length.

Coach Sam: *What ideas you have?*

Riley: *I think maybe giving them some items to measure. Just a little basket at the table just to get familiar with using the ruler and with centimeters. Cause that was the other thing too, when we had the ruler out before to draw the line in the lesson it was like, err err!*

Blake: *Yeah, like even noticing that there's two different units of measure on there.*

Riley: *So giving them something to do that is actually just valuable. Writing and recording some different sizes of different stuff at their table while I'm walking and observing might be useful to see who needs help.*

Coach Sam: *So almost starting with this (shows a recording chart for measuring objects) …and gathering what students can already do and what they're noticing.*

Riley: *Yeah.*

Coach Sam: *I like that.*

Blake and Riley make a suggestion for how to introduce students to metric measurement. While the teachers could have simply named their ideas, Riley presents deeper opportunities for learning by offering two rationales along with the instructional suggestion. First, Riley suggests that they provide students with an opportunity to use physical rulers to measure objects in centimeters. She justifies this idea by stating that it will help students, "get familiar with using the ruler and with centimeters," two learning goals for students in this lesson. Riley also refers to the previous lesson, pointing out that her students, like Carlos's students, struggled with using the rulers. There is an implicit rationale here that the students need more time to "get familiar" with rulers because they are still making sense of linear measurement. Second, Riley suggests that the teachers give students time to measure different objects with the rulers on their own. She explains that this will offer her an opportunity to circulate the room and observe students' progress. In both instances, Riley creates learning opportunities for her colleagues by providing a rationale for the proposed instructional plan. This helps others understand why Riley is making this suggestion and provides them with information that they could potentially use in their own decision-making.

In Examples 5A and 5B, teachers used student data to plan future instruction. Opportunities for learning emerged as teachers considered how they might support student learning, particularly when they made connections to specific learning needs and supported their suggestions with rationales. By connecting student data to instruction, teachers can adjust their instruction in response to what they learned from student data and create additional opportunities to learn from students in the future.

Discussion

This study identified and characterized teachers' interactions with student data in PLCs as they occurred "in the wild". In addition, this study investigated how teachers engaged with student mathematical thinking during data discussions and characterized teachers' opportunities for learning through those interactions.

Teachers' Interactions with Data and Student Mathematical Thinking in PLCs

The PLCs in this study typically engaged in activities involving instruction and assessment, and more time was spent planning instructional units than any other activity. This finding aligns with prior research, which suggests that instructional planning is a common activity for teacher workgroups (Cobb et al., 2020; Farley-Ripple & Buttram, 2014). In every observed PLC meeting, teachers interacted with some form of student data. These interactions with data occurred both during designated times (i.e., discussing assessment results) and spontaneously during other activities (i.e., unit planning). These results indicate that teachers *are* referring to student data in mathematics PLCs. During interactions with data, teachers referenced classroom data more frequently than external data. This is not surprising, given that classroom data is typically more current, accessible, interpretable, and relevant to teachers than external data (see Chapter 3; Barnes et al., 2022).

This study also revealed that the teachers attended to student mathematical thinking when discussing student data, and there were differences in the quality of those interactions. Discussing specific accounts of student mathematical thinking in detail provided the richest opportunities for learning. In these moments, teachers described student mathematical thinking with clarity and depth, unpacking student reasoning and digging into the data to understand how students were thinking about mathematics. This opportunity to investigate and wrestle with student mathematical thinking was not as clearly present during vague or superficial discussions of student data, limiting the potential for learning. Distinguishing between the quality of these interactions is not intended to suggest that student mathematical thinking should be discussed in depth during all interactions with data. Data serves a wide range of purposes (Ikemoto & Marsh, 2007; Marsh et al., 2006), and not all references to student data are intended to offer rich opportunities for learning. The purpose of providing these distinctions is to illustrate how teachers engage with data and student thinking in elementary mathematics PLCs and to consider how different discussions of student mathematical thinking might afford or constrain teacher learning.

Rich Opportunities for Learning with Data in PLCs

During the richest episodes, teachers merged discussions of student data with specific, descriptive accounts of student mathematical thinking. These episodes exclusively involved discussions of classroom data rather than external data. It appears that teachers may discuss classroom assessments more deeply, perhaps because the data is current, more relevant to their daily work, or more likely to reveal student mathematical thinking (see Chapter 3; Datnow et al., 2021). The influence of standardized testing and the accountability culture may place a higher value on external data than classroom data (Lai & Schildkamp, 2013; Mandinach & Schildkamp, 2021b). However, the findings here align with previous studies (e.g., Datnow et al., 2021; Kazemi & Franke, 2004; van Es & Sherin, 2008) that suggest classroom data (e.g., student work samples, observations, unit tests) may serve a vital role in enhancing teachers' opportunities for learning around student mathematical thinking, potentially supporting teachers' ability to understand and respond to their students.

In addition, discussions that were supported by the presence of student work samples almost always offered rich learning opportunities. Having student work samples present when analyzing student data may encourage deeper discussions of student mathematical thinking because the evidence is accessible and can be more easily discussed (Garner & Horn, 2018). Student mathematical thinking is often more visible in work samples, which affords opportunities for teachers to examine students' strategies in greater depth (see Chapter 3; Kazemi & Franke, 2004). Furthermore, it is important to note the affordance of student work samples in highlighting what students know and can do, perhaps contributing to an asset-oriented lens among teachers of students and their thinking (Suh et al., 2021). PLCs could apply these findings by considering the extent to which their assessments provide evidence of student mathematical thinking. Using high-quality assessments that offer easy access to information about student thinking may support rich discussions in PLCs.

Across the richest episodes, five characteristics seemed to contribute to teachers' opportunities for learning (Table 4.10), opening space within the conversations and providing teachers with the resources to engage in deep discussions of student mathematical thinking. Together, these characteristics suggested two shared orientations, one towards collaboration and another towards the teaching and learning of elementary mathematics. These two orientations are unpacked further in the sections that follow. Note that this study investigated teacher learning by identifying learning opportunities rather than measuring learning itself. Future research could adopt a measure of teacher learning to investigate the extent to which these rich opportunities lead to quantifiable changes in teacher learning.

Orientation towards Collaboration. In the richest opportunities for learning, teachers interacted in ways that conveyed an orientation towards collaboration and group participation in the PLCs. This orientation emerged with four indicators: accessibility of ideas, power distribution, creativity and inquiry, and a safe learning space.

Describing student mathematical thinking in detail and with specificity offered rich opportunities for learning because the ideas became accessible to everyone in the PLC. The ideas were discussed with clarity so everyone could make sense of how students were thinking about the mathematics. Offering classroom *replays* (Example 3B) served a similar purpose; by describing classroom interactions in detail, the speaker created a shared image of the events that the whole group could unpack together (Horn, 2005; 2010). Speakers also shared their internal thought processes and reasoning with the PLC as they *wondered aloud* (Example 2A), offered *replays* of data analysis (Example 3A), and provided *rationales* for instructional suggestions

(Example 5B). These practices opened space in the PLC by providing all members access to the ideas, thus creating opportunities for engagement and learning. This finding applies to all teachers, who may be able to support the learning of their colleagues by clearly articulating their thoughts, wonderings, and ideas aloud.

In the richest episodes, power was distributed among PLC members. Power is present within PLCs, whether intentionally or not. For example, the mathematics coach has power as a semi-administrator, the lead teacher in a grade level has power as the designated team leader, and other PLC members may have power through their years of teaching experience, social status, race, gender, or language background. Within these PLCs, there were moments that seemed to exhibit decentralized control (see Chapter 3; McKie et al., 2023), disrupting typical power structures and dispersing power more evenly across the PLC members. By *inviting participation*, the opportunity to contribute was extended to all teachers, not just the person speaking. The introduction of *uncertainty*, especially coming from the mathematics coach and the lead teachers, emphasized that one person did not have all the answers (Example 2A). Both characteristics emphasized the collaborative nature of the PLCs and helped redistribute the ownership of knowledge across all the PLC members. This finding has implications for coaches and lead teachers, who could support learning by decentralizing control of the PLC and developing a PLC culture of shared ownership and engagement.

In the richest episodes, *uncertainty* also invited PLC members to engage in creativity and inquiry. *Uncertainty* was embedded in conversations as teachers wondered, asked questions about the data, and admitted what they did not know. The dismantling of certainty invited moments of creativity into the conversation. Teachers were encouraged to think in diverse ways, both about how students may be reasoning (Example 2B) and about how they as teachers might respond accordingly (Example 2A). There was a tentative nature to these suggestions. Ideas were amended and challenged; at times, the conclusion was that more information was needed about the students' thinking. Teachers engaged critically with these suggestions rather than taking them to be definitive conclusions. By eliciting and considering multiple ideas, teachers made space both for creative brainstorming and constant refinement of ideas. Knowledge was not considered static but evolving, always open to change with the introduction of new information. Developing a team that emphasizes inquiry is an important aspect of organizational learning (Collinson et al., 2006); PLCs could learn from this finding by leaning into uncertainty and questioning initial interpretations of data.

Finally, the introduction of *professional vulnerability* into PLCs helped cultivate a safe space for learning (see Chapter 3). When the teachers were vulnerable with one another, it created an environment that welcomed all PLC members, regardless of how much they believed they could contribute. *Professional vulnerability* may have normalized feelings of uncertainty that can emerge when analyzing and responding to student data, acknowledging that data use is complex and that all participants have something to learn when engaging with data (Example 2A). Trust has been identified as a feature of PLCs that is foundational to teacher learning (Schildkamp & Datnow, 2022), and modeling professional vulnerability may foster the growth of trust. Coaches and administrators can model these practices in their roles, normalizing uncertainty and promoting a safe space for professional vulnerability.

Data for this study was collected during the first half of the school year and, although the PLC teams were relatively established, both PLCs had brand-new members on the team. Because PLCs can evolve over time (Hipp et al., 2008), it is possible that this collaborative orientation continued to develop throughout the school year. Future research investigations could trace the development of PLCs over time, noting how the evolution shapes interactions with data and whether similar or new characteristics of rich learning opportunities emerge.

Orientation towards Teaching and Learning of Mathematics. In addition to an orientation towards collaboration, the characteristics of the richest episodes suggested that these PLCs shared an orientation towards the teaching and learning of mathematics that centered student thinking. This orientation, grounded in teachers' investigations of student mathematical thinking at a deep level, emerged with three indicators: specific, descriptive discussions of student thinking; asset-based lenses of students; and targeted instructional responses.

During the richest episodes, teachers discussed both student thinking and mathematical concepts in specific, descriptive ways. Teachers teased apart aspects of student thinking and sought to understand student reasoning as they investigated and *asked questions* about students' *partial understanding* of mathematical concepts (Example 2B). This type of discussion surfaces specific mathematical concepts and has the potential to build teachers' mathematical content knowledge (Özgün-Koca et al., 2020). Unpacking student thinking can also attend to the ways children's understanding of mathematical concepts typically develops over time, potentially enriching teachers' knowledge of learning trajectories in mathematics (Suh et al., 2021). Rich discussions of both mathematical content and student mathematical thinking have the potential to build teachers' understanding of the content and their students.

