Toward a practice-based theory for how professional learning communities engage in the improvement of tools and practices for scientific modeling

Jessica J. Thompson1 | Sara Hagenah2 | Scott McDonald3 | Christie Barchenger1

1Department of Teaching, Learning, and Curriculum, University of Washington, Seattle, Washington
2Department of Curriculum, Instruction, and Foundational Studies, Boise State University College of Education, Boise, Idaho
3Department of Curriculum & Instruction, Pennsylvania State University, Pennsylvania

Abstract
To organize for the improvement of science instruction teachers need opportunities to collaboratively learn from practice, in practice, and to engage in the revision of classroom tools. In this paper, we examine how a professional learning community (PLC), comprised of middle school teachers and researchers, worked on the improvement of Ambitious Science Teaching (AST) practices and developed instructional practices and tools supporting model-based inquiry. This paper focuses on the first year of a 5-year research-practice partnership in which teachers and researchers routinely coplanned, cotaught, and codebriefed science lessons via improvement cycles. We conducted an analysis of teacher-designed tools, reflective talk, and classroom observations. All teachers engaged in increasingly sophisticated forms of AST practices over the year and began to use a similar tool to scaffold scientific modeling with students. Yet, there were two distinct variations that evolved with grade-level teams. One team developed a practice and tool supporting students’ final form articulation of ideas with models and the other team developed a practice and tools supporting the revision of models over a unit of instruction. We argue that both grade-level teams engaged in productive learning and that PLC benefited from
having different perspectives on relatively similar practices for scaffolding students’ scientific modeling. On the basis of the findings, we propose three key components to a practice-based theory for how PLCs negotiate tools as a part of the improvement of teaching practices: anchoring improvement in a particular tool and practice, supporting variation in teacher learning and making teachers’ pedagogical reasoning explicit.

**KEYWORDS**
improvement science, professional learning, science teaching practice, scientific modeling, tools

**1 | INTRODUCTION**

Efforts to improve instructional interactions in classrooms within the U.S. education system have been largely unsuccessful. In fact, some would argue the core of teaching—instructional practices—has remained fundamentally unchanged for more than a century (Cuban, 2013; Hiebert & Morris, 2012). In science classrooms, one way to improve instruction is to engage students in authentic, real-world problems through model-based inquiry, which begins by taking seriously students’ experiences and ideas about natural phenomena and then providing instructional experiences that support students in constructing and revising explanations and models over time (National Research Council, 2005, 2012). Through these experiences, students have opportunities to learn central scientific concepts, but also disciplinary practices, and as such they “learn how to learn and do” science. Yet shifting classroom teaching from a traditional focus on learning science facts to one that engages students in examining multiple forms of evidence (including students’ own experiences) to construct and revise scientific models and explanations is not an easy task (Thompson, Windschitl, & Braaten, 2013). This kind of teaching with scientific models requires new kinds of practices and tools that support students in articulating and revising ideas over time and that support teachers in being responsive to students’ emerging ideas and puzzlements (Kang, Windschitl, Stroupe & Thompson, 2016; Lehrer & Schauble, 2000; Schwarz & White, 2005). For over a decade, we have partnered with K–12 teachers to develop a set of such teaching practices and tools, which we describe as Ambitious Science Teaching practices (AST; Windschitl, Thompson & Braaten, 2018). Yet, just articulating practices and providing examples of classroom tools is not enough to support teachers in shifting learning opportunities in their classrooms; teachers need opportunities to adapt and localize the AST practices and wrestle with the problems of practices (Horn & Little, 2010) that arise as students encounter modeling, often for the first time in their K–12 experiences.

For this study, we drew on literature about how teachers collaboratively learn in Professional Learning Communities (PLCs; Windschitl, Thompson, & Braaten, 2011; Horn, Garner, Kane, & Brasel, 2017; Wei, Darling-Hammond, Andree, Richardson, & Orphanos, 2009), improvement science (Bryk, Gomez, Grunow, & LeMahieu, 2015), and professional learning with tools and practices (Engeström, 2004; Horn & Little, 2010; Knorr Cetina, 1997) to design a professional learning experience with a team of middle school teachers working in partnership with educational researchers (see Coburn & Penuel, 2016 for more about research–practice partnerships). The teachers in the PLC sought to “improve all students’ written and spoken scientific models and explanations” and partnered with researchers to engage in multiple improvement cycles over a 5-year period of time. For each cycle, the PLC identified a local problem of practice, planned lessons with specific teaching strategies and classroom tools, collected and analyzed student work, named promising practices, and devised a plan for learning in the next improvement cycle (Bryk et al., 2015). In this paper, we examine the first year the PLC (with teachers who had
varying levels of teaching experience and knowledge of model-based instruction) engaged in improvement cycles and developed tools and practices supporting model-based instruction. The paper contributes to a growing body of literature about PLCs and how they collaboratively construct knowledge about science teaching in general, and about AST in particular (Authors, in press; National Academies of Sciences, Engineering, and Medicine, 2015).

2 | LITERATURE REVIEW

2.1 | Scientific modeling and AST practices

AST recognizes that building, testing, and revising models and developing evidence-based explanations are central practices in scientific fields (Windschitl, Thompson & Braaten, 2018; Latour, 1990; Nersessian, 2005). A model-based inquiry approach engages students in scientific studies with the construction and revision of models in light of new evidence (Gouvea, & Passmore, 2017; Stewart, Cartier, & Passmore, 2005). AST is a set of teaching practices that expand this focus on modeling by (a) fundamentally valuing students’ ideas, perspectives, experiences, and cultural and linguistic ways of articulating ideas, scaffolding discussion, reinforcing norms of inclusiveness, seeking a diversity of ideas, and supporting sensemaking with ideas from previous instruction, everyday experiences, and established science facts or theories. and (b) engaging students in reasoning with models that reflect authentic, relevant and real-world phenomena (Lehrer & Schauble, 2000, 2006; NGSS Lead States, 2013; Schwarz & White, 2005; Schwarz et al., 2009; Shim & Kim, 2017; Stewart et al., 2005; Stroupe, 2014; Windschitl & Barton, 2016). For example, we have seen middle school students seek to understand pathogens spreading through hospitals by working with peers to develop models of variation in bacterial cells over multiple generations and reason with the ways in which bacteria become resistant to antibiotics. Students built on one another’s ideas to draw representations, layered on new evidence as they conducted experiments and read informational texts, and reflected on how their knowledge shifted over time.

We know from the literature that these kinds of experiences with developing and revising explanatory models provide students opportunities to actively participate in complex forms of reasoning, including: using abstractions to build conceptual understanding, designing experiments and collecting data based on hypotheses derived from models, constructing and critiquing representations of data and the phenomenon under study, rallying evidence to support or refute explanatory models, and reflecting on how their ideas about a phenomenon changed over time (Lehrer & Schauble, 2005; Schwarz & White, 2005; Windschitl & Barton, 2016).

Some research groups, including the AST group, have partnered with teachers to articulate a set of instructional practices teachers can use to support students in developing and revising scientific models (Windschitl, Thompson, Braaten, & Stroupe, 2012; Kloser, 2014). For example, we describe a set of practices for eliciting students’ scientific ideas with models; in short, teachers provide opportunities for students to draw and annotate diagrams of a focal phenomenon at the outset of a unit, such that teachers can learn about students’ prior experiences and language about the phenomenon and use this knowledge to adapt the unit (Windschitl, Thompson & Braaten, 2018; Schwarz et al., 2009). Teachers can use particular scaffolds on these models to support students in drawing diagrams and writing explanations (such as sentence stems and checklists of key ideas) and to provide students the opportunity to show what they know (Thompson et al., 2016). Other examples of AST practices support students in developing evidence-based explanations as they revise models throughout a unit of instruction. Teachers provide scaffolds to support students’ use of evidence for key parts of their explanatory models, work with students’ ideas to unpack learning about “what counts” as an evidence-based explanation, and support students in evaluating their own arguments and those of others (Windschitl, Thompson, Braaten, & Stroupe, 2012; Windschitl, Thompson & Braaten, 2018; McNeill & Krajcik, 2009; Radinsky, Oliva, & Alamar, 2010; Zembal-Saul, 2009).

Presented here, however, these teaching practices seem static—or as practices that could be easily presented and learned—yet the possibilities of these teaching practices are only fully realized in the context of PLCs collaboratively developing, contextualizing, and improving the practices. This study is one of the first to investigate the process of practicing teachers taking up and further developing such model-based instructional practices in a PLC.
2.2 PLCs improving AST practices

In this paper, we conceptualize the development and improvement of AST practices as being situated in PLCs. PLCs are a characterization of a broader set of teacher-learning contexts where teachers work together in peer groups in some configuration around local problems of practice (Wei et al., 2009). We reason that in PLCs, teams develop pedagogical ideas about teaching practices with scientific models for their local contexts, create and revise tools for students to model phenomena and for PLCs to reflect on how students are constructing ideas with and about models, develop norms and specialized language about teaching with models and about collaboratively inquiring into practices, and decide on the philosophical basis of what constitutes model-based instructional practices and outcomes for student learning.

