Chapter 4
High School Science Teachers Learning to Teach Science Reading Through a Functional Focus on Language: Toward a Grounded Theory of Teacher Learning

Jennifer Drake Patrick and Zhihui Fang

Abstract Reading is fundamental to the conception of science and the practice of scientists. Understanding the language used to create, discuss, and disseminate scientific knowledge is central to science teaching and learning. This chapter describes the experience of seven high school science teachers in a professional development (PD) program aimed at developing their expertise in teaching science reading through a functional focus on language. Data sources included interviews with participants, audiotaped PD sessions, and field notes from classroom observations. These data were analyzed using multi-tiered coding and constant comparison. Results indicated that the teachers developed a basic understanding about the relevance of language to science, the unique challenges of science reading, the special features of science language, and strategies for teaching science reading through a functional focus on these features. They demonstrated a willingness to try out what they were learning in their own classrooms and experienced varied degrees of success and satisfaction in their endeavors depending on their levels of familiarity and comfort with particular language features. Their learning and implementation were impacted by personal factors (e.g., conception of science, knowledge about English grammar, prior training, past learning experience, motivation to learn and try out new ideas), as well as contextual factors (e.g., school culture, classroom realities, opportunities to learn/share/reflect, level of support from experts/peers/administrators). These findings have important implications for science educators interested in using evidence-based language and literacy practices in service of science teaching and learning.

J. D. Patrick
Division of Elementary, Literacy, and Secondary Education, College of Education and Human Development, George Mason University, Fairfax, VA 22030, USA
e-mail: jdrakepa@gmu.edu

Z. Fang (✉)
School of Teaching and Learning, College of Education, University of Florida, Gainesville, FL 32611-7048, USA
e-mail: zfang@coe.ufl.edu

L. H. Seah et al. (eds.), *The Role of Language in Content Pedagogy*,
Studies in Singapore Education: Research, Innovation & Practice 4,
https://doi.org/10.1007/978-981-19-5351-4_4

4.1 Introduction

Science requires "both material and semiotic practices" (Halliday, 1998, p. 228). It involves conjecture, rhetoric, and argument, as well as the empirical work of observation and experiment in natural and laboratory settings. Contrary to popular misconceptions, the empirical work is not the bedrock upon which science is built, but rather a subsidiary activity used to support the discursive practice of generating and justifying knowledge claims about how the universe works (Osborne, 2002). Because of the centrality of language and literacy to science, science educators have been exhorted to "give prominence to the means and modes of representing scientific ideas, and explicitly to the teaching of *how to read*, *how to write* and *how to talk science*" (emphasis original, Wellington & Osborne, 2001, p. 138). National standards in the USA, such as the Next Generation Science Standards (www.nextgenscience.org) and the Common Core State Standards (www.corestandards.org), recognize the importance of language and literacy to science education, calling on science teachers to promote language use and support literacy development in service of science inquiry, learning, and sense making (National Research Council, 2012). Empirical research has consistently demonstrated that reading/writing is a powerful vehicle for engaging students' minds, fostering the construction of conceptual understanding, supporting inquiry and learning, building disciplinary knowledge, and cultivating scientific habits of mind (e.g., Cervetti et al., 2012; Chen et al., 2013; Fang & Wei, 2010). Without the ability to read/write science texts, or the fundamental sense of science literacy (Norris & Phillips, 2003), students are severely limited in the depth and breadth of science knowledge they can attain.

4.2 Science Language and Science Teaching/Learning

For schools to effectively develop students' ability to read/write science, the study of science language is essential (Fang, 2006; Seah & Silver, 2020; Yore et al., 2003). *Science language* refers to the linguistic register that is typically used by scientists to construe and communicate scientific knowledge, principles, understanding, and worldviews. This language differs from other varieties of language (e.g., everyday language) in that it is more technical, abstract, dense, and hierarchically structured (Fang, 2005). Science language is technical in part because it uses specialist terminology (e.g., *electromagnetic wave, penumbra*) and everyday words with technical meanings (e.g., *fault*, *matter*). It is abstract in part because it uses nominalizations (e.g., *polarization*, *frequency*), i.e., words that derive from concrete happenings (*polarize*) or qualities (*frequent*). It is dense in part because it uses long noun phrases that pack a heavy load of information (e.g., *Humidity is a measure of water vapor in atmospheric air*). It is hierarchically structured because it construes complex ideas and their relationships through expository genres such as report, explanation, and argumentation. The degree of technicality, abstraction, density, and hierarchy increases from elementary science through secondary science to professional science, presenting an ongoing challenge to science teaching and learning.