In the richest episodes, teachers' interactions with data communicated an asset-based lens towards student thinking. As teachers investigated students' *partial understanding* of mathematical concepts, they attended in more nuanced ways to what students may or may not have understood about the mathematics (Example 1A and 1B). Rather than immediately dismissing incorrect responses, the teachers approached the student thinking with curiosity and acknowledged the student understanding that was present. They *asked questions* to understand not only what students were thinking, but why (Example 2B). In these conversations the discussion of student thinking tended to be asset-based, focused on using current thinking to build further understanding. In this lens, errors were seen as a building block towards greater mathematics understanding rather than an indication that students were incapable of learning. As prior research has shown (e.g., Brodie, 2013; 2014), unpacking student errors in a positive light can shed insight into student thinking and support teacher learning about students and the mathematics. Coaches could apply this finding to their facilitation of PLCs, encouraging teachers to attend to students' partial understandings and focusing discussions on what students *can* do.

Finally, teachers designed *targeted instructional responses* based on their understanding of what students *can* do in mathematics (Example 5A, 5B). Because teachers unpacked their students' mathematical thinking – including their *partial understanding* of concepts (Example 1B) – there was a wealth of information teachers could draw upon when planning instruction (Example 5A). This information was specific to the current understandings of their own students, allowing them the chance to tailor their instructional responses to meet the specific needs of the students. Teachers could intentionally build off students' current understandings, leveraging what the students could already do to support their future learning. These discussions offered opportunities to support both student and teacher learning. As the teachers unpacked instructional suggestions and explained their reasoning with rationales, they had the opportunity to further develop their mathematical knowledge for teaching and their skills in responding to student thinking. This finding challenges the "triage" approach (Oláh et al., 2010, p. 239) that develops quick fixes to patch student misunderstandings, an approach that teachers utilize when faced with limited time and forced to respond quickly to the needs of an entire classroom of learners (Van Lare, 2016).

This finding has two important implications for school leaders. One, if teachers are expected to identify students' mathematical capabilities and develop instruction that pushes students along in their mathematical development, teachers need time to engage in these tasks, resources to develop their mathematical knowledge for teaching, and support from a learning community. School leaders must consider ways to provide teachers with the time, resources, and support needed to thoroughly respond to students' learning. Two, school leaders should consider ways to accomplish more by doing less. In other words, what expectations around data use can be taken off teachers' plates to provide the necessary time to engage with data substantially? Rather than adding a separate Data Day or an isolated data PD, consider ways to align data use with instructional planning while simultaneously building teacher capacity and supporting their learning. In addition to this research, other studies (e.g., Datnow et al., 2021; Kazemi et al., 2018) offer suggestions for how to embed data use into the daily work of teachers while also providing opportunities for teacher learning.

Because this study is situated in the context of Pinecone Elementary, the findings should be interpreted in relation to this context. For example, these PLCs were facilitated by an experienced and knowledgeable mathematics coach, and rich opportunities for learning may display different characteristics in PLCs led by a novice coach or no coach at all. Conducting similar studies in other settings could further investigate teachers' opportunities for learning through interactions with data in other contexts. In addition, this study focused on teachers' interactions within PLCs. Because the goal of using data and student thinking is typically to improve teaching practices and student learning, future research could investigate how interactions in PLCs translate into the classroom by examining teachers' instructional practices. Ultimately, research could examine whether a teacher's experience of rich learning opportunities with data impacts student mathematical learning.

There is a need for research that examines opportunities for teacher learning that are embedded in the daily work of teaching (Lefstein et al., 2020), such as interactions with student data in PLCs. This study points to ways that teachers' interactions in collaborative settings could support learning as teachers engage with evidence of student thinking, and it sets the stage for future research in elementary mathematics education as well as other grade bands and disciplines. The case of Pinecone Elementary serves as an example for the field, demonstrating that rich opportunities for learning are embedded in teachers' daily work and that these moments can be leveraged to support teacher learning.

CHAPTER 5: RECOMMENDATIONS FOR PRACTITIONERS

Making Data Meaningful: How Attention to Student Thinking in Data Discussions May Cultivate Rich Opportunities for Teacher Learning

Data is everywhere in our culture, and education is no exception. The push for data-driven decision making has become a priority in many educational settings, including professional learning communities (PLCs). However, both the literature (e.g., Schildkamp & Datnow, 2022) and my own experiences suggest that not all interactions with data are useful for educators. Curious about these differences, I recently studied teachers' interactions with data in two elementary mathematics PLCs at Pinecone Elementary. I observed 600 minutes of PLC meetings over five weeks and interviewed teachers, the mathematics coach, and the principal. The meetings and interviews were systematically analyzed to uncover how the PLC members interacted with data. Findings suggested that the ways teachers investigated student mathematical thinking differed greatly, altering the opportunities for teacher learning available through interactions with data.

In my work, it was clear that these learning opportunities did not happen at random. They were a byproduct of a culture that centered teacher and student learning. The teachers, the mathematics coach (Coach Sam), and the principal (Principal Emory) were working to cultivate an environment at Pinecone Elementary that leveraged data as a tool to promote teacher learning through deep investigations of student thinking.

Observing the PLCs at Pinecone Elementary opened my eyes to ways interactions with data could provide meaningful opportunities for teacher learning. Like Pinecone, other schools can make a schoolwide cultural shift towards viewing interactions with data as opportunities for teacher learning and emphasizing aspects of data use that promote teacher learning. In Table 5.1, I share five key recommendations to help develop a data-wise school culture invested in teacher learning in your community.

Table 5.1

Five Recommendations for Building a School Culture that Centers Teacher Learning in Interactions with Data

Recommendations
1. Create a safe space for participation and learning in PLCs. 2. Examine relevant data sources that reveal student thinking. 3. Unpack student thinking with a focus on student strengths. 4. Provide space in PLCs for reflection on instruction. 5. Collect and respond to teacher feedback about their learning.

(1) Create a safe space for participation and learning in PLCs.

Perhaps the most important part of the school culture was its professional learning communities. Professional learning communities operated as the heart of teachers' opportunities for learning at Pinecone Elementary, and PLCs were central to much of the work around data as well. Mathematics PLCs were organized as grade-level teams that met weekly and were facilitated by Coach Sam, a skilled and experienced educator with content-area expertise. Coach Sam played a critical role in cultivating a PLC culture that supported teacher learning.

One key element of the PLC culture was that it was a safe space for teachers. Teachers described the PLCs as a "safe place to share our ideas" and "a place where you can ask questions and be vulnerable", especially when sharing how lessons went. During PLC meetings, I observed teachers expressing professional vulnerability by asking questions, expressing uncertainty, and admitting what they were did not know. This practice was modeled by both Coach Sam and veteran PLC members, communicating to newer members that it was safe to express vulnerability. PLCs were also described as "a judgment-free zone" where teachers could share data from their classrooms without feeling like they would be looked down upon or fearing repercussions. This was supported by a collective responsibility for all students in the grade level.

In addition to being safe, the PLCs were welcoming spaces that encouraged participation from all members. While Coach Sam operated as the PLC facilitator, ownership of the PLC was distributed among the teachers. Teachers posed questions to others in the group, inviting everyone to contribute their ideas to the conversation. As teachers expressed their thoughts and ideas, they often did so in a way that made them accessible to everyone in the PLC. Classroom interactions were replayed in detail so others could follow along. Teachers wondered aloud and offered rationales for their thoughts to make their thinking and reasoning visible to the group. By eliciting thoughts from all team members and discussing ideas in an open and accessible manner, these PLCs established routines that encouraged teacher participation. Cultivating a safe community with opportunities for participation set conditions for learning in the PLC that could be built upon as teachers interacted with data.

(2) Examine relevant data sources that reveal student thinking.

While PLCs provided the space for teacher learning, data sources provided the content. At the time of this study, the school was developing a broad definition of data schoolwide. According to Principal Emory, “Everything is data.” Teachers constantly collected data about students and their learning, which included traditional data sources (e.g., test scores) as well as classroom observations, body language, emotions, and information about students’ experiences inside and outside the classroom (see Safir & Dugan, 2021 for more information). In PLCs, teachers referred to a wide range of data sources and often considered multiple data points simultaneously to make sense of data.

With such a wealth of data at their disposal, I was curious which data sources offered teachers the richest opportunities for learning. From a teacher learning perspective, it was apparent that discussions of classroom data sources that offered clear evidence of student thinking (e.g., exit slips, unit tests, observations) were different than discussions of other data sources. The discussions of student thinking and mathematical content were qualitatively different when PLCs analyzed common formative classroom data, particularly when student work was visible. Teachers attended to student mathematical thinking with specificity, describing in detail how students may have been thinking about the mathematics. These moments were different than other interactions with data in which teachers primarily discussed students' scores or did not acknowledge students' reasoning. Using relevant data sources with clear evidence of student thinking seemed to be a critical starting point for cultivating rich opportunities for teacher learning in PLCs.

(3) Unpack student thinking with a focus on student strengths.

As noted in the paragraph above, some interactions with data stood out among the others as rich opportunities for teacher learning. As one teacher explained, it was more helpful "to analyze the work that kids did as opposed to just the numbers," to take the data and "peel back the layers of what's really happening there." When teachers used data to unpack student thinking, rich learning opportunities emerged.

At Pinecone Elementary, unpacking data meant that teachers closely examined students' work to understand their thinking. Teachers approached the data with curiosity, asking questions about students' strategies and wondering why students used certain approaches. Teachers also felt comfortable expressing uncertainty when a strategy was confusing or difficult to follow.

These conversations provided opportunities for teachers to dive into the mathematical content, building their own content knowledge through discussions of students' strategies.

When unpacking student thinking, teachers approached the data with an asset-based lens. They focused on what students *could* do, rather than what they could *not* do. The teachers attended to the ways data revealed students' partial understanding of concepts. They noted when students were using valid strategies even if their final answers were incorrect, and they acknowledged that incorrect strategies still provided important information about how students were approaching the mathematics. These rich discussions of student thinking and mathematical content opened opportunities for teachers to learn about their students and the mathematics.

(4) Provide space in PLCs for designing and reflecting on instruction.

In addition to learning about their students and the mathematics. teachers also found value in learning about their instruction in PLCs. The teachers seemed to adopt an orientation that viewed student data as a reflection of their instruction. This impacted the ways teachers talked about data; they gauged the effectiveness of their teaching based on how students' progress and reflected on ways their instruction may or may not have supported learning. Several teachers pointed to this as an important way that data supported their learning. Because PLCs were seen as a safe space, teachers could compare data across classes without judgment. Teachers inquired about their peers' instruction when it appeared more effective than their own, learning from others' teaching strategies to improve their own practice.