Yet, research suggests that many professional learning opportunities lack support for teachers to have critical conversations around instructional practice and how practices translate to their own classrooms (Coburn, 2003). Part of the translation issue is a matter of setting; professional learning opportunities often take place outside of school hours and outside of the classroom. Such teacher-learning arrangements leave adaptations to local classrooms underspecified and understudied. PLCs, in particular, are often designed to address the disconnect between learning and practice by situating professional learning within the work of teachers’ classroom and supporting teachers in examining connections to their own contexts (Coggshall, Rasmussen, Colton, Milton, & Jacques, 2012; Kazemi & Hubbard, 2008; Wei et al., 2009). Examples of this kind of embedded learning include PLCs reviewing student work or video of classroom interactions after school or in video clubs (e.g., van Es & Sherin, 2010), and Lesson Study in which teachers collaboratively plan, teach, observe, debrief, and revise a single class lesson (e.g., Lewis, Perry, & Murata, 2006). These structures emphasize the social dimension of practice development by supporting teachers in close collaboration with one another and in connection with K–12 students’ developing ideas.

There is ample evidence suggesting teacher learning is best supported in PLCs when (a) teachers have collaborative opportunities to reflect on teaching and learning in their own classrooms with specific artifacts such as video and student work (Gallucci, Van Lare, Yoon, & Boatright, 2010); (b) teachers’ learning is part of ongoing instructional improvement work rather than exposure to disconnected teaching strategies (Darling-Hammond & McLaughlin, 1995; Woodland, 2016); (c) teachers have opportunities to test and get feedback on instructional practices (Bybee, 2013; Coggshall et al., 2012); and (d) teachers can negotiate practices and reason with perceived contextual constraints, such as the need to be in alignment with school-improvement goals (Allen & Penuel, 2015; Knapp, 2003). High-quality professional learning opportunities ideally support PLCs in developing a culture of inquiry with trust and open-mindedness, curiosity about student learning and a willingness to engage in principled risk-taking (Cochran-Smith & Lytle, 2009). Studies suggest that such cultures lead to increased student learning especially when the teams develop shared goals through reflective and substantive dialogue linking instructional choices with student learning goals (Horn et al., 2017; Stoll, Bolam, McMahon, Wallace, & Thomas, 2006; Vescio, Ross, & Adams, 2008).

To understand how a PLC worked on improving AST practices related to scientific modeling and on improving the process of collaborative inquiry, we drew on recent work from the Carnegie Foundation about improvement cycles (Bryk et al., 2015). They suggest that systematic, disciplined inquiry requires that teams of people identify a common problem of practice to focus on and engage in rapid improvement cycles, which include four phases: planning, doing, studying, and acting on identified change ideas. These phases structure inquiry and create an opportunity to accumulate knowledge about a process (or in our case, knowledge about instructional practices that support student learning with scientific models).

2.3 Sensemaking with tools and practices in PLCs

Though little is known about how PLCs work on practices and tools as they engage in improvement cycles specifically, the literature on PLCs suggests that it is important for teachers to have opportunities to engage in particular sensemaking conversations as members negotiate, investigate and test classroom tasks, talk and tools
and the ways in which tools and practices are used in their own classrooms. Through collaborative sensemaking conversations, PLCs create common artifacts and shared histories of inquiry (Anagnostopoulos, Smith, & Basmadjian, 2007; Horn & Little, 2010). These conversations shape what teachers try in their classrooms and in turn what teachers share in subsequent PLC meetings and ultimately inform how teachers adapt teaching practices for their local contexts (Kazemi & Hubbard, 2008). In terms of professional learning, the literature suggests there are at least three key areas of negotiation PLCs engage with as they work on the improvement of instructional practices and tools for their local contexts. We describe these below, yet raise questions about how these forms of negotiation unfold as PLCs engage in improvement cycles with tools and practices in general (Bryk et al., 2015), and with AST and scientific modeling practices and tools in particular.

2.3.1 | Negotiation of shared tools and resources supports the accumulation and diffusion of social knowledge

As PLCs work with classroom tools, they develop a common vision of teaching and strengthen their ideas about teaching as well as their knowledge of how they learn about instructional practices together (also see Grossman, Smagorinsky, & Valencia, 1999; Horn & Little, 2010). Horn and Little (2010) in their in-depth comparative analysis of two instructional teams’ conversational routines, found that common sets of curricular resources along with “agreed upon criteria and principles” (p. 210) supported one of the teams in developing a common frame of reference. In particular, the team that shared a common history and vision for teaching engaged in purposeful conversations about links between instructional choices and students’ mathematical learning. For this study, we investigated how a PLC accumulated knowledge and a "shared vision" of teaching and learning with scientific models as they engaged in improvement cycles with common tools and practices. We also considered how engagement with multiple improvement cycles might lead to variation in a PLC’s sensemaking, vision, practice, and tools.

2.3.2 | Negotiation of various members’ perceptions of tools and the contexts, cultural norms, and expectations in which the tools are used

Several studies have concluded, not surprisingly, that more than just the discourse within PLC there are larger social forces at work in the improvement of practices. In short, people’s perceptions of social, historical and institutional context matter to the differential use and development of reform-oriented tools and practices. Allen and Penuel (2015) found teachers from the same district, but in different schools interpreted district policy around new science standards contrarily and these interpretations influenced what and how they taught. In one school, teachers were given time as a part of professional development (PD) to reconcile perceived incoherence among curriculum, the Next-Generation Science Standards (NGSS), and goals of the district, which in turn supported teachers in developing tools (such as revised pacing guides) to support reform teaching. In the other school, teachers worked in isolation, had no time or tools to make sense of the discrepancies and were unable to shift teaching practices. This study clearly suggested that, given the multiple demands on their teaching, PLCs can make progress on improving instructional practices when they have the tools and opportunities to engage in sensemaking conversations with these contextual issues.

Yet, studies have shown PLCs do not equally support all participating teachers as they negotiate contextual differences in practices used in their professional learning and their classrooms. Individual teachers in PLCs often experience a lack of a shared “grammar of practice” (Grossman, Hammerness, & McDonald, 2009) because descriptions of practice can be vague and interpreted in multiple ways depending on teachers’ experiences. Braaten (2011) found three of the 16 teachers in a PLC (with science teachers from multiple secondary schools), experienced alienation, and as a result, did not adopt pedagogical concepts and tools central to the work of the PLC. Teachers’ perception of the distance between their work in schools (which emphasized memorization) and the PLC
(which emphasized in-depth writing with scientific models) was a nonstarter for their participation in meaningful conversations about teaching and learning. For the other 13 teachers, the perceived distance between their work in schools and with the PLC was less marked, and tools developed by the community easily transferred across schools and offered a chance for teachers to “replay” (Horn, 2010) the same tool in a new setting, and test the conditions under which it best supported student learning in their individual classrooms.

These studies and others (see Thompson et al., 2013; Grossman et al., 2009; Horn, 2010; Kazemi & Hubbard, 2008; Kennedy, 2016) suggest teachers’ interpretations of the perceived distances between communities of practice influence the creation and refinement of pedagogical tools, and this might vary for individuals in the same PLC, even if the PLC is comprised of teachers from the same school. For this study, we sought to understand similarities and differences among PLC members’ perceptions of their contexts, norms, and expectations as they iterated on tools and practices.

2.3.3 Negotiation (or lack thereof) of underlying assumptions of pedagogical tools

Assumptions about best teaching practices and student capabilities are often implicit in PLC conversations and in the materials they create. PLCs can be structured such that teachers have opportunities to understand others’ perspectives, and why colleagues make certain instructional decisions based on their personal histories and perceptions of their contexts (Horn & Campbell, 2015). This requires deliberate sensemaking conversations in which people make their reasoning public as they negotiate how to use tools (Edwards, 2012; Mäkitalo, 2012). For example, Anagnostopoulos et al. (2007) examined revisions to a pedagogical tool—in this case a rubric for student-led discussion—as mentor teachers, interns, and university method instructors negotiated how the tool could be improved. As they revised the tool, they negotiated underlying ideas about practices that promote student discourse and considered issues of accountability. Socially, this meant they agreed with one another, specified nuances, and pushed back against one another’s ideas as they revised the tool. The perspectives of different role actors were made visible and became part of the group’s living knowledge about the tool and the teaching practices that supported vibrant classroom discussions. In this current study, we examined the extent to which a middle school science PLC made ideas and theories about instruction and student learning explicit as they engaged in sensemaking conversations and inquired into the continual improvement of tools and practices for scientific modeling.

For this paper, we wanted to understand how a PLC began the work of improving AST practices and tools in a school-based PLC and in individual teachers’ classrooms. The teachers specifically focused on the improvement of students written and spoken models and explanations, and as such, we asked the following research questions:

1. In what ways did teachers shift their instructional practice with scientific modeling over time? What was improved and did the improvement of instructional practices and tools vary among teachers?
2. In their professional learning community, how did teachers engage in sensemaking conversations about the improvement of instructional practices and tools designed to support students with scientific modeling? How did this vary within the PLC?

Through asking these questions, we hope to describe an initial practice-based theory (meaning, a theory grounded in empirical findings from the field; Bryk et al., 2015) for how PLCs might locally adapt and continuously improve AST and scientific modeling practices and tools.