To support the development of science literacy, science teachers must demonstrate a solid understanding of science language and at the same time be equipped with strategies to help students make sense of and use this language (Fang, 2006; Patterson et al., 2018; Seah & Silver, 2020). Many science teachers are, however, ill prepared for this important work. Although most states in the USA now require a content area literacy course in secondary educator preparation programs to help teachers address the literacy demands of disciplinary learning (Romine et al., 1996), the course typically focuses on generalized reading strategies such as note taking, graphic organizer, and summarizing, with marginal attention to language (except for vocabulary). Professional development programs for in-service teachers, likewise, focus on essentially the same set of generalized reading skills and strategies, with teachers expected to integrate them into their teaching practices after limited exposure in workshops. Consequently, many secondary science teachers lack expertise and confidence to help their students tackle the unique challenges of science reading—they lack knowledge about different genres and registers of science texts and strategies for teaching students to comprehend and critique these texts. This contributes to their resistance to reading instruction; in fact, many science teachers view the teaching of reading/literacy as an optional extra that can wait until they have covered a curriculum that is already packed with content (Fang et al., 2008).

For these reasons, scholars (e.g., Fang, 2014; Patterson et al., 2018; Seah, 2016) have reiterated the imperative for science teachers to develop a foundational understanding about language and reading as part of their professional knowledge and skill. In this chapter, we report on a seven-month professional development (PD) program designed to support high school science teachers in learning how to teach reading in science through a functional focus on language. Two specific questions guided our study: (a) What understandings about science language did the science teachers develop through the PD experience? and (b) how did the science teachers integrate what they were learning into their teaching practices?

4.3 Methods

4.3.1 Setting

Our research took place in a large suburban Florida (USA) high school serving grades 9 through 12. The student population in the school totaled nearly 3000, with an ethnic makeup of approximately 60% White, 26% Black, 10% Hispanic, and 4% Asian/other. Twenty-two percent of the students were from low-income households, as evidenced in their being on the school's free or reduced-price lunch program.

The school administration encouraged teachers to learn about reading in content areas. It supported an after-school study group where teachers met regularly to discuss pertinent topics in education. Several texts that addressed generic content area reading strategies were used in this context, including Allen (1999), Beers (2002), and Tovani (2000). In addition, a reading specialist was on staff to provide support for teachers across all content areas. She regularly conducted workshops for faculty, addressing topics in fluency, vocabulary, and generic reading strategies.

4.3.2 Participants

Participants for the study were recruited through an institutionally sanctioned informed consent process. Their selection was based primarily on practical considerations such as willingness and access (Strauss & Corbin, 1998). Specifically, the high school principal reviewed a brief description of our research project and convened a meeting with the 28 teachers in the science department, where we presented information about our study (e.g., purpose, structure, time commitment) and offered incentives (a $300 stipend and two books on science and literacy) to encourage participation in the study. Seven science teachers—six females and one male—agreed to participate in the study. They represented various areas of science, including biology, anatomy and physiology, physical science, and marine science. Their teaching experience ranged from 5 to 34 years and covered grades 9–12. Individual profiles of the teachers are presented in Table 4.1.

4.3.3 Professional Development Program

The seven teachers participated in a professional development (PD) program that we, two university-based language and literacy researchers, designed to further their understanding of science language and science reading. In designing this program, we followed the guidelines teacher researchers (e.g., Borko, 2004; Desimone & Garet, 2015; Lee & Buxton, 2013) found effective in facilitating teacher learning and promoting change in beliefs and practices. Specifically, our PD program was content focused (i.e., science language/reading) and used a research-based model (Fang, 2013; Watson & Manning, 2008) that integrates learning, practice, and reflection. It lasted an extended period of time (7 months), which is sufficiently long to promote learning and bring about change. It encouraged peer collaboration, thoughtful conversation, and critical reflection, allowing teachers to examine whether/how their beliefs aligned with what was being studied. It also offered a safe place for teachers to try out new ideas, receive feedback, and build confidence.