The focus on students' strengths extended as PLCs planned instructional responses to the data. Teachers took students' demonstrated abilities into account and designed instruction that built off those strengths. For example, one teacher suggested using students' understanding of subtraction on a standard number line to help them transition to an open number line. Students could use both representations to solve a problem and compare the two strategies. As PLCs brainstormed together, teachers had an opportunity to learn from one other, discussing effective instructional responses and considering which teaching practices would best support student learning.

(5) Collect and respond to teacher feedback about their learning.

Teacher learning is never finished, and a learning-centered school culture constantly finds ways to improve learning opportunities for teachers. Pinecone Elementary engaged in continuous improvement at the school and PLC levels, using feedback from teachers to make changes. In PLCs, Coach Sam feedback from teachers on their learning needs, tailoring future learning opportunities in PLCs to the topics and skills teachers most wanted to improve. Coach Sam was also flexible during PLCs, attending to teachers needs in-the-moment during PLCs and allowing conversations to shift as needed based on areas of confusion or need. At the time of data collection, Pinecone Elementary was developing a schoolwide plan for professional development around data use practices. The leadership team had gathered feedback from teachers on their current capacity for data use, and the team was designing feature learning opportunities based on the feedback they received. Allowing teachers to have a voice in their own learning is an essential part of creating a school culture that values teachers and their learning.

As I write this article, Pinecone Elementary continues its pursuit towards improved student and teacher learning by engaging in deep discussions around data. The lessons learned from this school can support others as we work to create school cultures that prioritize meaningful, learning-oriented interactions with data.

CHAPTER 6: CONCLUSION

This dissertation comprises two distinct studies, presented in Chapters 3 and 4. While these studies use different approaches to investigate teachers' opportunities for learning through data use, together they paint a more cohesive picture of the phenomenon. Study #1 (Chapter 3) presented teachers' views on their own learning and demonstrated how teachers' learning experiences can be influenced by the characteristics of data and the nature of teachers' interactions with data. This study zoomed out to consider how teacher learning took shape within the broader educational system, and results suggested that features of this complex system, including nestedness and neighbor interactions with other teachers, impacted teachers' learning experiences. Study #2 (Chapter 4) addressed teacher learning through data use from a narrower perspective, zooming in and closely examining interactions with data in PLCs. This study indicated that teachers reference student data in PLCs in a variety of ways and noted how rich discussions of student mathematical thinking provided opportunities for teachers to learn from student data. Together, these studies describe opportunities for teacher learning that emerged through teachers' interactions with data and suggest directions for future research.

Recommendations for Future Research

First and foremost, these studies suggest that teachers have opportunities to learn when engaging with student data, including opportunities to learn about students, their mathematical thinking, the mathematical content, teachers' instruction, and about how to engage with the data itself. These opportunities for learning appear to be particularly prevalent in job-embedded settings such as PLCs. As emphasized by Lefstein and colleagues (2020), research on teachers' "in the wild", on-the-job discourse holds promise for increasing the field's understanding of learning opportunities that emerge throughout teachers' daily interactions. Replication studies could provide important information about the extent to which these learning opportunities emerge with different participants across different contexts. In addition, this work points to evidence of student mathematical thinking as a potential site for fruitful learning opportunities. Future research could examine how attention to evidence of student mathematical thinking connects to learning opportunities in other PLCs or other learning contexts (e.g., informal settings, engagement with resources).

The results of these studies have implications beyond the realm of elementary mathematics. Another avenue for investigation could involve conducting similar studies in different contexts, such as other grade bands or disciplines. Research on teachers' interactions with data and opportunities for learning could highlight the extent to which these findings hold up in other settings, while also offering insight into ways that different contexts influence teachers' opportunities for learning.

The coach was an important factor in teachers' learning experiences across both studies. Studies have pointed to the influence that a coach can have on teachers' experiences with data (e.g., Huguet et al., 2014, Marsh et al., 2015), but additional research is needed to understand the specific moves and coaching practices that support teacher learning through interactions with data. The results of these studies suggest practices that may offer opportunities for teacher learning (e.g., encouraging teacher participation; examining students' partial understanding) and can provide a starting point for future investigations.

Because these studies were conducted over a relatively short period of time, additional insight could be gained by examining teacher learning over a longer duration. Conducting a similar naturalistic study with a longitudinal design could expose aspects of teachers' interactions with data that emerge at different points in the school year. For example, interactions with data may change in response to the administration of quarterly interim assessments or towards the end of the school year in preparation for statewide, standardized assessments. Furthermore, tracing how teachers' interactions with data evolve across multiple years would also be worthwhile in relation to the group's working dynamics (e.g., long-term PLC members; new members of the PLC) and the shifting demands and responsibilities external to the PLC. Examining teachers' interactions with data longitudinally could capture a more diverse range of interactions with data and potentially observe shifts in teachers' data use practices, while also offering insight into opportunities for learning.

A compelling area for future exploration involves the development and use of common, high-quality assessments (DuFour & Reeves, 2016) to support teacher learning in elementary mathematics. The PLCs in these studies consistently utilized common assessments, and opportunities for learning seemed to emerge as teachers unpacked the student mathematical thinking revealed by these assessments. An intervention study in another setting could investigate how teachers' interactions with data shift when common assessments are developed and utilized in PLCs, potentially creating additional and new types of opportunities for teacher learning. In addition, future research could consider how qualities of these assessments impact teachers' learning opportunities, particularly the extent to which an assessment provides accessible information about student mathematical thinking.

Moving forward, future research could extend these studies into classrooms and examine both teaching practices and student learning. Teachers' interactions with data may often take place outside the classroom, but the implications of those interactions play out in classroom settings as teachers work directly with students. Future research could examine how rich opportunities for learning in PLCs influence teachers' instructional practices, especially over time. Because the ultimate goal of data use is typically to improve student learning outcomes, future research on teachers' opportunities to learn through data use could also benefit from investigating their impact on student learning.

As the findings of both studies suggest, teacher learning and data use take place in a complex system. As demonstrated in Study #1, the field could benefit from research that examines both teacher learning and data use with a complex lens. Additional investigations into the characteristics and conditions of complex systems that support teacher learning through data use could support or alter the findings presented here. Collecting additional data at other levels of the system and across even more stakeholders would add depth to future studies, possibly even extending to interviews with parents, local school board members, or state legislators.

One promising direction for these future studies could involve the development of research-practice partnerships between local school districts and universities. DBDM is a hot topic in educational settings, and investigating ways to promote teachers' use of data in beneficial ways is a current goal of many districts (Honig & Venkateswaran, 2012). Because the future research recommended could potentially align with the goals of districts, research-practice partnerships offer promise by combining university resources with the direct impact of district work in ways that promote robust and meaningful collaborations. In particular, involving teachers in the design and iterative analysis of research studies could result in research that connects to teachers' work in meaningful ways while simultaneously supporting their opportunities for learning.

Overall, the results of this dissertation study support improvements in teacher learning and data use practices in elementary mathematics in three ways. First, this research highlights voices and experiences of practitioners, especially teachers, who are responsible for implementing DBDM daily. These experiences reveal how teachers currently learn from data and emphasize teacher expertise, offering insight into practices for understanding students and their learning. Second, this research examines teachers' interactions with data at a fine-grained level and considers the extent to which those interactions provide on-the-job learning opportunities. This information could be used by mathematics educators to guide the design and facilitation of teacher collaborative spaces such as PLCs. Third, this research considers how DBDM is situated within the broader system of data use at a school. It acknowledges the complexity of these interactions within a dynamic system impacted by multiple factors. In communicating the diverse perspectives of educators, this research highlights areas of both cohesion and misalignment around data use in the system. In summary, this research contributes to the national conversation around data use by both zooming out and zooming in on teachers' learning opportunities through interactions with data.

REFERENCES

Abrams, L. M., Varier, D., & Mehdi, T. (2021). The intersection of school context and teachers' data use practice: Implications for an integrated approach to capacity building. *Studies in Educational Evaluation*, *69*, 100868. https://doi.org/10.1016/j.stueduc.2020.100868

Adams, P. (2006). Exploring social constructivism: Theories and practicalities. *Education*, *34*(3), 243-257.

Aguirre, J., Herbel-Eisenmann, B., Celedon-Pattichis, S., Civil, M., Wilkerson, T., Stephan, M., ... & Clements, D. H. (2017). Equity within mathematics education research as a political act: Moving from choice to intentional collective professional responsibility. *Journal for Research in Mathematics Education*, *48*(2), 124-147.

Aguirre, J., Martin, D., & Mayfield-Ingram, K. (2013). The impact of identity in K-8 mathematics: Rethinking equity-based practices national council of teachers of mathematics.

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education*, *59*(5), 389-407.

Barnes, N., Brighton, C. M., Fives, H., Meyers, C., & Moon, T. R. (2022). Where's the data to support educators' data use for instructional practice? *Theory Into Practice*, *61*(3), 277–287. https://doi.org/10.1080/00405841.2022.2096379

Benade, L. (2016) Teachers' reflective practice in the context of twenty-first century learning: Applying Vagle's five-component post-intentional plan for phenomenological research. *Open Review of Educational Research*, *3*(1), 133-147. DOI: 10.1080/23265507.2016.1201777

Bertrand, M., & Marsh, J. A. (2015). Teachers' sensemaking of data and implications for equity. *American Educational Research Journal*, *52*(5), 861-893.

Bertrand, M., & Marsh, J. (2021). How data-driven reform can drive deficit thinking. *Phi Delta Kappan*, *102*(8), 35-39.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher*, *33*(8), 3–15. https://doi.org/10.3102/0013189X033008003

Boylan, M., Coldwell, M., Maxwell, B., & Jordan, J. (2018). Rethinking models of professional learning as tools: A conceptual analysis to inform research and practice. *Professional Development in Education*, *44*(1), 120–139. https://doi.org/10.1080/19415257.2017.1306789

Brodie, K. (2013). The power of professional learning communities. *Education as Change*. https://www.tandfonline.com/doi/abs/10.1080/16823206.2013.773929

Brodie, K. (2014). Learning about learner errors in professional learning communities. *Educational Studies in Mathematics*, *85*(2), 221–239. https://doi.org/10.1007/s10649-013-9507-1

Brodie, K., & Chimhande, T. (2020). Teacher talk in professional learning communities. *International Journal of Education in Mathematics, Science and Technology*, *8*(2), Article 2. https://doi.org/10.46328/ijemst.v8i2.782

Carpenter, T. P., Fennema, E., Peterson, P. L., Chiang, C. P., & Loef, M. (1989). Using knowledge of children's mathematics thinking in classroom teaching: An experimental study. *American Educational Research Journal*, *26*(4), 499–531. https://doi.org/10.3102/00028312026004499

Chapin, S. H., O'Connor, C., & Anderson, N. C. (2013). *Classroom discussions: Using math talk to help students learn, Grades K-6*. (3rd ed.) CA: Math Solutions.