3 DESIGN AND METHODS

3.1 Research–practice partners

The PLC consisted of five middle school science teachers from Tahoma Middle School (pseudonym)—Ms. Kelly, Ms. Ross, Ms. Campbell, Ms. Smith, and Ms. Gardner—and two educational researchers (the first two authors). The
teachers were familiar with the AST practices to varying degrees (Table 1). At the outset of the academic year, four of the five teachers had some common teaching practices as they all used phenomenon-based units and used an AST tool called the “summary table” as a public representation (large butcher paper posters that listed all the activities in the unit and connections to the larger phenomenon). The seventh-grade teachers had deeply engaged with the AST practices in previous years as a teacher candidate (Ms. Kelly) and as a cooperating teacher (Ms. Ross). Ms. Gardner, an eighth-grade teacher, learned about the practices during an AST summer institute with Ms. Ross. Ms. Campbell was split between seventh- and eighth-grade and was somewhat familiar with the AST practices as Ms. Kelly and Ms. Ross shared lesson plans with her. Ms. Campbell, however, spent most of her time planning with the eighth-grade team. Ms. Smith had transferred to Tahoma Middle School the year before and of all of the teachers, she was least familiar with the practices.

The educational researchers who partnered with the Tahoma PLC are former middle and high school science teachers and currently teach science methods courses in teacher preparation programs. They have expertise in teacher learning and have conducted studies that partner with preservice and in-service teachers in classrooms (Thompson et al., 2013; Thompson et al., under review). In the past decade, they have taken a research–practice partnership approach (Coburn & Penuel, 2016) with multiple school-based PLCs to identify and work on local problems-of-practice using an improvement science perspective (Bryk et al., 2015).

In this paper, the role of the “researchers as partners” is not foregrounded in the analysis of the improvement of teaching practices as we were primarily interested in the negotiations of the teachers around the development of their own practices and tools. We unpack these relationships and how the research–practice partnership unfolded with Tahoma and seven other schools in the same district over a 5-year period of time in other manuscripts (see Thompson et al., under review).

### 3.2 School context

Tahoma Middle School is a culturally and linguistically diverse school (36.2% Hispanic/Latino, 2.2% American Indian/Alaskan Native, 23.6% Asian, 12.2% African American, 4.7% Native Hawaiian/Other Pacific Islander, 15.7% White, 5.3% two or more races and 16.8% transitional bilingual). It is also a high-poverty school with 86.0% of the students on free-and-reduced lunch. Forty-two percent of the students passed the required state testing for science. On the basis of a history of low test scores in mathematics and literacy, the school was identified as a school in need of state-level supervision and support. In 2009, the school was awarded a state School Improvement Grant, yet by 2013 it was still underperforming by district and state standards. As compared to other schools in the state, students at Tahoma were ranked in the 15th percentile for reading and 36th percentile for math. University educational researchers began partnering with the science department as a whole in the fall of 2012, as the school was facing pressure from the state to show improvement by June of 2013.

### Table 1 Teacher background and knowledge of model-based teaching practices

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Grade level</th>
<th>Number of years teaching</th>
<th>Knowledge of the model-based science teaching practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms. Kelly</td>
<td>7</td>
<td>2</td>
<td>Graduate of teacher preparation program focused on the practices</td>
</tr>
<tr>
<td>Ms. Ross</td>
<td>7</td>
<td>11</td>
<td>Participated in a project that partnered with cooperating teachers for two years</td>
</tr>
<tr>
<td>Ms. Campbell</td>
<td>7 &amp; 8</td>
<td>20</td>
<td>2 years of exposure through planning with colleagues</td>
</tr>
<tr>
<td>Ms. Gardner</td>
<td>8</td>
<td>11</td>
<td>Participated in one summer institute</td>
</tr>
<tr>
<td>Ms. Smith</td>
<td>8</td>
<td>5</td>
<td>1 year of exposure through planning with colleagues</td>
</tr>
</tbody>
</table>
3.3 | Professional learning context

We recognize that ideas about instructional improvement move through at least three mechanisms that we can influence in a professional learning model: through people, through tools and tool use, and through joint engagement within designed settings that bring together different stakeholders—students, teachers, and researchers (Bryk, Gomez, & Grunow, 2011; Coburn, 2003). Our professional learning design reflects these insights. To support new social arrangements and activities in the first year of this research–practice partnership, the research team: (a) facilitated six Studios (in which the seventh- and eighth-grade teachers and university researchers coplanned, cotaught, and codebriefed lessons focused on scientific modeling), (b) supported teachers’ school sanctioned professional learning meetings to support planning with the new teaching practices emerging from the Studios, and (c) provided participatory coaching around the new practices. See Figure 1 for an overview of activities. The aim of these activities was not to have teachers replicate AST practices but to engage in improvement cycles to develop local translations of the practices. The professional learning design was iterative, codeveloped between teachers and researchers, and highly specific to the particular school (Penuel, Fishman, Haugan Cheng, & Sabelli, 2011).

3.3.1 | Studios

Both seventh- and eighth-grade teachers and university researchers (the first two authors) participated in six Studios, which were a kind of job-embedded professional development (Croft, Coggshall, & Elizabeth Powers, 2010) where we coplanned, cotaught, and codebriefed lessons focused on scientific modeling. The aim of the Studios was to support the PLC in collecting practice-based evidence for which teaching strategies worked best, under which conditions and for whom (Bryk et al., 2015). We adapted the Studio model from the mathematics department at Tacoma Middle School (designed by the Teacher Development Group, TDG, 2010) to engage in full-day professional development activities to improve mathematical tasks and routines. Structurally, the Studio model had similar features to Lesson Study (Lewis et al., 2006) in terms of supporting the collegial improvement of teaching through cycles, but differed in terms of the object of improvement—a particular lesson in lesson study versus a particular teaching practice in Studios. Although science Studios focused on a wide variety of science content, the goal of each Studio was the same: to develop practices and tools that supported students in creating evidence-based explanations and models for a scientific phenomenon.

3.3.2 | Improvement cycles

We structured the science Studios around the four phases of improvement cycles, which included planning, doing, studying, and acting (Bryk et al., 2015). Planning for each Studio took place 1 month before the Studio and focused

---

**FIGURE 1** Professional learning opportunities with science teachers at Tahoma Middle School
on adapting a unit of instruction for one of the teacher’s classrooms (which we referred to as the host teacher, with seventh- and eighth-grade teams alternating as host teachers). To plan, seventh- and eighth-grade teachers and researchers used school sanctioned PLC time to identify a puzzling phenomenon for the science unit, draw a model of the phenomenon as a group and identify gaps in our content knowledge, identify problems-of-practice to focus on, and design tools to support students in modeling and talking about their ideas. Teachers would often propose and negotiate the design of tools, hypothesizing what would best support students’ construction of scientific models and explanations. Researchers also offered ideas about how the tools might support student learning, possible tweaks to tools teachers were constructing and shared resources (research articles, working papers).

Following the initial Studio-planning meeting, host teachers and researchers used online resources to further understand the scientific big ideas; we exchanged emails about the science content and emerging thoughts about how to address a particular problem of practice in their particular classrooms. On the day of the Studio, the PLC members continued the planning phase by fine-tuning the lesson and unpacking levels of a scientific explanations students might supply (Windschitl, Thompson, & Braaten, 2011; Braaten & Windschitl, 2011), then we moved to the doing phase.

In the "doing phase," we cotaught the lesson in the host teacher’s classroom twice in 1 day (two 60 min periods). Coteaching consisted of the host teacher leading her lesson, with other teachers and researchers monitoring student progress by video recording and listening to student talk, as well as asking questions as students engaged with modeling tools. We often limited the number of times the teachers and researchers would interact with students to better understand how the tools we designed supported or failed to support students without constant intervention from a facilitator.

Following the first class period, we convened in a conference room to begin the “study phase” by examining written artifacts from all the students and reviewing video of student talk. Both teachers and researchers selected segments of video that showed student reasoning with the puzzling phenomenon to share with the PLC. We analyzed how students used everyday and scientific language in the classroom video and in students’ work, the depth of students’ scientific explanations, and how students used tools. We discussed emergent problems-of-practice and brainstormed possible changes to the tools and practices that would better support student thinking. For the “act phase,” the PLC named a change they would like to make before teaching the lesson for a second time later in the same day. This named change was then used to modify existing tools and the instructional sequence of the lesson. These changes were then implemented in a second do phase in the same host classroom in the next period, followed by another round of studying and acting. From an improvement science perspective, the PLC engaged in two rounds of doing small tests with small changes (Bryk et al., 2015) during one Studio.

Following Studios, the first and second authors visited teachers’ individual classrooms and partnered with teachers to apply new ideas derived from Studios. This type of coaching involved active engagement in planning, teaching and reflecting with individual teachers (as opposed to passive observation and debriefing after the fact; Knight, 2007). Then teachers and researchers would begin the next cycle of improvement, starting again with planning for the upcoming Studio and maintaining a focus on improving all students’ written and spoken explanations and models.