The goal of our PD program was to help the teachers develop a foundational understanding of the language demands of science reading and the strategies needed

Table 4.1 Profiles of teacher participants

Name	Degree	Route to teaching	Years in teaching	Grades taught	Subject taught
Bette	Bachelor in biology with a minor in chemistry and Spanish	Alternative teacher certification program	5 years	9th and 10th grades	Honors biology
Casey	Bachelor in health education	Traditional four-year teacher preparation program	15 years	10th and 11th grades	Anatomy and physiology
Lisa	Bachelor in secondary education with a concentration in biology and a minor in chemistry	Traditional four-year teacher preparation program	34 years	11th and 12th grades	Marine science
Mona	Bachelor in science education	Traditional four-year teacher preparation program	17 years	9th grade	Physical science
Billie	Bachelor in chemistry	Alternative teacher certification program	6 years	9th grade	Physical science
Brad	Bachelor in biology with a minor in education	Alternative teacher certification program	8 years	10th grade	Biology
Patsy	Bachelor in psychobiology	Alternative teacher certification program	12 years	10th and 11th grades	Honors biology and advanced placement (AP) biology

to cope with these reading challenges. Toward this end, we designed and delivered five learning modules as follows:

- Module 1: Overview of the challenges of science reading in secondary schooling
- Module 2: The *technicality* of science language and coping strategies
- Module 3: The *abstraction* of science language and coping strategies
- Module 4: The *density* of science language and coping strategies
- Module 5: The *genres* of science and coping strategies.

Each module included examination of relevant journal articles (e.g., Fang, 2005, 2006, 2008; Fang & Schleppegrell, 2010; Osborne, 2002) and chapters (e.g., Fang, 2010; Fang & Schleppegrell, 2008; Halliday, 2006; Saul, 2004; Wellington & Osborne, 2001). In addition, the teachers brought science textbooks and other classroom reading materials to each PD session so that they could analyze language use in these texts, discuss the challenges science language presented to their students, and consider strategies for tackling these language demands.

These modules were delivered over eight meetings, with a 3–4-week interval between the meetings. Each meeting included a 2-h formal session, broken down into an hour of expert study and an hour of practice-based discussion (Watson & Manning, 2008). The first hour of expert study included discussion of professional readings and modeling of strategies. During this hour, the teachers were encouraged to analyze, weigh, and question the information presented in the readings against their own experiences. During the second hour, the teachers discussed the usefulness of the concepts covered and the strategies demonstrated in relation to their own practice. They then used their own materials to plan for classroom implementation and reflect on the feasibility of using the information from the first hour in their own classrooms. Additionally, topic-relevant questions were posed at the beginning and end of the meeting to stimulate thinking and conversation. In between the eight meetings, we visited the teachers' classrooms on a weekly basis, offering support through informal observations and follow-up conversations. This ongoing cycle of meeting, trying out new ideas, and discussing the challenges and successes of classroom implementation encouraged the teachers to actively reflect on how their understanding of science language/reading helped shape their teaching practices (Fang, 2013).

4.3.4 Data Collection

To answer the two research questions, we collected several types of data. The primary data sources were transcripts of PD sessions and individual teacher interviews. Secondary data sources included classroom observations, informal conversations with the teachers, email communications between us and the teachers, and the concept maps the teachers constructed to demonstrate their understanding of the topics discussed. Data consisted of approximately 25 h of audio recordings of eight PD sessions, 7 h of interviews, 2 h of informal conversations, and 22 h of classroom observations. These resulted in nearly 500 pages of transcription and over 70 pages of field notes. More details about the interviews, informal conversations, and classroom observations are provided in Table 4.2.

Table 4.2 Details about select data sources

Data sources	Details
Interviews	Each teacher participated in two semi-structured interviews, each lasting between 20 and 30 min. Each interview was recorded with a digital-voice recorder and then transcribed. A mid-term interview was conducted to assess the teachers' understanding and views of the PD content. A final (or exit) interview further assessed what the teachers had learned from the PD experience and probed for how they would continue to develop and implement their learning about science language and science reading. These interviews provided valuable perspectives on what influenced the learning process of individual teachers
Informal conversations	Informal conversations with individual teachers were carried out throughout the duration of the study. Field notes about the content of these conversations were recorded in a research log. These conversations focused on the teachers' understanding of science language/reading and their experience teaching it. They provided additional insights into the successes and challenges that the teachers experienced as they attempted to integrate the newly acquired ideas or strategies into their daily teaching routines
Classroom observations	We conducted observations of the teachers in action to determine (a) the degree of consistency between what the teachers said in the PD sessions about their classroom practices and what was actually occurring and (b) if/how the teachers were implementing any of the strategies discussed in the PD meetings. The observations took place on a weekly basis contingent upon a mutually agreed upon time between us and each teacher. Each observation lasted 30–50 min Detailed field notes were recorded during the classroom observations. The observation protocol included both a descriptive column and a reflective column. In the descriptive column, we recorded information about observed classroom activities that involved reading or attended directly to a concept or strategy discussed in the PD sessions. In the reflective column, we recorded wonderings and thoughts about what was happening in the classroom as it pertained to our study. After each observation, we held a debriefing conference with the teacher to discuss these two questions: (a) What do you think went well with your lesson? and (b) what would you do differently if you try this lesson again?