Cobb, P., Jackson, K., Henrick, E., & Smith, T. M. (2020). *Systems for instructional improvement: Creating coherence from the classroom to the district office*. Harvard Education Press.

Cobb, P., & Smith, T. (2008). District development as a means of improving mathematics teaching and learning at scale. In K. Krainer & T. Wood (Eds.), *International handbook of mathematics teacher education: Vol. 3. Participants in mathematics teacher education: Individuals, teams, communities, and networks* (pp. 231–254). Rotterdam, the Netherlands: Sense Publishers.

Coburn, C. E., & Talbert, J. E. (2006). Conceptions of evidence use in school districts: Mapping the terrain. *American Journal of Education*, *112*(4), 469-495.

Coburn, C. E., Honig, M. I., & Stein, M. K. (2009a). What's the evidence on districts' use of evidence? *The Role of Research in Educational Improvement*, 67-87.

Coburn, C. E., Touré, J., & Yamashita, M. (2009b). Evidence, interpretation, and persuasion: Instructional decision making at the district central office. *Teachers College Record*, *111*(4), 1115-1161.

Coburn, C. E., & Turner, E. O. (2011). Research on data use: A framework and analysis. *Measurement: Interdisciplinary Research and Perspectives, 9*(4), 173–206. https://doi.org/10.1080/15366367.2011.626729

Coburn, C. E., & Turner, E. O. (2012). The practice of data use: An introduction. *American Journal of Education*, *118*(2), 99–111. https://doi.org/10.1086/663272

Collinson, V., Cook, T. F., & Conley, S. (2006). Organizational learning in schools and school systems: Improving learning, teaching, and leading. *Theory into Practice*, *45*(2), 107–116. doi:10.1207/s15430421tip4502_2

Cochran-Smith, M., Ell, F., Ludlow, L., Grudnoff, L., & Aitken, G. (2014). The challenge and promise of complexity theory for teacher education research. *Teachers College Record: The Voice of Scholarship in Education*, *116*(4), 1–38. https://doi.org/10.1177/016146811411600407

Cosner, S. (2011). Teacher learning, instructional considerations and principal communication: Lessons from a longitudinal study of collaborative data use by teachers. *Educational Management Administration & Leadership*, *39*(5), 568-589.

Creswell, J. W., & Poth, C. N. (2016). *Qualitative inquiry and research design: Choosing among five approaches*. SAGE Publications.

Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017). *Effective teacher professional development.*

Datnow, A., Choi, B., Park, V., & John, E. S. (2018). Teacher talk about student ability and achievement in the era of data-driven decision making. *Teachers College Record*, *120*(4), 1-34.

Datnow, A., & Hubbard, L. (2015). Teachers' use of assessment data to inform instruction: Lessons from the past and prospects for the future. *Teachers College Record: The Voice of Scholarship in Education*, *117*(4), 1–26. https://doi.org/10.1177/016146811511700408

Datnow, A., Lockton, M., & Weddle, H. (2021). Capacity building to bridge data use and instructional improvement through evidence on student thinking. *Studies in Educational Evaluation*, *69*, 100869. https://doi.org/10.1016/j.stueduc.2020.100869

Davis, B., & Simmt, E. (2003). Understanding learning systems: Mathematics education and complexity science. *Journal for Research in Mathematics Education*, *34*(2), 137–167. https://doi.org/10.2307/30034903

Davis, B., & Sumara, D. (2006). *Complexity and education: Inquiries into learning, teaching, and research*. Routledge & CRC Press. https://www.routledge.com/Complexity-and-Education-Inquiries-Into-Learning-Teaching-and-Research/Davis-Sumara/p/book/9780805859355

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher, 38*(3), 181-199.

DuFour, R. (2004). What is a "professional learning community"? *Educational Leadership, 61*(8), 6–11.

DuFour, R., & Eaker, R. (2009). *Professional Learning Communities at Work TM: Best Practices for Enhancing Students Achievement*. Solution Tree Press.

DuFour, R., & Reeves, D. (2016). The futility of PLC Lite. *Phi Delta Kappan*, *97*(6), 69–71. https://doi.org/10.1177/0031721716636878

Dunn, K. E., Airola, D. T., Lo, W. J., & Garrison, M. (2013). Becoming data driven: The influence of teachers' sense of efficacy on concerns related to data-driven decision making. *The Journal of Experimental Education*, *81*(2), 222-241.

Ebbeler, J., Poortman, C. L., Schildkamp, K., & Pieters, J. M. (2017). The effects of a data use intervention on educators' satisfaction and data literacy. *Educational Assessment, Evaluation and Accountability*, *29*(1), 83–105. https://doi.org/10.1007/s11092-016-9251-z

Ell, F., Cochran-Smith, M., Hill, M., Haigh, M., Grudnoff, L., & Ludlow, L. (2019). Complexity theory as a guide to qualitative methodology in teacher education. In *Oxford Research Encyclopedia of Education*. https://doi.org/10.1093/acrefore/9780190264093.013.523

Farley-Ripple, E. N., & Buttram, J. L. (2014). Developing collaborative data use through professional learning communities: Early lessons from Delaware. *Studies in Educational Evaluation*, *42*, 41–53. https://doi.org/10.1016/j.stueduc.2013.09.006

Farley-Ripple, E. N., Jennings, A. S., & Buttram, J. (2019). Toward a framework for classifying teachers' use of assessment data. *AERA Open*, *5*(4), 2332858419883571. https://doi.org/10.1177/2332858419883571

Faulkner, V. N., Marshall, P. L., & Stiff, L. V. (2019). *The stories we tell: Math, race, bias, and opportunity*. Rowman & Littlefield.

Franke, M. L., & Kazemi, E. (2001). *Learning to teach mathematics: Focus on student thinking*. https://doi.org/10.1207/s15430421tip4002_4

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, *38*(4), 915–945.

Garner, B., & Horn, I. (2018). Using Standardized-Test Data as a Starting Point for Inquiry: A Case of Thoughtful Compliance. In *Cases of Teachers' Data Use*. Routledge.

Goldstein, L. S. (2008). Kindergarten teachers making "street-level" education policy in the wake of No Child Left Behind. *Early Education and Development*, *19*(3), 448–478. https://doi.org/10.1080/10409280802065387

Gummer, E. (2021). Complexity and then some: Theories of action and theories of learning in data-informed decision making. *Studies in Educational Evaluation*, *69*, 100960. https://doi.org/10.1016/j.stueduc.2020.100960

Hall, R., & Horn, I. (2012). Talk and conceptual change at work: Adequate representation and epistemic stance in a comparative analysis of statistical consulting and teacher workgroups. *Mind, Culture, and Activity*, *19*(3), 240–258.

Harvey, F., & Teledahl, A. (2022). Characteristics of professional learning communities in mathematics: A systematic review. *Mathematics Teacher Education and Development.*, *24*(1), 72–95.

Hetherington, L. (2013). Complexity thinking and methodology: The potential of 'complex case study' for educational research. *Complicity: An International Journal of Complexity Theory and Education*, *10*, 71. https://doi.org/10.29173/cmplct20401

Hipp, K. K., Huffman, J. B., Pankake, A. M., & Olivier, D. F. (2008). Sustaining professional learning communities: Case studies. *Journal of Educational Change*, *9*(2), 173–195. https://doi.org/10.1007/s10833-007-9060-8

Honig, M. I., & Coburn, C. (2008). Evidence-based decision making in school district central offices: Toward a policy and research agenda. *Educational Policy, 22*(4), 578-608.

Honig, M. I., & Venkateswaran, N. (2012). School–central office relationships in evidence use: Understanding evidence use as a systems problem. *American Journal of Education*, *118*(2), 199–222. https://doi.org/10.1086/663282

Hord, S. M. (1997). Professional learning communities: Communities of continuous inquiry and improvement. *Southwest Educational Development Laboratory.*

Horn, I. S. (2005). Learning on the job: A situated account of teacher learning in high school mathematics departments. *Cognition and Instruction*, *23*(2), 207-236.

Horn, I. S. (2010). Teaching replays, teaching rehearsals, and re-visions of practice: Learning from colleagues in a mathematics teacher community. *Teachers College Record*, *112*(1), 225–259. https://doi.org/10.1177/016146811011200109

Horn, I. S., Garner, B., Kane, B. D., & Brasel, J. (2017). A taxonomy of instructional learning opportunities in teachers' workgroup conversations. *Journal of Teacher Education*, *68*(1), 41–54. https://doi.org/10.1177/0022487116676315

Horn, I. S., & Kane, B. D. (2015). Opportunities for professional learning in mathematics teacher workgroup conversations: Relationships to instructional expertise. *Journal of the Learning Sciences*, *24*(3), 373–418.

Horn, I. S., Kane, B. D., & Wilson, J. (2015). Making sense of student performance data: Data use logics and mathematics teachers' learning opportunities. *American Educational Research Journal*, *52*(2), 208-242.

Horn, I. S., & Little, J. W. (2010). Attending to problems of practice: Routines and resources for professional learning in teachers' workplace interactions. *American Educational Research Journal*, *47*(1), 181-217.

Huguet, A., Marsh, J. A., & Farrell, C. (2014). Building teachers' data-use capacity: Insights from strong and developing coaches. *Education Policy Analysis Archives*, *22*(0), 52. https://doi.org/10.14507/epaa.v22n52.2014

Huinker, D., Yeh, C., & Marshall, A. M. (2020). *Catalyzing change in early childhood and elementary mathematics: Initiating critical conversations.*

Ikemoto, G. S., & Marsh, J. A. (2007). Cutting through the "data-driven" mantra: Different conceptions of data-driven decision making. *Teachers College Record*, *109*(13), 105-131.

Jackson, K., & Cobb, P. (2013). Coordinating professional development across contexts and role groups. *Teacher Education and Pedagogy: Theory, Policy and Practice*, *46*(2), 80–99. https://doi.org/10.1080/03057925.2015.1074832

Jacobs, V. R., Franke, M. L., Carpenter, T. P., Levi, L., & Battey, D. (2007). Professional development focused on children's algebraic reasoning in elementary school. *Journal for Research in Mathematics Education*, *38*(3), 258–288. https://doi.org/10.2307/30034868

Jacobs, V. R., Lamb, L. L. C., & Philipp, R. A. (2010). Professional noticing of children's mathematical thinking. *Journal for Research in Mathematics Education*, *41*(2), 169–202.

Jennings, A. S., & Jennings, A. (2020). Comprehensive and superficial data users: A convergent mixed methods study of teachers' practice of interim assessment data use. *Teachers College Record*, *122*(12), 1-46.

Jimerson, J. B., Garry, V., Poortman, C. L., & Schildkamp, K. (2021). Implementation of a collaborative data use model in a United States context. *Studies in Educational Evaluation*, *69*, 100866. https://doi.org/10.1016/j.stueduc.2020.100866

Kanselaar, G. (2002). Constructivism and socio-constructivism. *Constructivism and socio-constructivism*, 1-7.