### 3.3.3 Foundational AST focus in Studios

Important to the science Studio model was an underlying set of evidence-based AST practices designed to engage students in developing scientific models and making their thinking visible and explicit (Windschitl, Thompson, Braaten, & Stroupe, 2012, 2018). Figure 2 provides a brief description of the practices, which included (a) planning for engagement with important science ideas, in which teachers developed tasks that supported students in developing model-based explanations linking unobservable and observable entities of a phenomena; (b) eliciting students’ ideas to adapt instruction, in which students were prompted to share and build ideas that shaped the development of an explanatory model; (c) supporting ongoing changes in thinking, in which students were supported in connecting classroom activities to the developing explanatory model; and (d) pressing for evidence-based explanations, in which
students rallied evidence to justify relationships in explanatory models (see Windschitl, Thompson, Braaten, & Stroupe, 2012, Thompson et al., 2013 for a description of how this progression developed and tested). Researchers used this progression as a reflection tool with teachers, asking teachers to reflect upon and track where they were individually and collectively. This progression also provided foundational shared language in which PLC members could discuss the progression of practices and the use of tools to support student thinking.

### 3.4 Data sources

Data sources for this study included 42 hr of video from six Studios (7 hr/Studio; in total this was video data from approximately 9 hr of planning phase, 12 hr of doing phase, 12 hr of study phase, 9 hr of acting phase), weekly participatory coaching logs, individual classroom observations, and 8 hr of video of a convening at the end of the first year of the project. Video records included interactions among teachers and researchers as well as interactions in classrooms with students. Coaching records were detailed after each coaching session and included images of tools teachers used in their classrooms. Convening records included video of teachers describing what they learned as a PLC over the year and written reflections from each teacher about the development of tools and practices in their own classrooms over the course of the year.

### 3.5 Data analysis

For this paper, we analyzed PLC conversations, teacher-designed tools, and classroom observations to study how teachers in a PLC make sense of and develop instructional practices and tools designed to support students with scientific modeling.

---

**FIGURE 2** Performance progression of model-based inquiry science teaching practices. See Authors (2009, Windschitl, Thompson, Braaten, & Stroupe, 2012, Thompson et al., 2013) for a description of these practices and the development of the progression and Thompson et al., under review for an updated version.
3.5.1 Discourse analysis of the PLC’s reflective talk

Our analysis focused on collective sensemaking opportunities (Creswell & Poth, 2018; Lincoln & Guba, 1985) in improvement cycles during Studios. We examined video data from the planning, studying, and debriefing phases of the Studios using Studiocode, a video analysis software. Specifically, this meant that we examined conversations at the beginning of the Studios, between the first and second lessons and after the second lesson when the PLC debriefed student learning and teachers made instructional decisions about how to act on what they learned before the next Studio. In particular, we looked at PLC discourse around the development and refinement of tools and instruction (Sohmer, Michaels, O’Connor, & Resnick, 2009) with attention to how the PLC members reasoned with student data (video and student work) and made decisions about what and how to teach with the model-based tools. Initially, we used general codes to analyze conversations about the practices, tools, and student learning: (a) student ideas—PLC conversations about how student ideas were scaffolded in models; (b) science ideas—PLC conversations about how students presented scientific understandings in their explanatory models; (c) suggestions—PLC conversations about suggested changes to tools and practices that could be implemented in upcoming lessons; (d) tools—PLC conversations about how tools supported students’ writing and classroom discussion; and (e) processes—how teachers built on/or failed to build on one another’s ideas. From this analysis we found patterns in (a) the type of tool most often discussed and revised in the PLC, (b) the way in which the seventh- and eighth-grade teams developed tools for modeling over time, with talk about addressing different problems of practice, (c) patterns in social interactions in the PLC as individuals aligned and supportively critiqued one another, and (d) patterns in how teams inquired into the practices over time. We conducted member checks with all teachers about these findings at the end-of-year convening.

3.5.2 Content analysis of teacher-designed tools

Supporting our analysis of the PLC conversations, was an analysis of the tools that were designed for Studios and for individual teachers’ classrooms. We examined all tools used during Studios (e.g., summary tables, student generated checklists, lists of hypotheses about phenomenon, back pocket questions, see Windschitl, Thompson & Braaten, 2018 for further details on each of these tools), but this paper focuses on how the PLC tested and revised scaffolds on model templates, as this tool was routinely used during each Studio and each unit of instruction teachers taught throughout the school year. A model template is a handout that supports students in drawing diagrams and writing explanations to provide students the opportunity to show what they know about a scientific phenomenon (Thompson et al., 2016). Model templates include specific scaffolds such as sentence starters, checklists of key disciplinary ideas, and specific areas for students to use evidence gathered throughout a unit to explain observable and unobservable components of scientific phenomena. This tool was used across all seventh- and eighth-grade classroom observations and Studios and was highly negotiated amongst the PLC (further rationale for the focus on model templates is discussed in the findings section). Specifically, we examined how teachers used scaffolds on the model templates to support students’ explanatory models (also see Thompson et al., 2016).

3.5.3 Classroom observations

Teachers were observed five times over the course of the academic year. We observed each seventh- and eighth-grade teacher and student interactions teach five 60-min lessons. We coded lessons based on the AST performance progression (Figure 2; Thompson et al., 2013). A rating of 4 represented the most sophisticated and a rating of 1 was the least sophisticated practice. For example, in the practice of Supporting on-going changes in thinking lessons scored a 4 if the lesson observed demonstrated a model-based inquiry focus (Figure 2). Observations and ratings were done by the first two authors and discussed to ensure alignment. We combined classroom observation scores for each practice for each time point and ran a linear regression analysis to determine if the team improved some
practices more than others. It should be noted that on the scale we were using, there are significant qualitative differences in the instruction characterized at each level. For example, when teachers move from a Level 2 in the practice of Pressing for explanation to a Level 3, they have made the nature of the intellectual work more challenging and likely put new tools into the hands of learners to accomplish what was expected. An increase from 2 to 3 on the first two practices and 3 to 4 on the third and fourth practices represents a significant change in rigorous and responsive classroom interactions (Thompson et al., 2016). We note also that it gets progressively more difficult to move practice forward if teachers start at a high level (as Ms. Kelly and Ms. Ross did).

4 | FINDINGS

Five science teachers from Tahoma Middle School and two science education researchers met regularly to coplan, coteach and codebrief science units and lessons as we aimed to improve all students’ written and spoken models and explanations. Although the PLC worked on this improvement aim for 5 years, this paper reports on the first year the team took up AST practices, identified local problems of practice, and began developing and testing science teaching practices and tools that scaffolded student reasoning with scientific modeling. In the findings section, we first describe how teachers took up AST and scientific modeling practices in classrooms and the PLC, then describe the tools and practices that became objects of improvement in classrooms and the PLC and finally describe negotiations within the PLC that supported the development of instructional practices and tools. We focus on similarities and variation in the PLC.

4.1 | Improving practice: Developing similar practices and tools

To answer our first research question, in what ways do teachers shift their instructional practice with scientific modeling over time, we used a performance progression of the four AST practices as an initial benchmark for assessing if and how teachers improved instruction. Table 2 shows observational data from the five teachers over five points in time during the academic year. The teachers generally improved their performance on each of the practices. Taken together these ratings suggest students were engaged in thinking about models of puzzling phenomena, expressing their initial ideas and the revision of their ideas over time, reasoning with how and why explanations, and making connections across activities within a unit of instruction. Their improvement was slightly higher for the pressing for evidence-based explanation practice, which supported students in coordinating and synthesizing model-based explanations at the end of a unit of instruction. However, teachers also improved practices used at the beginning and middle of a unit of instruction (such as eliciting students’ ideas and building ideas across activities).

There was variation in starting places and growth over time for teachers within the PLC. The classroom observation data (Table 2) indicated that the seventh-grade teachers (Ms. Kelly and Ms. Ross) started with sophisticated instantiations of the practices. For Ms. Kelly, there was a ceiling effect, meaning her lessons were consistently rated at the most sophisticated level of each practice. The eighth-grade teachers (Ms. Campbell, Ms. Gardner, and Ms. Smith) steadily improved by the 4th observation. For time point 5 (the end of the school year) we noticed that one teacher, Ms. Gardner, had fewer attempts at sophisticated versions of the practices. Her unit was coplanned with other eighth-grade teachers but enacted differently. Ms. Gardner struggled with the practice of eliciting students’ ideas to adapt instruction. We reason that it might be the case that being adept at eliciting students’ ideas might be prerequisite practice supporting pressing for an evidence-based explanation. Nonetheless, toward the end of the school year, there was less variation in the AST practices across the teachers in the PLC.