4.3.5 Data Analysis

Data were analyzed using methods characteristic of grounded theory studies, including repeated reading, multi-tiered coding, and constant comparisons (Creswell, 2007; Strauss & Corbin, 1998). Specifically, we read and coded data in several stages in an attempt to discover categories, relate categories, and finally organize the categories to create a theory of what facilitated or inhibited the teachers' learning about science language/reading. In stage one, we engaged in open coding by examining the interviews and PD transcripts line by line, aiming to generate preliminary categories and themes (e.g., barriers, struggles, concerns, issues, resistance, excitement, insights, successes) that explained how the teachers made sense of the information presented in the PD. We also used ‘memoing’—i.e., the process of jotting down notes about an evolving theory—to record our reflections on what we were learning from the data. This helped us keep track of our own thoughts, questions, and changes in ideas as the research progressed.

In the second stage, we engaged in axial coding, seeking to discover relationships and connections among categories as we worked to put the data back together in a new way. We looked for links among categories that might aid in conceptualizing the factors that contributed to or hindered a teacher embracing and implementing a concept or a strategy presented about science language/reading. At this point, initial codes were collapsed into larger categories, and analysis of data continued until evidence of support for axial codes was found. This process enabled us to build a theory by creating categories around the conditions, actions, and consequences that were significant to the phenomenon being studied.

The last stage of coding was selective coding, which involved identifying a central category and an explanation for how the sub-categories fit together within that category. Memos and all data analysis up to this point contributed to the identification of selective codes.

In our study, data were analyzed both within and across cases. Findings from within-case analysis identified the experiences of each teacher. Cross-case analysis was then used to examine data along the lines of technicality, abstraction, density, and genres. This analysis procedure contributed to the formulation of a theory about how the teachers conceptualized and interpreted science language/reading and related it to their own teaching practice. The analysis was ongoing and iterative throughout the data collection period. This systematic coding process allowed the identification of themes and categories, helping build a theory about how the teachers learned about science language/reading and integrated it into their teaching practice.

4.4 Findings

During the PD experience, the seven science teachers were excited to learn about science language/reading and ways of integrating it into their classrooms. They developed a foundational understanding of the relevance of language to science, the unique challenges of science reading, the special features of science language, and strategies for teaching science reading through a functional focus on these features. They demonstrated a willingness to try out what they were learning in their own classrooms and experienced successes and satisfaction, as well as barriers, misgivings, and frustration, in their implementation. These findings are presented in detail below.

4.4.1 *Embracing a New Perspective on Science Language/Reading*

Prior to the PD, the teachers viewed science language as consisting primarily of vocabulary. They did not consider issues of abstraction, density, or genre when thinking about how to teach reading in science. Nor did they consider how science language was functional in presenting ideas and developing arguments in science. During the PD experience, they began to think differently about language in science.

For example, Patsy noted in her final interview that looking at how language functions in science was a new perspective to her. Although she knew that science language was filled with technical words, she had not considered how technicality contributed to the complexity of science language, nor had she ever learned about the concepts of abstraction, density, or genre. She contrasted her prior knowledge about science teaching with her new awareness about the role of language in science:

> We always are taught hands on, hands on – they've drummed it into us. And as scientists and science studiers of the process, we jump right on that. But there is more involved, and I never stopped to think about it's not just the labs, it's not just the hands on, it's the language approach too. (Final Interview)

With the new understanding about science language, the teachers gained fresh insights into why their students found science texts challenging. Prior to this PD, the teachers identified issues with student behavior, technology, student interest, and poor preparation from early grades as reasons that students would not or could not read science well now and in later grades. After the PD, the teachers had a better understanding of why science is difficult for students to read. They realized that unfamiliarity with science language could contribute to students' lack of proficiency or interest in reading science texts. According to Bette, it was the expository nature of science writing that made science texts less entertaining and more difficult to read than stories. Billie attributed her students' struggles with science texts to their lack of experience with these texts, noting

> The kids struggle because of the differences between what they're used to reading in the younger grades, per se, and what they have to read now [in secondary science] -- it is so much more complicated and dense. (Mid-Term Interview)