Karp, K. S., Dougherty, B. J., & Bush, S. B. (2020). *The math pact, elementary: Achieving instructional coherence within and across grades*. Corwin.

Kazemi, E., & Franke, M. L. (2004). Teacher learning in mathematics: Using student work to promote collective inquiry. *Journal Of Mathematics Teacher Education, 7*, 203-235.

Kazemi, E., Gibbons, L., Lewis, R., Fox, A., Hintz, A., Kelley-Petersen, M., Cunard, A., Lomax, K., Lenges, A., & Balf, R. (2018). Math labs: Teachers, teacher educators, and school leaders learning together with and from their own students. *NCSM Journal*, 23–36.

Kazemi, E., & Resnick, A. F. (2019). Organising schools for teacher and leader learning. In *International Handbook of Mathematics Teacher Education: Volume 3* (pp. 393-420). Brill.

Kazemi, E., Resnick, A. F., & Gibbons, L. (2022). Principal leadership for school-wide transformation of elementary mathematics teaching: Why the principal's conception of teacher learning matters. *American Educational Research Journal*, *59*(6), 1051–1089. https://doi.org/10.3102/00028312221130706

Kennedy, M. M. (1982). Working knowledge. In M. M. Kennedy (Ed.), *Working knowledge and other essays* (pp. 1-28). Cambridge, MA: The Huron Institute.

Kippers, W. B., Poortman, C. L., Schildkamp, K., & Visscher, A. J. (2018). Data literacy: What do educators learn and struggle with during a data use intervention? *Studies in Educational Evaluation*, *56*, 21–31. https://doi.org/10.1016/j.stueduc.2017.11.001

Kotter, J. P. (1995). Why transformation efforts fail. *Harvard Business Review*, *73*(2), 59-67.

Lai, M., & Schildkamp, K. (2013). Data-based decision making: An overview. In K. Schildkamp, M. Lai, & L. Earl (Eds.), *Data-based decision making in education. Studies in educational leadership, 17*. Dortrecht: Springer.

Lasater, K., Bengtson, E., & Albiladi, W. S. (2021). Data use for equity?: How data practices incite deficit thinking in schools. *Studies in Educational Evaluation, 69*, 100845. https://doi.org/10.1016/j.stueduc.2020.100845

Leatham, K. R., Peterson, B. E., Stockero, S. L., & Zoest, L. R. V. (2015). Conceptualizing mathematically significant pedagogical opportunities to build on student thinking. *Journal for Research in Mathematics Education*, *46*(1), 88–124. https://doi.org/10.5951/jresematheduc.46.1.0088

Lefstein, A., Vedder-Weiss, D., & Segal, A. (2020). Relocating research on teacher learning: toward pedagogically productive talk. *Educational Researcher, 49*(5), 360–368. https://doi.org/10.3102/0013189X20922998

Little, J. W. (2012). Understanding data use practice among teachers: The contribution of micro-process studies. *American Journal of Education*, *118*(2), 143–166. https://doi.org/10.1086/663271

Louie, N. L. (2017). The culture of exclusion in mathematics education and its persistence in equity-oriented teaching. *Journal for Research in Mathematics Education, 48*(5), 488-519.

Mandinach, E. B., & Schildkamp, K. (2021a). The complexity of data-based decision making: An introduction to the special issue. *Studies in Educational Evaluation, 69*, 100906.

Mandinach, E. B., & Schildkamp, K. (2021b). Misconceptions about data-based decision making in education: An exploration of the literature. *Studies in Educational Evaluation*, *69*, 100842. https://doi.org/10.1016/j.stueduc.2020.100842

Marsh, J. A. (2012). Interventions promoting educators' use of data: Research insights and gaps. *Teachers College Record*, *114*(11), 1–48. https://doi.org/10.1177/016146811211401106

Marsh, J. A., Pane, J. F., & Hamilton, L. S. (2006). Making sense of data-driven decision making in education: Evidence from recent RAND research. Occasional Paper. In *RAND Corporation*. RAND Corporation.

Marsh, J. A., Bertrand, M., & Huguet, A. (2015). Using data to alter instructional practice: The mediating role of coaches and professional learning communities. *Teachers College Record*, *117*(4), 1-40.

Mason, M. (2008). Complexity theory and the philosophy of education. *Educational Philosophy and Theory*, *40*(1), 4-18.

McKie, K. (2023). *The complexity of mathematics teachers' collaborative professional learning.* [Doctoral dissertation, University of Ottawa]. https://ruor.uottawa.ca/server/api/core/bitstreams/61ce0e86-51d9-4d5e-a6d7-0e0068569b0a/content

McKie, K., Anderson, R. K., Overwijk, A., & Temple, S. (2023). Complexity and professionalization: The nested collaborative nature of teacher learning. *International Journal of Complexity in Education*, *4*(2), Article 2. https://doi.org/10.26262/ijce.v4i2.9813

McKie, K., Suurtamm, C., & Lazarus, J. (2017). Supporting professional learning in mathematics. *Gazette - Ontario Association for Mathematics*, *56*(2), 30–34.

Means, B., Padilla, C., DeBarger, A., & Bakia, M. (2009). Implementing data-informed decision making in schools: Teacher access, supports and use. *US Department of Education*.

Means, B., Padilla, C., & Gallagher, L. (2010). Use of education data at the local level: From accountability to instructional improvement. *US Department of Education*.

Merritt, E. G. (2016). Time for teacher learning, planning critical for school reform. *Phi Delta Kappan*, *98*(4), 31-36.

Moss, P. A. (2012). Exploring the macro-micro dynamic in data use practice. *American Journal of Education*, *118*(2), 223–232. https://doi.org/10.1086/663274

Moustakas, C. E. (1994). *Phenomenological Research Methods.* Sage Publications, Inc.

Munter, C. (2014). Developing visions of high-quality mathematics instruction. *Journal for Research in Mathematics Education, 45*(5), 584-635.

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics.* Reston, VA: Author.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Reston, VA: Author.

National Council of Teachers of Mathematics. (2014). *Principles to actions: Ensuring mathematical success for all.* National Council of Teachers of Mathematics.

National Governors Association Center for Best Practices & Council of Chief State School Officers (NGA Center and CCSSO). (2010). *Common core state standards for mathematics.* Washington, DC: Author. Retrieved from http://www.corestandards.org/assets/CCSSI_Math%20Standards.pdf

National Research Council, & Mathematics Learning Study Committee. (2001). *Adding it up: Helping children learn mathematics*. National Academies Press.

Nawab, A., & Sharar, T. (2022). Coordination in planning and implementing professional development programs for teachers: A much-needed component in rural areas. *SAGE Open*, *12*(1), 21582440211068489.

NC2ML (2018, February). Developing Vision for High-Quality Math Instruction. *Research-Practice Briefs*. North Carolina Collaborative for Mathematics Learning. Greensboro, NC. Retrieved from nc2ml.org/brief-25.

Newmann, F. M., & Associates. (1996). *Authentic achievement: Restructuring schools for intellectual quality.* San Francisco, CA: Jossey-Bass.

North Carolina Department of Public Instruction (NCDPI). (n.d.). *Multi-tiered system of support (MTSS) for families*. https://www.dpi.nc.gov/students-families/parents-corner/multi-tiered-system-support-mtss-families

O'Connor, B. (2021). *The impact of effective collaboration on data-based decision-making and instructional practice for teachers participating in professional learning communities* [Thesis]. https://ttu-ir.tdl.org/handle/2346/88748

Oláh, L. N., Lawrence, N. R., & Riggan, M. (2010). Learning to learn from benchmark assessment data: How teachers analyze results. *Peabody Journal of Education, 85*(2), 226-245.

Opfer, V. D., & Pedder, D. (2011). Conceptualizing teacher professional learning. *Review of Educational Research*, *81*(3), 376-407.

Özgün-Koca, S. A., Lewis, J. M., & Edwards, T. (2020). Fostering middle school teachers' mathematical knowledge for teaching via analysis of tasks and student work. *Mathematics Teacher Educator, 9*(1), 50-62.

Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research, 62*(1), 307–332.

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health*, *42*(5), 533-544. doi:10.1007/s10488-013-0528-y

Penuel, W. R. (2019). Infrastructuring as a practice of design-based research for supporting and studying equitable implementation and sustainability of innovations. *Journal of the Learning Sciences*, *28*(4–5), 659–677.

Peterson, P. L., McCartney, S. J., & Elmore, R. F. (1996). Learning from school restructuring. *American Educational Research Journal*, *33*(1), 119–153. doi:10.3102/00028312033001119

Popp, J. S., & Goldman, S. R. (2016). Knowledge building in teacher professional learning communities: Focus of meeting matters. *Teaching and Teacher Education*, *59*, 347–359. https://doi.org/10.1016/j.tate.2016.06.007

Postholm, M. B. (2012). Teachers' professional development: A theoretical review. *Educational Research*, *54*(4), 405–429. https://doi.org/10.1080/00131881.2012.734725

Poth, C. N., & Bullock, E. P. (2023). Mixed methods research design practices to address complexity in education. In R. J. Tierney, F. Rizvi, & K. Ercikan (Eds.), *International Encyclopedia of Education (Fourth Edition)* (pp. 615–625). Elsevier. https://doi.org/10.1016/B978-0-12-818630-5.11061-9

Riggan, M., & Nabors Oláh, L. (2011). Locating interim assessments within teachers' assessment practice. *Educational Assessment*, *16*(1), 1-14.

Safir, S., & Dugan, J. (2021). *Street data: A next-generation model for equity, pedagogy, and school transformation*. Corwin.

Sammut-Bonnici, T. (2015). Complexity theory. In *Wiley Encyclopedia of Management.* John Wiley & Sons, Ltd.

Schelling, N., & Rubenstein, L. D. (2021). Elementary teachers' perceptions of data-driven decision-making. *Educational Assessment, Evaluation and Accountability*, *33*(2), 317–344. https://doi.org/10.1007/s11092-021-09356-w

Schildkamp, K. (2019). Data-based decision-making for school improvement: Research insights and gaps. *Educational Research*, *61*(3), 257–273. https://doi.org/10.1080/00131881.2019.1625716

Schildkamp, K., & Datnow, A. (2022). When data teams struggle: Learning from less successful data use efforts. *Leadership and Policy in Schools*, *21*(2), 147–166. https://doi.org/10.1080/15700763.2020.1734630

Schildkamp, K., Poortman, C. L., & Handelzalts, A. (2016). Data teams for school improvement. *School Effectiveness and School Improvement*, *27*(2), 228–254. https://doi.org/10.1080/09243453.2015.1056192

Smith, M. S. & Stein, M. K. (2018). *5 practices for orchestrating productive mathematics discussion*. National Council of Teachers of Mathematics.

Soule, K. E., & Freeman, M. (2019). So you want to do post-intentional phenomenological research? *The Qualitative Report*, *24*(4), 857-872. https://doi.org/10.46743/2160-3715/2019.3305

Spillane, J. P., Reiser, B., & Gomez, L. M. (2006). Policy implementation and cognition: The role of human, social, and distributed cognition in framing policy implementation. In M. I. Honig (Ed.), *New directions in educational policy implementation: Confronting complexity* (pp. 47–64). Albany, NY: State University of New York Press.