Teachers also began to use a similar classroom tool with these practices. In particular, all teachers began using a scientific model “template” that scaffolded students in writing and drawing for each unit of instruction. Use of this tool was seen across all classroom observations and Studios, but the design of the tool originated in the first Studio.
<table>
<thead>
<tr>
<th>Teacher</th>
<th>Classroom observation #</th>
<th>Lesson</th>
<th>Planning for engagement with important science ideas</th>
<th>Eliciting students' ideas to adapt instruction</th>
<th>Supporting on-going changes in thinking</th>
<th>Pressing for evidence-based explanations</th>
<th>How/ partial why something happened explanation</th>
<th>Causal explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 Ms. Ross (7th)</td>
<td>Obs 1</td>
<td>Density</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Obs 2</td>
<td>Bonding</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Obs 3</td>
<td>Polarity</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Obs 4</td>
<td>Cell membrane function</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Obs 5</td>
<td>Mendel inheritance</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>T2 Ms. Kelly (7th)</td>
<td>Obs 1</td>
<td>Density</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Obs 2</td>
<td>Bonding</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Obs 3</td>
<td>Polarity</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Obs 4</td>
<td>Cell membrane function</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Obs 5</td>
<td>Canine genotypes and phenotypes</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Teacher</td>
<td>Classroom observation #</td>
<td>Lesson</td>
<td>Topic focus</td>
<td>Process focus</td>
<td>Theory focus</td>
<td>Planning for engagement with important science ideas</td>
<td>Eliciting students' ideas to adapt instruction</td>
<td>Supporting on-going changes in thinking</td>
</tr>
<tr>
<td>---------</td>
<td>-------------------------</td>
<td>--------</td>
<td>-------------</td>
<td>---------------</td>
<td>--------------</td>
<td>----------------------------------------------------</td>
<td>----------------------------------------------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>T3 Ms. Campbell (7th/8th)</td>
<td>Obs 1</td>
<td>Friction (8th)</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Obs 2</td>
<td>Reactions (7th)</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Obs 3</td>
<td>Yeast cell energy story (7th)</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Obs 4</td>
<td>Inheritance (7th)</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Obs 5</td>
<td>Fossil evidence (8th)</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>T4 Ms. Gardner (8th)</td>
<td>Obs 1</td>
<td>Plate tectonics</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Obs 2</td>
<td>Rock cycle</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Obs 3</td>
<td>Convection investigation</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

(Continues)
<table>
<thead>
<tr>
<th>Teacher</th>
<th>Classroom observation #</th>
<th>Lesson</th>
<th>Topic focus</th>
<th>Process focus</th>
<th>Theory focus</th>
<th>Monitoring, checking, reteaching ideas</th>
<th>Elicits students’ ideas &amp; adapts instruction</th>
<th>References students’ ideas &amp; adapts instruction</th>
<th>Scientific method focus</th>
<th>Discovering or confirming science ideas</th>
<th>Linking, building science concepts</th>
<th>Epistemic fluency/MBI focus</th>
<th>Pressing for evidence-based explanations</th>
<th>How/ partial why something happened explanation</th>
<th>Causal explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obs 4</td>
<td>Hurricane sandy</td>
<td></td>
<td></td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Obs 5</td>
<td>Day and night</td>
<td></td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>T5 Ms. Smith (8th)</td>
<td>Obs 1</td>
<td>Plate tectonics</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Obs 2</td>
<td>Rock cycle</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Obs 3</td>
<td>Convection investigation</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Obs 4</td>
<td>Hurricane sandy</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Obs 5</td>
<td>Day and night</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Abbreviation: MBI, model-based inquiry
In the first Studio, teachers decided to have students draw large life-size posters of boiling water for Top Ramen (Figure 3), but after the first improvement cycle, the team quickly realized that students were spending too much time drawing and not enough time reasoning. For the second Studio, in November the teachers provided students with a model template for a unit on forces and motion on an 11 × 17 piece of paper (Figure 3). For the remaining Studios, the teachers came to use the model template tool with a drawn image of a scientific phenomenon and space for students to record their thinking, typically on an 11 × 17 piece of paper (Figure 3). More than a glorified

**FIGURE 3** Model template tools designed by teachers for improvement cycles during Studios, September through April [Color figure can be viewed at wileyonlinelibrary.com]
worksheet, this tool not only provided multiple ways for students to express their ideas (drawing and writing) but it supplied data for teachers to situate their conversations about student learning when debriefing the lesson. In our analysis of the Studio debriefing conversations, this tool was referenced and its structure negotiated considerably more often than other tools. Though all teachers improved AST practices and came to use the model template tool in their own classrooms, there were important differences between grade-level teams, which helped us articulate how the two teams learned differently.

**January Studio**
Ms. Smith 8th grade
Phenomenon: Rock Cycle & processes that change matter

**March Studio**
Ms. Kelly 7th grade
Phenomenon: Iraqibacter bacterium and variation in genetic material

**April Studio**
Ms. Owens 7th grade
Phenomenon: Hicks Lake phosphorus pollution & interactions between biotic and abiotic factors

**FIGURE 3** Continued
4.2 | Developing productive variations: practices and tools for Scaffolding Scientific Modeling

To further address our first research question, we sought to understand variation within the PLC team (Bryk et al., 2015). In this PLC, grade-level teams identified different problems of practice and used Studios to develop two variations of a practice that we would later call Scaffolding Scientific Modeling. The model template was the central shared tool negotiated as part of the PLCs work; however, grade-level teams showed different patterns in how they iterated on the tool during Studios and how they used the tool in their own classrooms. In short, we found the eighth-grade teachers developed a model template tool that scaffolded students’ construction of a model at the end of a unit of instruction as a way to help the teachers work on the problem of assessing students’ thinking at the end of a unit of instruction. Meanwhile, the seventh-grade team developed scaffolds for students to use and revise models throughout a unit of instruction. Their aim was to improve formative assessments and build on students’ lines of thinking. Below we describe findings from PLC interactions and our content analysis of the iterations of model templates to show how grade-level teams worked on these variations.

4.2.1 | Eighth-grade team variation: Developing reusable summative model templates to help students show the depth of their knowledge

By the end of the academic year, the eighth-grade teachers ended each unit by having students complete an 11 × 17 piece of paper with supports for drawing a scientific model and writing an explanation. The model template tool was used to assess content students learned throughout a unit. Six features of the model template became consistent regardless of content and teacher. These features are overlaid on a model template the eighth-grade teachers used (Figure 4) and help show how the tool was oriented toward final form evaluation of student’s thinking.
Teachers asked students to draw a model of a phenomenon (often not contextualized in students’ lives and experiences, i.e., drawing a model of the rock cycle and the seasons, Figures 3 and 4; Feature 1).

Teachers used the model template at the end of a unit to help students answer an overarching question. This question was clearly stated at the top of the model (Feature 2).

Students were given space to explain their current thinking by writing an explanation (Feature 3) and drawing a model (Feature 4).

Teacher expectations were provided in the form of an explanation checklist (Feature 5) and were linked to grading rubric (Feature 6).

The eighth-grade teachers came to believe that supplying students with a model template provided students with an opportunity to “show what they know,” and helped teachers manage the time constraints they felt when teaching in new and complex ways. Ms. Smith explained:

We’re interested in assessments that will be equitable for the population that we all serve but as we know this kind of science teaching is super-duper time-consuming to do so during the course of the year what Ms. Gardner and I pretty much came up with was a kind of assessment that could be used again and again without tweaking too much… So we came up with a template where we asked them to talk about their topic, draw a picture of their model and then explain answering our prompt. They needed more opportunity to do visual work. If they mess up on the picture, they might be able to show it in words. It helped me to see what they knew much more clearly because they had a couple of different ways to do it. And the students have a much better way to show what they know. I found myself saying that a lot. “Show what you know.”

(Ms. Smith, end-of-year public reflection with PLC)
In this quote, Ms. Smith described her theory for how the model template tool supported the team’s summative assessment practice. She reasoned with how students expressed ideas, given particular scaffolds built onto the eighth-grade model template tool, and how this supported the assessment process. Notably, the eighth-grade teachers focused on the improvement of students’ construction of models of processes (Gouvea & Passmore, 2017) at the end of each unit. By contrast, the seventh-grade teachers supported students in modeling observable and unobservable processes over the course of a unit of instruction.

4.2.2 | Seventh-grade team variation: Scientific modeling with multiple, malleable tools across units of instruction

Analysis of the seventh-grade tools and the teachers’ talk revealed a strong relationship between the goals of supporting students revising their scientific ideas over time and teachers’ adapting their instruction based on students’ emerging lines of thinking. Ms. Kelly explained:

> What I think is so cool about this model I used this year was that it was actually revisable and kids kept them the whole unit... They (students) started out just drawing the yeast cell and adding bit by bit as we learned about organelles or that salt kills yeast... so they really added and added and added and added, eventually writing a whole explanation from their really chaotic models. (Ms. Kelly, end-of-year reflection with PLC)

This quote touches on Ms. Kelly’s and Ms. Ross’ idea that students learn by constructing and revising ideas, and that the instructional practice of scaffolding scientific modeling should support students in these processes. They developed tools that reflected these ideas.

The seventh-grade teachers (similar to the 8th-grade teachers) added structural features to their model template tools to scaffold modeling and the revision of ideas over time. They designed 11 × 17 model templates that varied from one unit to the next. At the beginning of a unit, teachers often included fewer scaffolds as compared to the end of a unit. In one seventh-grade classroom, the models created by students varied across class periods in terms of the key ideas emphasized and the representations of unobservable processes. Across all classrooms three features became common:

- Teachers asked students to model a puzzling phenomenon, not found in textbooks (i.e., how Acinetobacter baumannii/Iraqibacter mutated and infected US Army service members in Iraq and how carbon in bread the class baked changed into energy students could use, Figures 3 and 5; Feature 1).
- Teachers used zoom-in bubbles and question boxes to provide space for students to reason with important “places” on the model, which were often places where unobservable processes occurred (Feature 2).
- Teachers asked students to revise models over the course of one or multiple units of instruction. Students indicated revisions on models (Feature 3).