Understanding reading challenges through a language lens also impacted how the science teachers viewed their own responsibilities in teaching reading. Casey admitted she used to think that her students avoided or struggled with reading because they were lazy/disinterested or because textbooks were poorly written. She described how her thinking evolved during the PD below:

> I had become so accustomed to reading science materials that I didn't really realize that the students would have difficulty with it and why. Now, I'm more aware. In the past, I just became frustrated that they don't read their books, or I would be frustrated with the writers of the books because like, why can't they make a book that the students can read and understand? Whereas, now, I understand that what we have going on here is the fact that the students are more familiar with narrative and other types of writing. They're going to have

> to eventually be able to read science texts, so we're in that kind of transition where we have to get them to do something that they don't feel comfortable with. I have this awareness now that, okay, it's not just that the students don't want to read, it's not that they can't write a text that the students can read. Now, I do see my role more clearly as having to give them some strategies that can help them to be able to get more comfortable with science reading since they're going to need to be able to do it in the future. (Final Interview)

With a keen sense of responsibility for teaching reading, the science teachers were excited about and grateful for the new instructional strategies that they had been learning during the PD. They believed these strategies would enable them to engage their students in science learning in new, powerful ways. As Lisa said,

> And this [PD] gave us a whole box full of tools that are eminently useable. We know how to do them. You took us under the hood of the car and showed us this one will loosen this nut and bolt – it's like oh, light goes on. I feel much more – and I really love this word – empowered. I really feel more empowered to help the students deal with all these aspects. (Final Interview)

4.4.2 Learning About Science Language

Through the PD experience, the science teachers developed a basic understanding of the specialized features of science language (i.e., technicality, abstraction, density, genre), albeit not without struggles. They most easily embraced technicality and genre, yet wrestled mightily with abstraction and density. These understandings, or declarative knowledge about science language, contributed to their levels of comfort and success in teaching the four linguistic concepts, or procedural knowledge about science language, as will be shown in the next section.

4.4.2.1 Technicality

The science teachers rated technicality as the feature with which they were most familiar and comfortable. In the initial PD meeting, they understood that science language is technical due to its use of specialist terminology such as *lithosphere* and *plate tectonics*. They recognized that technical vocabulary presented a challenge to their students and were able to address it in science lessons. According to Casey, for example,

> I had the most background knowledge there [technicality] to begin with and then, of course, built upon that. I feel very comfortable with analyzing the word parts. That's something that I had actually done before. Not in such a systematic way as we learned how to do, but I feel very comfortable with that. (Final Interview)

The teachers' understanding of technicality deepened over the course of the PD. They were able to elaborate on technicality and became more aware of the need to attend to it in their teaching. In the mid-term interview, Patsy was able to identify different types of technical words—such as naming words (e.g., *trachea*), process words (e.g., *photosynthesis*), concept words (e.g., *force*), and mathematical words (e.g., *statistical*)—in a way that was consistent with how the topic had been presented during the PD and voiced a commitment to directly teach the meanings of these types of science words in her classroom.

Although the teachers were initially aware of specialist terminology (e.g., *mitosis*), they had not considered how everyday words such as *medium*, *library*, and *matter* could also contribute to the technicality of science language. In fact, they expressed surprise in thinking about technicality from this perspective. Bette indicated that it had not occurred to her that students might be confused by this type of technical words. She recalled science lessons in which her students mistook *sponge* (a sea creature) as "a cleaning tool" and *fault* (a crack in the earth) as "something that's wrong". She now recognized the need to explicitly draw students' attention to these commonsense words that are used in a scientific sense. Similar sentiments were shared by Brad and Lisa, who developed a heightened awareness of words that can have a different meaning when used in a different context.

4.4.2.2 Abstraction

Unlike technicality, abstraction sounded foreign to the science teachers. They had a difficult time grasping what abstraction in science language means. Prior to the PD, they had not thought about the possibility of science language being abstract. They associated abstraction in science language with an abstract science concept or idea that cannot be easily seen or touch (e.g., *cells*, *DNA*). Casey discussed how her understanding of abstraction evolved:

> I started out with a misconception that abstractness had to do with the fact that many of the concepts in science are not something that the student can see or touch. That was my idea of abstractness. I had thought about science as dealing with abstraction, but just more in that a lot of it is not concrete, visible. They can't touch it because we might be talking about something microscopic, you know, something that we only have theories about how it works. We don't even really know because nobody can see it, touch it, feel it kind of thing. So that was my idea of abstraction in science prior to this. I had just never thought that a word could be abstract because it has so much information in it. (Mid-Term Interview)

As the teachers were introduced to the concept of nominalization, they seemed to gravitate toward the process of changing an adjective or a verb into a noun (e.g., *discover* → *discovery*, *significant* → *significance*), but paid little attention to the functions of nominalization, such as distilling information, creating technical taxonomy, and facilitating discursive flow. They recognized that when a verb or an adjective is turned into a noun, it makes a text more challenging for students to understand. This nascent understanding can be seen in Billie's comments during one of the PD sessions.