Staman, L., Timmermans, A. C., & Visscher, A. J. (2017). Effects of a data-based decision making intervention on student achievement. *Studies in Educational Evaluation*, *55*, 58–67. https://doi.org/10.1016/j.stueduc.2017.07.002

Stoll, L., Bolam, R., McMahon, A., Wallace, M., & Thomas, S. (2006). Professional learning communities: A review of the literature. *Journal of Educational Change*, *7*(4), 221–258. https://doi.org/10.1007/s10833-006-0001-8

Strom, K. J., & Viesca, K. M. (2021). Towards a complex framework of teacher learning-practice. *Professional Development in Education*, *47*(2–3), 209–224. https://doi.org/10.1080/19415257.2020.1827449

Suh, J. M., Birkhead, S., Frank, T., Baker, C., Galanti, T., & Seshaiyer, P. (2021). Developing an asset-based view of students' mathematical competencies through learning trajectory-based lesson study. *Mathematics Teacher Educator*, *9*(3), 229–245.

Sun, J., Przybylski, R., & Johnson, B. J. (2016). A review of research on teachers' use of student data: From the perspective of school leadership. *Educational Assessment, Evaluation and Accountability, 28,* 5–33. https://doi.org/10.1007/s11092-016-9238-9

Supovitz, J., & Sirinides, P. (2018). The linking study: An experiment to strengthen teachers' engagement with data on teaching and learning. *American Journal of Education*, *124*(2), 161–189. https://doi.org/10.1086/695610

Vagle, M. D. (2018). *Crafting phenomenological research*. Routledge.

van Es, E. A., & Sherin, M. G. (2008). Mathematics teachers' "learning to notice" in the context of a video club. *Teaching and Teacher Education*, *24*(2), 244–276. https://doi.org/10.1016/j.tate.2006.11.005

Van Lare, M. D. (2016). "Obviously, that worked": Examining links between data use and classroom instruction. *Journal of School Leadership*, *26*(5), 756-782.

Vescio, V., Ross, D., & Adams, A. (2008). A review of research on the impact of professional learning communities on teaching practice and student learning. *Teaching and Teacher Education*, *24*(1), 80–91. https://doi.org/10.1016/j.tate.2007.01.004

Wenger, E. (1998). Communities of practice: Learning as a social system. *Systems thinker*, *9*(5), 2-3.

Wilson, J., Nazemi, M., Jackson, K., & Wilhelm, A. G. (2019). Investigating teaching in conceptually oriented mathematics classrooms characterized by African American student success. *Journal for Research in Mathematics Education*, *50*(4), 362-400.

Witte, A. L., Knoche, L. L., Sheridan, S. M., & Koziol, N. (2023). How teachers use data: Description and differences across Pre-K through third grade. *Early Childhood Education Journal*. https://doi.org/10.1007/s10643-023-01588-3

Woolfolk, A. E. (1993) *Educational psychology* (Boston, Allyn and Bacon).

Young, V. M. (2006). Teachers' use of data: Loose coupling, agenda setting, and team norms. *American Journal of Education*, *112*(4), 521-548.

Yin, R. K. (2018). *Case study research and applications*. Sage.

Yurkofsky, M. M., Peterson, A. J., Mehta, J. D., Horwitz-Willis, R., & Frumin, K. M. (2020). Research on continuous improvement: Exploring the complexities of managing educational change. *Review of Research in Education*, *44*(1), 403–433. https://doi.org/10.3102/0091732X20907363

APPENDICES

Appendix A

Initial Interview Protocol: Teacher Interview

Memo to Participant:

I'm conducting this study because I'm curious about your experiences in elementary math education here at Pinecone Elementary.

I'm going to ask you some questions about topics such as math instruction, professional learning, and data use. There will be an introduction and 4 main sections. I will cue you as we move from section to section in the interview so you know what the questions will focus on. You might also see me taking brief notes.

The interview will be recorded and transcribed for data analysis. The recordings will be deleted after being transcribed, and your name will be removed from the transcript.

Now I'm going to ask for your consent: This interview is voluntary and you have the right to pause or conclude the interview at any point in time. Do you agree to participate in this interview and study?

I'm going to start recording now. (START RECORDING) This is RESEARCHER with ID XXXX for an interview on DATE.

<u>Introduction Questions</u>

Let's start with introductions.

1. Can you briefly tell me your story as an educator?
   Probe if necessary:
   a. What is your current position? How long have you been in this position?
   b. What previous roles have you had in teaching or in education, and for how long?

<u>Math Instruction</u>

I'm first going to ask you some questions about math instruction.

1. What has been your experience of math instruction at **SCHOOL?
   Probe if necessary:
   a. What does math look like across a typical day in your classroom?
   b. What does a math block typically look like? What does it sound like? What does it feel like?
   c. How do you feel during math instruction?
   d. About how many minutes per day do teachers spend on math?
2. What has been your experience of the curriculum materials at **SCHOOL?
   Probe if necessary:
   a. What types of curriculum materials do you use when planning for math instruction?
   b. Tell me more about what is provided for you in the form of curriculum materials for math.
   c. Do you supplement what is provided with other resources? If so, what types of resources, and where do you find them?

<u>Vision for Mathematics Instruction</u>

Now I'm going to ask you about your vision of high-quality and equitable mathematics instruction at the elementary level.

1. If you were asked to observe an elementary teacher's math instruction for one or more lessons…
    a. What would you look for to decide whether the instruction is high quality?
    Probe if necessary:
        i. What would the classroom look like?
        ii. What would it sound like?
        iii. How would students feel?
        iv. How would the teacher feel?
        v. Why do you think it is important to use/do ___ in a math classroom?
    b. What would you look for to decide whether the instruction is equitable?
    Probe if necessary:
        i. What would the classroom look like?
        ii. What would it sound like?
        iii. How would students feel?
        iv. How would the teacher feel?
        v. Why do you think it is important to use/do ___ in a math classroom?
    c. Is there anything else you would look for? If so, what? Why?
2. You've just described your vision for high-quality and equitable mathematics instruction.
    a. What has been your experience implementing this vision at SCHOOL?
    b. When does it feel like you all are able to realize this vision?
    Probe if necessary:
        i. What helps you all get there?
        ii. How does that feel?
        iii. Where do you find support for implementing this vision of mathematics instruction?
    c. When are you not able to realize this vision?
    Probe if necessary:
        i. What stands in the way?
        ii. How does that feel?
        iii. What are the greatest barriers to teaching this way?

<u>Professional Learning</u>

In this next section, I want to ask you about opportunities for professional learning and growth at SCHOOL. I'm first going to ask you some broad questions about professional learning.

1. What does it mean to learn and grow as an educator?
Probe if necessary:
    a. Is that important? Why or why not?
2. What has been your experience of professional learning at SCHOOL?

Next, I'd like to ask you some questions about professional learning communities, or PLCs.

1. How long have you been working with this current math PLC team?
2. Now, let's talk more about PLC meetings that are focused on math. What has been your experience of math PLC at **SCHOOL?
Probe if necessary:
    a. What do the conversations and discussions look like?

i. What do the conversations sound like?
ii. What do they feel like?
iii. How would you describe the conversations in a math PLC to someone who had never been there before?

b. What is the purpose of a math PLC?
c. What is the focus of a typical math PLC meeting?
   i. What are some of the activities that take place within math PLCs?
   ii. How are agendas set?
   iii. Who leads the meetings?

3. Tell me broadly about opportunities you've had to learn, if any, in your math PLC. (Pause) Thinking about your experiences over time with this PLC, could you describe what happens during your best learning experiences?
   a. What contributes to these learning experiences?
   b. What activities in PLCs often lead to learning opportunities?
   c. In your experience, what activities in PLCs don't lead to learning opportunities?
      i. What contributes to the lack of learning?
   d. If you were in charge of this PLC, which elements would you keep and which would you change?
4. You've described your experience within PLCs. Could you describe your communication, if any, with colleagues about math outside of PLC meetings? (Probe, if necessary: What do you talk about or communicate about with colleagues as it relates to math?)
   a. How and when do these communications typically take place? (Probe, if necessary: For example, on e-mail, text, in person, etc.)
5. We've discussed PLCs as one space for professional learning. What has been your experience with other opportunities for professional learning in mathematics at SCHOOL?
   a. Tell me about professional learning opportunities that you have experienced in mathematics.
      Probe if necessary:
      i. What opportunities has your school or district provided?
      ii. What has been your experience with coaching in mathematics?
      iii. What has been your experience of formal professional development in mathematics?
      iv. What opportunities do you have to learn during the school day?
   b. Tell me about any professional learning opportunities in mathematics that you have pursued on your own outside of what is provided. (This includes informal PD opportunities like social media, too).

<u>Data in Math Education</u>

In this final section, I want to ask you about data use in education.

1. First, how would you define data in the context of education?
   Probe if necessary:
   a. Could you give me examples of data?
2. What has been your experience using data in math at **SCHOOL?

   a. What data do you use in math in your current role? (Pause) How do you use that data?
   b. How do you use data individually?
   c. How do you use data in collaboration with colleagues?
   d. Are there additional ways in which you would like to use data in the future? If so, describe.
3. How do you feel about the use of data in elementary math? (Pause) Why?
4. How would you describe the culture of data use at your school?
5. Describe communication or discussion, if any, with colleagues about data. (Probe, if necessary: What do you talk about or communicate about with colleagues as it relates to data?)
   a. Describe the communication you receive or generate at your school about data.
   b. Describe the communication you receive from the district about data.
   c. Probe, if necessary:
   d. How and when do these communications typically take place? (For example, on e-mail, text, in person, etc.)
6. How do you (or do you not) see data being used in your school to support all students' progression in their math learning?
   a. In your experience, how does data use in math affect students of color, multilingual learners, students in poverty, and students in special education?
7. What has been your experience with professional learning opportunities around data?
   a. Tell me about professional learning opportunities that your school or district has provided around data.
   b. Tell me about any professional learning opportunities you've pursued on your own outside of school around data. (This includes informal PD opportunities like social media, too).
   c. Tell me about any professional learning opportunities that you have previously had around data.
8. Is there anything else you would like to add about data use in elementary math?

<u>Conclusion</u>

1. Is there anything else you would like to share?

Thank you so much for your time.

Initial Interview Protocol: Coach and Principal Interview

Memo to Participant:

I'm conducting this study because I'm curious about your experiences in elementary math education here at Pinecone Elementary.

I'm going to ask you some questions about topics such as math instruction, professional learning, and data use. There will be an introduction and 4 main sections. I will cue you as we move from section to section in the interview so you know what the questions will focus on. You might also see me taking brief notes.

The interview will be recorded and transcribed for data analysis. The recordings will be deleted after being transcribed, and your name will be removed from the transcript.