Figure 5 shows an initial model that was revised as students learned about how bread rises. “Zoom-ins” were used by teachers as structures to guide students toward reasoning with processes inside the bread. The model on the right followed this unit and was focused on providing students space and structure to apply their thinking from earlier models to a new, related phenomenon (digestion and cellular respiration in the human body).

As with the eighth-grade teachers, the seventh-grade teachers provided supports for students to show their understanding. A key difference was the seventh-grade tools were developed with the intention of having students iteratively build their explanations, in drawing and writing, over time and then apply their newly developed understanding. As a seventh-grade teacher explained:
At the end of the unit, we had them go back and then talk about the bread that they had to bake and what's happening in your cells with the bread. We made them apply it (on the story of carbon poster) and then they had to apply it again on the Chihuahua poster (Ms. Ross, end of year reflection with PLC).

Later in the year, the seventh-grade teachers reified the idea of applying concepts to new phenomena by developing a new tool they referred to as “How It All Connects” (see Figure 6). The tool helped students summarize and make connections across three units of instruction. They continued to use zoom-ins and content-specific boxes, but they extended the purpose of the model template such that students would use the tool to explain their thinking over time to parents and guardians during conferences. In this way, it had a similar function to the eighth-grade teachers’ model templates as a tool for demonstrating knowledge but conveyed a message about scientific models as representing knowledge being built over time.

The model template tool supported teachers in working on the problem of needing to assess students’ ideas in-the-moment and in being responsive to students’ lines of thinking. One seventh-grade teacher explained how two teachers used the tool to support different content learning:

(Cellular respiration and conservation of matter) was my main theme because that’s where my kids went with it. I think it depends a lot on students’ ideas, I know Ms. Campbell incorporated plants and comparing photosynthesis a lot in hers but my kids didn’t go there. (Ms. Kelly, end of year reflection with PLC)

Similarly, another seventh-grade teacher described how they used student thinking on models to assess how students were reasoning with evidence-based explanations and to adapt instructional content.

Some kids would reference, inside the picture, they would reference some of the labs that we did. They would draw little flasks blowing up and things like that, so they used the evidence directly to show why that whatever it was that they were using was part of the equation. From there, we were able to cover quite a few topics, we

![Figure 6](https://wileyonlinelibrary.com)
talked about things like the cell, what the cell needs, what it produces, what actually makes up something that’s alive, what the parts of the cell are and what all those do. (Ms. Ross, end of year reflection with PLC)

In this way, there appeared to be a developing relationship between the teachers’ use of the model template tool and their working theory for “following student thinking”, whereby the tools helped teachers uncover what students were thinking so teachers could adapt instruction and support students’ model-based explanations.

4.3 | PLC sensemaking: Negotiating variations of Scaffolding Scientific Modeling

To understand how the PLC made room for two variations on a similar practice, Scaffolding Scientific Modeling, (and to address our second research question) we examined conversational interactions from Studios. Structurally, seventh- and eighth-grade teams alternated taking the lead on the Studio each month, which offered each team a chance to work on a problem of practice they viewed as most pressing as they learned to teach with scientific models. The eighth-grade team wanted to work on having students record their ideas on paper and gaining access
to students’ best thinking, so they could focus on assessment. The seventh-grade team wanted to better understand how the questions they posed and scaffolds they included on the models supported students in reasoning with models over the course of a unit.

In addition to having different problems of practice foci, the teams also had different patterns in how they engaged in inquiry. The eighth-grade teachers’ improvement cycles focused on processing new ideas and making minor tweaks during the Studios, then making more significant changes around tools and practices toward the end of the year. We called this a process of incubation, then development. The seventh-grade team instead tested features on the model template tool during each Studio throughout the year, thus engaging in rapid cycles of development and testing. Below we provide examples from two Studios—one hosted by an eighth-grade teacher and one by a seventh-grade teacher—that occurred in the middle of the year, as teachers were in the midst of shifting their practice. In the examples, we highlight the differences in foci and approach to improvement cycles for the

---

**TABLE 4** Studio #4 dialogue about *Scaffolding Scientific Modeling* with eighth- and seventh-grade teachers reflecting on lessons learned from the Studio

<table>
<thead>
<tr>
<th>8th-grade team: Reflecting on improvements to their developing practice</th>
<th>7th-grade team: Making connections to their variation of the scaffolding practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms. Gardner: I’m taking away quite a bit. We definitely need to set them up with words, <strong>process words</strong>, to use when they’re talking to each other and when they’re writing. So if we can help them in the beginning then they can put those thoughts together into an explanation. I think it’s going to help them see the big picture.</td>
<td>Ms. Kelly: ...Something Ms. Smith and I talked about when we were looking at this (student work) is how kids go from thinking or talking to writing and the things that they need to make it happen. They can tell me everything that I hoped that they would learn but they can't write any of it down. So it's kind of what today has made me think about <strong>generic writing supports</strong>.</td>
</tr>
<tr>
<td>Ms. Smith: I think that really helped.</td>
<td>Ms. Ross: I was thinking back to the last time (Studio 3), we gave kids something that was very basic and we came back and we really beefed it up and it did wonders. And then this time, we had something that didn’t seem to support all of the kids. So I’m wondering how I can continue to work on making a <strong>better structure or better scaffolded piece of paper</strong> for kids to work off of.</td>
</tr>
<tr>
<td>Ms. Gardner: Your template helped some and didn’t help, it wasn’t useful for everybody.</td>
<td>Ms. Kelly: …Something Ms. Smith and I talked about when we were looking at this (student work) is how kids go from thinking or talking to writing and the things that they need to make it happen. They can tell me everything that I hoped that they would learn but they can't write any of it down. So it's kind of what today has made me think about <strong>generic writing supports</strong>.</td>
</tr>
<tr>
<td>Ms. Smith: It wasn’t useful for everybody. That’s really true.</td>
<td>Ms. Ross: I was thinking back to the last time (Studio 3), we gave kids something that was very basic and we came back and we really beefed it up and it did wonders. And then this time, we had something that didn’t seem to support all of the kids. So I’m wondering how I can continue to work on making a <strong>better structure or better scaffolded piece of paper</strong> for kids to work off of.</td>
</tr>
<tr>
<td>Ms. Gardner: Yeah, maybe even just posting a diagram but then letting them go without being hung up on that specific template might be a different way to go.</td>
<td>Ms. Kelly: …Something Ms. Smith and I talked about when we were looking at this (student work) is how kids go from thinking or talking to writing and the things that they need to make it happen. They can tell me everything that I hoped that they would learn but they can't write any of it down. So it's kind of what today has made me think about <strong>generic writing supports</strong>.</td>
</tr>
<tr>
<td>Ms. Gardener: I’m just wondering if for some kids...this (student work) might have been okay for some kids but maybe having a little bit more support in here for them like having the sentence stems on here.</td>
<td>Ms. Ross: I was thinking back to the last time (Studio 3), we gave kids something that was very basic and we came back and we really beefed it up and it did wonders. And then this time, we had something that didn’t seem to support all of the kids. So I’m wondering how I can continue to work on making a <strong>better structure or better scaffolded piece of paper</strong> for kids to work off of.</td>
</tr>
</tbody>
</table>
grade-level teams as evident in PLC talk with tools. We also highlight the importance of “teacher press” as teachers with different perspectives on similar practices pressed one another to articulate their purposes for making particular instructional choices.

4.3.1 Eighth-grade improvement cycles: Incubating with tools and practices

During Studios, the eighth-grade team tinkered with a variety of tools and strategies that supported students in recording their ideas on model templates. In terms of improvement cycles, they often planned strategies, did quick assessments of students’ writing on model templates, then made either subtle or no change to the lesson. For the study phase of the inquiry cycles, the teachers often evaluated if students supplied correct answers or if students produced a large quantity of writing; these were quick litmus tests for the effectiveness of instruction.

What follows is an excerpt from the 4th Studio hosted in Ms. Smith’s classroom, which featured students completing an end-of-unit rock cycle model. Unlike previous Studios, the eighth-grade teachers became interested in shifting their teaching toward having students describe rather than label processes. The shift started with the seventh-grade teachers challenging the purpose of having students do matching exercises. The eighth-grade teachers then considered how to move students quickly through the process of recalling particular instructional activities, so students could spend more time focusing on rock formation processes. In Table 3 we divided the PLC’s discourse into two columns so that the reader could see the seventh-grade teachers’ press and eighth-grade teachers’ sensemaking with student reasoning with a proposed instructional change for the second improvement cycle.

In this conversation, the teachers considered and questioned strategies for having students recall activities and name rock cycle processes. At this point in the year, the model template tool was not an object of revision; rather it was a resource for eighth-grade teachers to assess students’ use of vocabulary. Despite the press from Ms. Ross and Ms. Kelly to consider spending less time on matching and more time on modeling processes, Ms. Smith and Ms. Gardner opted to keep the entry task and tool unchanged except to prompt students to recall activities completed during the unit and to use “process words” rather than just the names of phases of the rock cycle.

While the eighth-grade teachers appeared satisfied with the model template, by the end of the day they began to question the usefulness of the model template for supporting all students, as well as a need to shift from focusing on labeling to adding “process” words to support more robust written explanations.

In this segment, the eighth-grade teachers used observations of students using (and not using) the tool and loosely articulated a theory for how students learn through inductive reasoning—through talking and writing students can assemble pieces to understand the big picture with the right kinds of scaffolds, yet some students might need more scaffolds on the model template than others. As such the teachers began to take an improvement stance on their teaching with observational data, not just basing decisions on hunches about how students might perform. Following this Studio, Ms. Smith, Ms. Gardner and Ms. Campbell started iterating on the end of unit model template assessment with more scaffolds in place. They included blank spaces for students to draw less-structured models, an explanation checklist with process words, and writing scaffolds such as sentence starters. By May they had the five different features built into their assessments (see Figure 4).

The segment in Table 4 also shows how both seventh- and eighth-grade members of the PLC seemed to agree that additional scaffolds would support students in articulating their ideas. In this way, the teachers expressed some overlap in their conceptual and epistemic reasons for Scaffolding Scientific Modeling, but with different end goals and pedagogical tools. As seen in Table 4 the seventh-grade teachers similarly used Studio 4 as further evidence for embedding writing prompts on the model template. We describe their improvement cycles next.
4.3.2 | Seventh-grade improvement cycles: Testing features of tools

The major difference in the approach to inquiry in the Studios lead by seventh-grade teachers as compared to those lead by eighth-grade teachers, was the modifications teachers made to pedagogical tools during improvement cycles. The seventh-grade teachers used Studios to test small changes to scaffolds on the model template tool and continued to use the scaffolds they tested in subsequent units of instruction in their own classrooms. In terms of improvement cycles, they often planned questions and prompts to support students in reasoning with models, made visible changes to tools, collected and analyzed data on the scientific and everyday language students used, and then made strategic changes to the model template tool. It should be noted that Ms. Ross and Ms. Kelly had prior experience using the evidence-based science teaching practices and tools, which might have supported the seventh-grade team in taking a testing rather than an exploratory approach to improvement cycles.

The following example comes from the third Studio of the year (but the first Studio the seventh-grade team lead) and highlights how the seventh-grade teachers examined student data and made shifts to the model template tool based on data following the first improvement cycle. When debriefing the first lesson the seventh-grade teachers decided to include “zoom-in boxes” for students to show their reasoning as they modeled chemical reactions and electrical flow for a makeshift battery with pencils. Students were asked to model how a light bulb...
turned on when two pencils were placed in a cup of salt water and were connected to a battery and light bulb. Similar to the example from the fourth Studio, the eighth-grade teachers pressed the seventh-grade teachers to clarify their expectations. Ms. Kelly, Ms. Ross, and a researcher discussed how and where, visually on the model template, students reasoned about ionization (Table 5).

Ms. Ross and Ms. Kelly respond to Ms. Gardner’s press by using the same terms, yet continued to focus on the process of reasoning rather than assessing vocabulary. Figure 7 shows the shifts the teachers made to the model template, which included more zoom-ins and targeted questions to support students in reasoning with the process of ionization (Figure 7).

As the teachers engaged in modifying the tool they imagined how the tool would support student reasoning, thus drawing hypothetical links among the material and conceptual dimensions of the practice. Ms. Ross rationalized that the changes would be important for her 5th period as she had a high number of English Language Learners and special education students who would need additional linguistic support. Ms. Kelly further reasoned that the targeted question boxes would support students’ building a scientific explanation.

For round one, the students can draw a zoom-in of the wire on both sides and in round two, draw the tip of the pencil in the salt water on both sides. So, they would have to draw the salt water and no bubbles, and then the other one they would draw the salt water again but then they should draw these clouds and there should be bubbles. They can compare the off versus on, and if they do the wire before the water, then that will help them or at least give you something to point out to get them to draw the cloud of charges. First, we want them to reason with what the charge does to it, coming from the battery and what is already in the water. It just lets them build their thinking. (Ms. Kelly, Studio 3)

In this quote, her theory for how students learn with the practice is not described in detail, but she provided clear links between the model template and scaffolding “rounds” of talk. Throughout the year, Ms. Kelly and Ms. Ross consistently referred back to this Studio as a time of critical learning about scaffolds and how they could better support all students. Subsequently, they both routinely used zoom-ins and targeted writing boxes when asking students to model phenomena.

Similar to other Studios, this one provided an opportunity for one grade-level team to build an understanding of the Scaffolding Scientific Modeling practice but there were missed opportunities to highlight the variation in the practices each team was developing—particularly in terms of the conceptual and epistemic rationale. The talk about “sequencing” was similar among participants, but the talk about “what knowledge students enter with” and “what are students currently reasoning with” were different. Others have described the phenomenon of talking past one another as an “invisible transparent problem” (McDonald, 2016), in which words but not meaning were shared. For example, had the eighth-grade teachers or researchers pressed the seventh-grade teachers for clarification of the
purpose behind sequencing students’ ideas, the seventh-grade teachers may have made public some of their developing theories about student learning with scaffolds.

4.3.3 Summary of sensemaking with improvement cycles

During their work as a PLC, both teams used improvement cycles to work on problems-of-practice they identified and developed tools and practices for Scaffolding Scientific Modeling. The seventh-grade team’s revisions were visible as they worked directly on the tools, adding scaffolds to the model template and engaging in joint inquiry. They tested links and identified areas of a model template that required deeper student reasoning, devised a scaffold to support writing, and compared which scenario supported students in writing and reasoning, then made further modifications. The eighth-grade team also made revisions during improvement cycles, but these were often not tested as part of their Studio work. Rather than performing targeted tests, they used cycles to devise and “try on” strategies that would support knowledge acquisition and summative assessments with models. Only later modifying the pedagogical tools based on this period of incubation. Improvement cycles for both teams, however, were supported by teachers across grade levels pressing one another to justify their goals and purposes, which helped surface shared issues around developing tools and instructional practices.

5 DISCUSSION

This paper examined the first year a professional learning community (PLC), with a team of secondary science teachers and educational researchers, engaged in improvement work around the AST practices and tools (see Windschitl, Thompson & Braaten, 2018). For this project, the goal was not to have teachers adopt and reproduce AST practices, but rather to contribute to the continual development of the practices. The team chose to focus on improving students’ written and spoken models and explanations and by the end of the year, the PLC had developed a localized practice that we now call Scaffolding Scientific Modeling. Understanding how PLCs adapt and improve practices is vital to the continual improvement of teaching; such a focus moves beyond the simple goal of “improving teachers” to consider what is possible when teachers invest in interactions with one another and develop practices and tools designed to address local problems of practice (Hiebert & Morris, 2012).

On the basis of the findings we discuss three features of teachers’ collaborative learning with tools in the context of the improvement of practices: (a) Anchoring improvement with a common focal tool to address recognizable problems of practice, (b) supporting variation in approaches to inquiry and practice development within the same PLC, and (c) making pedagogical reasoning and emergent theories of teaching and learning explicit in a PLC. We believe these discussion points contribute to the development of a practice-based theory for how PLCs locally adapt and continuously improve AST practices and tools.

5.1 Anchoring improvement

Research on teacher learning indicates shared tools and resources can support the accumulation and diffusion of social knowledge. Specifically, the research suggests that PLCs working with tools can support the development of a common vision and clarify members’ views on learning (Grossman et al., 1999; Horn & Little, 2010). Furthermore, tool theorists suggest that tools are more than just objects of activity; they support learning when they become a part of the process of knowledge work (Engeström, 2004; Knorr Cetina, 1997). For this study, the PLC’s learning was supported within and across grade-level teams, as they engaged in the development and revision of a common tool—the model template tool—to address recognizable problems of practice. We reason that it might have helped that pre-established tools were not available to the PLC; in this way, the creation and testing of the tools could support generative forms of learning (Engeström, 2004).
We were curious about why the model template tool became the object of improvement and other tools did not; we speculate the tool might have important features and uses that supported the PLC in the revision process over time. For example, the tool included blank spaces for students to represent their ideas about complex processes both visually and in writing, which made it easy for teachers to see the variation among students’ written artifacts and to make data-based inquiries about student participation. Furthermore, teachers could see the variation in students’ ideas that were produced as seventh-grade teachers concretely added scaffolds to the tool and compared student responses on earlier versions from the same day of enactment. This meant the PLC generated practice-based evidence (Bryk et al., 2015) linking specific structural changes in the tool to improvements in student thinking and participation.

We speculate the multimodal model template’s inadequacies became clear in and across improvement cycles and allowed the PLC to treat the tool as an object of critique. Much like multimodal tools in other fields (e.g., architecture; Ewenstein & Whyte, 2009) the visual components can engage people in dialogue and collective sensemaking as the incompleteness of the tool becomes apparent. Teachers identified particular areas of the tool that supported or failed to support students’ reasoning with the phenomenon, then strategically made changes. As teachers tested tools collaboratively they began to amass shared stories of success and failures about the tool-in-use that were used to inform later iterations.