Now I'm going to ask for your consent: This interview is voluntary and you have the right to pause or conclude the interview at any point in time. Do you agree to participate in this interview and study?

I'm going to start recording now. (START RECORDING) This is RESEARCHER with ID XXXX for an interview on DATE.

Introduction Questions

Let's start with introductions.

1. Can you briefly tell me your story as an educator?
   Probe if necessary:
   a. What is your current position? How long have you been in this position?
   b. What previous roles have you had in teaching or in education, and for how long?

Math Instruction

I'm first going to ask you some questions about math instruction.

1. What does math look like across a typical day at **SCHOOL?
   Probe if necessary:
   a. What does a math block typically look like?
   b. About how many minutes per day do teachers spend on math?
2. What types of curriculum materials do teachers use when planning for math instruction?
   a. Tell me more about what is provided to teachers in the form of curriculum materials for math. (Pause) What has been your experience using these materials? How do teachers use these materials?
   b. Do teachers supplement what is provided with other resources? If so, what types of resources, and where do they find them?

Vision for Mathematics Instruction

Now I'm going to ask you about your vision of high-quality and equitable mathematics instruction at the elementary level.

1. If you were asked to observe an elementary teacher's math instruction for one or more lessons…
   a. What would you look for to decide whether the instruction is high quality?
      Probe if necessary:
      i. What would the classroom look like?
      ii. What would it sound like?
      iii. How would students feel?
      iv. How would the teacher feel?
      v. Why do you think it is important to use/do ___ in a math classroom?
   b. What would you look for to decide whether the instruction is equitable?
      Probe if necessary:
      i. What would the classroom look like?
      ii. What would it sound like?
      iii. How would students feel?

iv. How would the teacher feel?
v. Why do you think it is important to use/do ___ in a math classroom?
c. Is there anything else you would look for? If so, what? Why?
2. You've just described your vision for high-quality and equitable mathematics instruction.
    a. What has been your experience implementing this vision at SCHOOL?
    b. When does it feel like you all are able to realize this vision?
    Probe if necessary:
        i. What helps you all get there?
        ii. How does that feel?
        iii. Where is there support for implementing this vision of mathematics instruction?
    c. When are you not able to realize this vision?
    Probe if necessary:
        i. What stands in the way?
        ii. How does that feel?
        iii. What are the greatest barriers to teaching this way?

<u>Professional Learning</u>

In this next section, I want to ask you about opportunities for professional learning and growth at SCHOOL. I'm first going to ask you some broad questions about professional learning.

1. What has been your experience of professional learning at SCHOOL?

Next, I'd like to ask you some questions about professional learning communities, or PLCs.

1. How long have you been working with this current math PLC team? *(coach only)*
2. Now, let's talk more about PLC meetings that are focused on math. What has been your experience of math PLC at **SCHOOL?
    Probe if necessary:
    a. What do the conversations and discussions look like?
        i. What do the conversations sound like?
        ii. What do they feel like?
        iii. How would you describe the conversations in a math PLC to someone who had never been there before?
    b. What is the purpose of a math PLC?
    c. What is the focus of a typical math PLC meeting?
        i. What are some of the activities that take place within math PLCs?
        ii. How are agendas set?
        iii. Who leads the meetings?
3. Tell me broadly about opportunities for learning, if any, in math PLCs. (Pause) Thinking about your experiences over time with PLCs, could you describe what happens during the best learning experiences?
    a. What contributes to these learning experiences?
    b. What activities in PLCs often lead to learning opportunities?
    c. In your experience, what activities in PLCs don't lead to learning opportunities?
        i. What contributes to the lack of learning?
    d. If you were in charge of math PLCs at this school, which elements would you keep and which would you change?

4. You've described your experience within PLCs. Could you describe your communication, if any, with colleagues about math outside of PLC meetings? (Probe, if necessary: What do you talk about or communicate about with colleagues as it relates to math?)
    a. How and when do these communications typically take place? (Probe, if necessary: For example, on e-mail, text, in person, etc.)
5. We've discussed PLCs as one space for professional learning. What has been your experience with other opportunities for professional learning in mathematics at SCHOOL?
    a. Tell me about professional learning opportunities that you have experienced in mathematics, both for you and for teachers.
       Probe if necessary:
        i. What opportunities has your school or district provided?
        ii. What has been your experience with coaching in mathematics?
        iii. What has been your experience of formal professional development in mathematics?
        iv. What opportunities do you have to learn during the school day?
    b. Tell me about any professional learning opportunities in mathematics that you or teachers have pursued on your own outside of what is provided. (This includes informal PD opportunities like social media, too).

<u>Data in Math Education</u>

In this final section, I want to ask you about data use in education.

1. First, how would you define data in the context of education?
   Probe if necessary:
    a. Could you give me examples of data?
2. What has been your experience using data in math at **SCHOOL?
    a. What data do you use in math in your current role? (Pause) How do you use that data?
    b. How do teachers use data?
    c. Are there additional ways in which you would like to use data to be used in your school?
3. How do you feel about the use of data in elementary math? (Pause) Why?
4. How would you describe the culture of data use at your school?
5. Describe communication or discussion, if any, with colleagues about data. (Probe, if necessary: What do you talk about or communicate about with colleagues as it relates to data?)
    a. Describe the communication you receive or generate at your school about data.
    b. Describe the communication you receive from the district about data.
    c. Probe, if necessary:
    d. How and when do these communications typically take place? (For example, on e-mail, text, in person, etc.)
6. How do you (or do you not) see data being used in your school to support all students' progression in their math learning?
    a. In your experience, how does data use in math affect students of color, multilingual learners, students in poverty, and students in special education?

7. What has been your experience with professional learning opportunities around data?
    a. Tell me about professional learning opportunities that your school or district has provided around data for you or for teachers.
    b. Tell me about any professional learning opportunities around data that you or teachers have pursued on your own outside of school. (This includes informal PD opportunities like social media, too).
    c. Tell me about any professional learning opportunities that you have previously had around data.
8. Is there anything else you would like to add about data use in elementary math?

<u>Conclusion</u>

1. Is there anything else you would like to share?

Thank you so much for your time.

Follow-up Interview: Fourth-Grade Teachers and Coach

I have had the pleasure of observing your PLC meetings for the past 6 weeks, and I'd like to ask you some questions about what I've observed.

1. I noticed that you and your team discuss exit tickets and checkpoints data. How do you determine what students have learned from those assessments?
    a. I also observed your team discussing EOG and AIMSweb screener data. How do you determine what students have learned from those assessments?
2. Two weeks ago, at the last PLC, I noticed that you and your team made adjustments to your planning documents based on observations of students in class. How have those experiences informed what you've done in your classroom recently?
   Probe if necessary:
    a. How do you plan for small groups?
    b. How do you organize small groups?
    c. How does your plan from PLC translate to the classroom?
3. Describe any opportunities you have had to learn from data in this PLC.
   Probe if necessary:
    a. When interacting with data in PLCs, what supports your learning the most?
    b. When interacting with data in PLCs, what does not support your learning?
4. Do you have anything else you would like to add about data use?

Follow-up Interview: Second-Grade Teachers

I have had the pleasure of observing your PLC meetings for the past 6 weeks, and I'd like to ask you some questions about what I've observed.

At the last PLC, I noticed that you and your team decided to press pause on your instruction for a week and shift to small groups.

1. What information did you use to make that decision?

   a. How do you determine what students have learned from that data?
2. How did that experience in PLC inform what you've done in your classroom recently?
   a. How do you plan for small groups?
   b. How do you organize small groups?
   c. How does your plan from PLC translate to the classroom?
3. Describe any opportunities you have had to learn from data in this PLC.
   a. When interacting with data in PLCs, what supports your learning the most?
   b. When interacting with data in PLCs, what does not support your learning?
4. Do you have anything else you would like to add about data use?

Initial Interview: District Staff

Memo to Participant

The purpose of this study is to understand the current state of elementary mathematics education from the perspective of teachers, coaches, principals, and district leaders.

Throughout this interview, I will ask you questions about your experiences with elementary math education in your role. The interview will be recorded and transcribed for data analysis, and all recordings will be deleted after being transcribed. In addition, I will take brief notes throughout the interview.

This interview is voluntary and you have the right to pause or conclude the interview at any point in time. Do you agree to participate in this interview and study? I'm going to start recording now.

This is Danielle with ID XXXX for a district leadership interview on DATE. The interview is broken up into several sections. I will cue you as we move from section to section so you know what the questions will focus on.

<u>Introduction Questions</u>

Let's begin with a few introductory questions.

1. What is your current position? How long have you been in this position? Were you in the same role before the pandemic?
2. What previous roles have you had in teaching or in education?

<u>Math Instruction</u>

I'm first going to ask you some questions about math instruction.

1. Could you tell me a little about elementary math instruction in the district? What does a typical day look like? About how many minutes per day do teachers spend on math? Is this consistent across elementary schools?
2. What types of curriculum materials do teachers use when planning for math instruction?
   a. Tell me more about what the district provides teachers in the form of curriculum materials for math. (Pause) How do teachers use these materials?
   b. Do teachers supplement what the district provides with other resources? If so, what types of resources, and where do they find them?
3. How, if at all, has math instruction changed in this district from before the pandemic until now?
   a. What are the benefits of those changes?

b. What are the challenges of those changes?

Professional Learning

In this next section, I want to ask you about opportunities for professional learning and collaboration. I'm going to ask you some questions about PLCs in general, then we'll talk more about PLCs and math.

1. First, broadly across all disciplines, do teachers in the elementary schools have designated PLCs? Tell me more about the PLCs. (Pause)
    a. Follow up as necessary: Do they have a designated time that they meet? How long are the meetings, and how often? Who attends the PLCs? What is the focus of a typical PLC meeting? How are agendas set?
2. Now, let's talk more about PLC meetings that are focused on math. How often do the PLCs focus on math? What do the conversations and discussions look like?
3. How and when do most of your conversations about elementary mathematics typically take place? With whom? (Probe, if necessary: For example, on e-mail, text, in person, etc.)
    a. What do you talk about or communicate about with colleagues as it relates to math?
4. What opportunities, if at all, do teachers have for professional learning in mathematics? What opportunities do principals have? What opportunities do you have?
    a. Tell me about professional learning opportunities that the district has provided in mathematics.
    b. What opportunities do you have for professional learning in mathematics?
    c. Tell me about any professional learning opportunities in mathematics that you or others in the district have pursued outside of school. (This includes informal PD opportunities like social media, too).

Vision for Mathematics Instruction

Now I'm going to ask you about your vision of high-quality mathematics instruction at the elementary level.