Improvement science suggests teachers were making visible the variability in student learning as a result of having simple ways to measure improvement, which then acted as a support for their improvement cycles (Bryk et al., 2015). Thus, our findings contribute richness and nuance to earlier research around the role of tools in social knowledge development within PLCs by suggesting that to support improvement, tools should make visible students’ complex, multimodal thinking (the object of inquiry and improvement) and should be used across both classroom and PLC interactions. Having tools with these affordances anchors improvement cycles in the important data for understanding and designing for variation and measurement across students and contexts.

5.2 | Sensemaking and supporting variation

The literature suggests the appropriation of tools and practices by communities is dependent on how people perceive and engage in sensemaking with tools and the contexts, cultural norms and expectations in which the tools are used (Allen & Penuel, 2015; Braaten, 2011; Grossman et al., 2009; Horn, 2010; Kazemi & Hubbard, 2008; Kennedy, 2016). This study adds to the literature by highlighting the importance of a particular form of sensemaking with the tools; namely PLCs’ collaborative approaches to inquiry and improvement. In the Tahoma PLC, the grade-level teams each developed scaffolds for the model template tool, but they deployed different improvement cycle processes with different end goals in mind. They perceived and worked on different problems of practice and created different norms and processes for improving instructional practice and tools. The eighth-grade team went through several improvement cycles, examining student interactions with a model template and creating a common vision around summative assessments focused on models of scientific processes. By the end of the year, they put several scaffolds in place to support summative assessment. We described this improvement process as incubation then development. The seventh-grade team iteratively tested scaffolds within the model template tool within and across Studios, while deepening theories of students’ engagement in modeling over time. We described their improvement process as rapid cycles of development and testing.

We wonder about similarities between the patterns of improvement cycles of the two teams and typical patterns of research and development more broadly (Bryk et al., 2015; Lewis, 2015)—with the eighth-grade team engaging in research and later development, and the seventh-grade team in short improvement cycles with constant testing and iterations. These approaches might reflect different epistemological beliefs about inquiry and the act of reflecting on one’s practice (Schön, 1983); the eighth-grade team seemed to take the view that problem-solving is a technical procedure that begins with research focused on a generalizable outcome which is then applied a practical application, and the seventh-grade team seemed to take the view that inquiry is an intertwining of
research and practice which necessitates the making of representations to support practice under complex and uncertain conditions. We recognize these approaches to inquiry and tool development are dependent on social interactions with tools as well as the historical opportunities teachers have with testing tools and using students’ ideas as indicators of improvement. Thus, it might not be a coincidence the seventh-grade team—with two prior years of opportunities to examine tools and the epistemological principles of the AST practices—felt more comfortable to engage in short improvement cycles that intertwined those principles with practical instructional designs.

We reason there is merit to both processes and though the difference may be a result of the different social and historical contexts of the two grade-level groups, incubation processes might be particularly important for teachers just starting to work with improvement cycles. For example, it might be important in PLCs for teachers new to collaborative inquiry to have time to work around the edges of practices and tools and become dissatisfied with their current practice. Regardless of the approach to inquiry, it is clear the different ways that teachers do this study must be treated as appropriate differentiation, and that subgroups of teachers within a PLC can productively engage with multiple frameworks for collaborative inquiry.

In this PLC teachers were given agency to work on the problems of practice they understood as relevant to their classrooms and to engage in the improvement cycles in the way that worked best for them. Teachers did not experience alienation (Braaten, 2011; Horn & Little, 2010). One of the limitations of our analysis was not examining the role of the relationship between the researcher and teachers, as well as the "deep rules" for how teachers develop and use status to influence the PLC (Sutton & Shouse, 2019). This analysis might help us further understand how researchers and teachers supported variation within PLCs.

5.3 Making explicit the practice under development

Pedagogical tools have implicit assumptions (about what counts as learning, as effective instruction, and as accountable practice) that must be unpacked and examined in order for the tools to be productively used for teacher learning. We reason that in order for teachers to negotiate complex issues of practice, they first need to engage in a social process of developing a common understanding of the implicit assumptions of the tools. In this study, we found that teachers often made their pedagogical reasoning explicit by justifying their choices to use a particular scaffold or instructional move with ideas about how students would/did reason with the science concepts (see Tables 3–5). The PLC engaged in this kind of unpacking of implicit assumptions of practices as they worked on revising tools during Studios. Importantly, the grade-level teams used the Studios as a context where they explicitly pushed each other about the underlying assumptions of their instructional design. We speculate three activity structures and social processes that helped the PLC surface, challenge and work on the principles of practice that were foundational to their instructional choices. First, teachers deprivatized their classrooms (Wei et al., 2009) and made their practice explicit by enacting similar tools and practices with and in front of colleagues. As such, they acquired shared experiences and narratives about successes and failures with their routine (and probably previously unquestioned) practices. Second, when reflecting on suggestions for instructional improvements, teachers pressed one another to articulate theories about how a tool or teaching strategy might result in student learning (similar to Anagnostopoulos et al., 2007). Even though the approaches of the two teams were different, we reason they had developed similar enough language about Scaffolding Scientific Modeling that they could challenge one another’s familiar, or "ready to hand" (Edwards, 2012; Knorr Cetina, 1997), ideas about tools and practices. These explicit hypotheses or hunches (Bryk et al., 2015) could then be tested in subsequent improvement cycles. Third, we recognize these forms of discursive exchanges would not have been possible if Studios only featured one grade-level team. Thus, it seems that productive variations of practice and approaches to inquiries within the PLC were supported by having opportunities for all teachers to collaboratively lead improvement cycles with their own approaches, goals, and tools.
However, the findings also suggest that there were several missed opportunities for teachers and researchers to unpack *implicit theories of teaching and learning*. Teachers would often state partial theories, but the dialogue stayed at the level of pedagogical choices based on student reasoning, without diving into theories for how those forms of reasoning supported student learning. In this way, theories about how students construct ideas over time and how power dynamics and larger institutional forces shape classroom interactions were not considered. The discussion stayed at the level of the particular classroom interaction and the PLC did not generalize to theory. Bryk et al. (2015) describe the interrelationships among theory, practice and data as a “learning loop for quality improvement” (p. 90), suggesting that more work is needed to better understand how PLCs engage in substantive dialogue about theory in relation to teaching practices and classroom tools and data about students’ reasoning.

6 | IMPLICATIONS

6.1 | Implications for PLCs improving instruction

This study suggests that PLCs can collaboratively improve teaching practices when they make a particular problem of practice and its related tools an object of study. In this study, the PLC focused on a particular instructional practice, *Scaffolding Scientific Modeling*, by identifying emergent problems of practice, engaging in iterative cycles of studying student work and systematically testing parts of the practice and tools. Studios seemed to provide the infrastructure for the PLC to continuous investigate the practice, but it also seemed that the grade-level variation in practice was supported by encouraging different teachers to be host teachers. We speculate this design decision helped members of the PLC feel recognized as professionals and included rather than alienated, as described in other PLCs (Braaten, 2011; Horn & Little, 2010). Teachers took turns hosting Studios in their classrooms, which meant each teacher experienced being both supported and challenged as they considered how the practice under study translated to their individual classroom and how to use common model templates with their grade-level team. As a host teacher in the Studios, they not only made decisions about how to enact the practice, but how to test ideas.

Thus, we suggest that PLC facilitators consider how to intentionally open up teacher-learning contexts to differentiate learning. Taking turns taking the lead was one strategy we used, but we can also imagine how we could have better-supported teacher learning by asking more questions about how the teachers saw connections between their pedagogical choices and their implicit theories of students’ learning. With these assumptions being explicit, we could have highlighted how the different grade-level teams were working on different dimensions of similar practices and could have encouraged teachers to not just press and probe one another, but also to support one another in building productive variations of the instructional practices. Along these lines we suggest PLC facilitators engage the team in reflecting on community learning about (a) focal problems of practice and the development of associated tools; (b) the conditions under which the tools and practices support student learning for particular students, and (c) how the team engages in improvement cycles and their varied approaches to planning, doing, studying, and acting on interpretations of student data.

6.2 | Implications for future research

Although not fully explored in this manuscript, this study raises questions about the role of researcher partners in PLCs. Rather than dropping into the PD, researchers partnered with teachers as co-designers and inquirers. In subsequent years, researchers continued to partner with this team and seven other teams from the same district, using Studios to support inquiry and improvement cycles focused on science teaching practices (Thompson et al., under review). As new research–practice partnership models emerge more research is needed on the initial partnership phase and how partners launch into work with one another, as well as long-term studies of how the partnership unfolds and continues to support practice and tool development (Coburn & Penuel, 2016).
This study also makes clear teacher-learning research questions that are left unanswered. For example, this study found that generally, teachers improved AST practices in the classroom, but examining teacher’s individual classroom inquiries might support the field in understanding connections between individual and collective improvement cycles. Working on such questions will help the field better understand the links between professional learning and shifts in classroom instruction and what the role is of practices and tools in mediating PLC learning.

ORCID
Jessica J. Thompson http://orcid.org/0000-0002-1449-932X

REFERENCES