1. If you were asked to observe an elementary teacher's math instruction for one or more lessons, what would you look for to decide whether the instruction is high quality?
2. Why do you think it is important to use/do ___ in a math classroom? Is there anything else you would look for? If so, what? Why?
3. You've just described your vision for high-quality mathematics instruction. To what extent do you feel teachers are able to implement this in their classrooms?
    a. How, if at all, has your vision shifted as a result of the pandemic?
    b. Where do teachers find support for implementing this vision of mathematics instruction?
    c. What are the greatest barriers to teaching this way?
4. Who in the district would describe their vision of high-quality math instruction in similar ways? Please refer to an individual's position rather than using the person's name. (i.e., say "principal" or "administration" instead of "Ms. X")
    a. If so, how do you know?
    b. If not, what are the differences in the vision of high-quality math instruction?

Challenges and Opportunities

You've shared a lot of information about components of elementary math education. In this final section, I'd like you to take a step back and think about the current state of elementary math across the district.

1. Thinking holistically about elementary mathematics in the district, what do you think is the greatest challenge currently? Why?
    a. What do you think teachers would say is the greatest challenge?
    b. What do you think math coaches would say is the greatest challenge?
    c. What do you think principals would say is the greatest challenge?
    d. What are you doing to address this challenge? What is being done at the school level? What is being done at the district level?
2. Still thinking holistically about elementary mathematics in the district, what do you think is the greatest opportunity right now? Why?
    a. What do you think teachers would say is the greatest opportunity?
    b. What do you think math coaches would say is the greatest opportunity?
    c. What do you think principals would say is the greatest opportunity?
    d. What are you doing to capitalize on this opportunity? What is being done at the school level? What is being done at the district level?
3. I have one more question for you. You've just described challenges and opportunities in elementary math right now. Describe communication (this includes written communication and in discussions/conversations) about these challenges/opportunities between teachers. (Pause) Describe communication at the school level about these challenges/opportunities. (Pause). Describe communication at the district level about these challenges/opportunities (Pause).
    a. From your perspective, what are the strengths and areas for improvement for the various communications that you've just described?

Is there anything else you would like to share?

Thank you so much for your time.

Follow-up Interview: Math Facilitator (District Staff)

Data in Math Education

In this section, I want to ask you about data use in education.

1. First, how would you define data in the context of education?
   Probe if necessary:
    a. Could you give me examples of data?
2. What has been your experience using data in math at Garden County Schools?
    a. What data do you use in math in your current role? (Pause) How do you use that data?
    b. How do teachers use data in elementary math?
        i. How do teachers use data, individually and/or in collaboration with colleagues?

   c. Are there additional ways in which you would like to use data to be used for elementary math in your district?
3. How do you feel about the use of data in elementary math? (Pause) Why?
4. How would you describe the culture of data use in your district?
5. Describe communication or discussion in your district, if any, about data in elementary math. (Probe, if necessary: What do you talk about or communicate about as it relates to data?)
   Probe, if necessary:
   a. Describe the communication you receive or generate about data.
   b. Describe the communication teachers receive from the district about data.
   c. How and when do these communications typically take place? (For example, on e-mail, text, in person, etc.)
6. How do you (or do you not) see data being used in your district to support all students' progression in their math learning?
   a. In your experience, how does data use in math affect students of color, multilingual learners, students in poverty, and students in special education?
7. What has been your experience with professional learning opportunities around data?
   a. Tell me about professional learning opportunities that schools or the district has provided around data for you or for teachers.
   b. Tell me about any professional learning opportunities around data that you or teachers have pursued on your own outside of school. (This includes informal PD opportunities like social media, too).
   c. Tell me about any professional learning opportunities that you have previously had around data.
8. Is there anything else you would like to add about data use in elementary math?

<u>Member Checking</u>

Data Use

> *Last year (July 2022), you noted that student data wasn't always at the forefront of PLCs. You explained that in previous years, teachers thought about data regularly and flexibly in PLCs, investigating student work samples to learn about instruction and respond to kids' needs. Currently, it seemed that there was a reliance on AIMSweb (universal screener) as the single data point and that schools were going through the motions of interventions and progress monitoring rather than authentically using data.*

Is there anything you would like to add or change to this description for this year?

PLCs

> *Last year (July 2022), you described PLCs as being inconsistent across the district. In some places there were rich, math conversations, while other PLCs were "more about compliance and MTSS". You mentioned that admin plays a huge role in setting expectations for PLCs. You felt like "MTSS drives a lot of the PLC process", especially around interactions with data. You described how teacher ownership was important to the success of a PLC, but you thought some of that has been lost over the years due to the*

> *pandemic and the increase in math coaches. Finally, you indicated that the district was "relaunching PLCs" through a partnership with Partner Team.*

Is there anything you would like to add or change to this description for this year?

Appendix B

Example Post-Reflexive Memos (Thematic)

Post-Reflexion Memo

*B: "I don't feel like I've had formal data professional development here at **SCHOOL**. Maybe I have. But I can't recollect anything that stands out to me as like, that was PD about data."*

Across the board, teachers indicated that neither the school nor the district had provided formal professional development around data.

B described, "I don't feel like I've had formal data professional development here at Pinecone. Maybe I have. But I can't recollect anything that stands out to me as like, that was PD about data."

I think this needs to be in conversation with the quotes about how teachers DO learn. I think it's a bit misconstrued if it's isolated…
R -- learn during data days, "real life use"
D -- learn on her own

I'm acknowledging here that I'm a fan of professional learning for teachers as a whole. I'm not certain spending time learning about data in formal settings is the best use of time for anyone, but I do as a whole think teachers can and should have opportunities for learning about data on the job.

Post-Reflexion Memo

One thing that I'm noticing across these examples is that teachers are describing interactions with one another. By that I mean, it seems important that the teachers are interacting with one another. These teachers are close to each other in proximity, and have a shared understanding of the grade content, instructional practices of the curriculum, shared understanding of students in a particular grade, and a shared understanding of the lessons that they've been teaching. However, it's worth noting that the teachers also brought a range of diverse experiences to the PLC's (internal diversity). (This internal diversity seemed to play out especially with teachers previous teaching experiences in this context or others. I'm thinking about M and how she talked about learning as a new teacher on the grade level team, and same with D. Contrasting this with B and C as veteran teachers in the school, grade level, and PLC.)

I could say more about internal diversity later. But back to neighbor interactions, there's something about how these teachers were situated close to one another that provided the opportunity to interact with one another in meaningful ways.

As for neighbor interactions with the data, I am reminded of how L described the data that is "close" as the relevant data. It seems that interactions with data that is close to teachers, provided the meaningful interactions, and therefore the opportunities for learning. The other things teachers described as useful or meaningful interactions with data included sharing data across the grade level. This seemed to provide an awareness of how students in other classes were performing and helped teachers contextualize their class's results. This seemed useful when the teachers noticed areas where their students were struggling or when teachers noticed discrepancies in the data, especially when one class outperformed the others on a particular skill.

Example Post-Reflexive Memo (Analytic)

3/12/24, 2:59 PM
Post-Reflexion Memo - Phase 3 (Whole)
I used the interview question as a clue to what "level" the participant might be
I used the phrases in the participant's response as clues
- "In my classroom…"
- "Across the school…"

There are some things that I'm not sure about yet…
- parents
- MTSS
    - tiered interventions, tier 2 and tier 3, core instruction
    - WIN time, intervention time
- grades, report cards
- AIMSweb - universal screener, district-mandated but MTSS related
- EC, AIG, ML

The distinction between PLC / classroom is difficult… not the "main" designation of a quote, but the in-between references… because the teachers are constantly referring to classroom stuff while in the PLCs.

1. Individual
    - feelings
    - beliefs
2. Classroom
3. PLC
    - consistent core —> alignment w/in grade level
4. School
    - admin
    - expectations with curriculum
    - WIN intervention time
    - consistent core —> vertical alignment across school
5. District
    - check-ins
    - "proficiency" based on check-ins
    - expectations with curriculum
    - focus on core instruction
6. State
    - standards
    - EOG
    - "proficiency" based on EOG
    - testing
    - grade level expectations (getting kids ready for the next grade level)
7. External (societal)
    - COVID

Appendix C

Codebook: Conditions and Characteristics of Complex Learning Systems (Adapted from McKie, 2023)

Characteristics	*Definition*
Emergence	Participant makes direct/indirect reference to the emergence of learning.
Nestedness	Participant makes direct/indirect reference to ways they, or their system is connected/nested within a larger system.
Adaptation	Participant makes direct/indirect reference to ways that the system adapted to disruptions and/or perturbations.
Self-organization	Participant makes direct/indirect reference to ways that the system organized.
Conditions	*Definition*
Decentralized control	Participant makes direct/indirect reference to the ways the PLC was controlled or led.
Neighbor interactions	Participant makes direct/indirect reference to interacting with others, their ideas, or resources.
Redundancy	Participant makes direct/indirect reference to common traits and understandings.
Diversity	Participant makes direct/indirect reference to the differences such as experiences, beliefs, and attitudes.
Randomness	Participant makes direct/indirect reference to openness and/or freedom.
Coherence	Participant makes direct/indirect reference to the need to align with objectives, mandates, or goals.

Appendix D

Sample of a Descriptive Memo to Characterize Rich Opportunities for Learning

Sample of Section 1: Thick Description

2nd PLC — 9/28/23
Backwards number line

>>>>>>>>>>> DESCRIPTIVE MEMO <<<<<<<<<<<<

Section 1: Thick description

<u>Describe</u> in a paragraph what happened. —> (Someone doesn't have to read the transcript to gain an understanding of the episode. Include quotes as needed.)

<u>Background context</u>

This was a preparation day for the upcoming unit (Unit 2). The teachers were at the end of the unit and were planning to give the post assessment the following day. Their current focus in the PLC meeting was to plan the first lessons for this unit, which would take place in the upcoming week.

To be honest, I'm not exactly sure where the open number line comes in with this unit or the previous unit. (*1) [Okay, I went back to check, and the previous unit involved number lines. However, there was not much discussion in PLC about number lines except for the fact that they showed up on the assessment, and according to JB, "we haven't been pushing number line right now" (220).]

This episode picks up at the point where the teachers are planning small group instruction for the following week. According to DS, the goal of small groups for this week should be review from the previous unit, because the teachers wouldn't have data on the current unit by next week. AA mentions that number combinations could be a focus, and the group talks about how to embed independent practice with number combinations throughout the math block and the school day.

Sample of Section 2: Commentary

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Section 2: Commentary

*1 — Is my lack of knowledge about the open number line indicative of this being a new unit, my lack of attention to this PLC, or this PLC being less clear and willing to discuss strategies?

*2 --- This is one of DS's classic moments where she describes what students are doing and her teaching simultaneously. She naturally transitions between describing student strategies and her instructional response. (This can also make it difficult at times to know if she's referencing hypothetical students or students from this class, because she naturally draws on her many years of teaching experience to provide examples. See comment on lines 492–501).

*3 — In both PLCs, the PLC lead (DS or HD) often makes a point to draw in the other teachers. In this example, DS asks a specific question to the other teachers about their lessons, so that the other teachers can contribute. While it's briefly taken up by SG, it dies quickly because she does not have much to contribute about the students' thinking. (See below.)