> … it's more natural to say, "The storm made a *significant* impact on the community." That's report – that's how you might hear in reporting. But you might write about it. You want to be more assertive in your writing as a scientist because you want people to believe you and so a lot of scientists will take – instead of saying, "That storm was – that was a *significant*

> storm." They might then talk about, "The *significance* of the storm." Now you've taken that adjective – you've switched it into a noun. Well, in our narrative writing the nouns of our sentences, the *who*'s and the *what*'s are primarily peoples' names, places and, you know, *I, he, she*, *your* pronouns. In science, they're abstract: *the discovery*, *the significance.* (PD Session #5)

To help the teachers better understand the importance and functions of nominalization, we designed a sentence completion task (Fang, 2010), where they were to use an abstract noun (e.g., *the journey*) to summarize the information presented in a previous sentence (e.g., *head north for cold water of the Artic*) and make it be the subject of the ensuing sentence, as the example below illustrates:

> During the winter, humpback whales head north for cold water of the Arctic. is long and dangerous. [Answer: The journey]

This task was designed to help the teachers see how nominalization synthesizes information in a prior sentence for subsequent discussion and, in so doing, facilitates the information flow from one sentence to the next.

We also had the teachers bring their textbooks to the PD sessions, working in pairs to identify nominalizations and discussing the roles these nominalizations serve in the development of text and argument. In the following example generated by the teachers, we discussed how the nominalization "*these conditions*" condenses the information in the preceding sentences to become the subject of the last sentence and at the same time develops a line of reasoning that contributes to the cohesiveness of the text.

> Sometimes a population grows more rapidly than the available resources can handle. Resources that are needed for life, such as food and water, become scarce or contaminated. The amount of waste produced by a population becomes difficult to dispose of properly. *These conditions* can lead to stress on current resources and contribute to the spread of diseases that affect the stability of human populations both now and to come.

Despite our efforts, the teachers' struggles continued. Some teachers (e.g., Casey and Patsy) seemed to be making more progress than others (e.g., Brad and Lisa) in understanding abstraction. Toward the end of the PD, most teachers realized that abstraction was a major challenge they took for granted before and vowed to pay more attention to it in their work with students. However, two-thirds of the teachers still did not seem to substantially expand their initial understanding of the concept of abstraction; they continued to associate it only with the idea of not being tangible or to focus on the form but neglect the functions of nominalization.

4.4.2.3 Density

Like abstraction, the concept of density also presented a formidable challenge to the science teachers. They described density in terms of how much information is presented in a science text rather than how long noun phrases are used to pack dense information into a single clause. They were apprehensive about having to break down complex noun phrases because of their own lack of knowledge about the language structures. During the first PD module, the teachers were introduced to the concept of density by reading Fang (2008). They agreed that science texts were too dense and that density was a problem for their students.

When the teachers were subsequently directed to find examples of density in their science textbooks, they had a hard time finding noun phrases. Instead, they identified an entire sentence, such as "The innermost sensory tunic of the eye is the delicate white retina which extends anteriorly only to the ciliary body.", thinking that the more unfamiliar or technical words there were in a sentence, the higher the informational density. While they were able to identify simple nouns (e.g., *the eye*, *the white retina*) and verb (e.g., *is*), they had trouble recognizing larger chunks of the sentence, including complex noun phrases such as "the innermost sensory tunic of the eye" and "the delicate white retina which extends anteriorly only to the ciliary body". Billie expressed her unease with talking to her students about grammatical structures, remarking

> Well, English could be very helpful now that I am learning about this stuff. And it's so funny because I tease my students. You don't realize, oh, I'll never do this again. And then somewhere down the road you're like, if I only had paid attention to English. (Informal Conversation)

We led the teachers in completing several exercises involving deconstructing and building complex noun phrases (Fang, 2010) so that they could understand how information is packed into a long noun phrase. For example, we showed the teachers that "the innermost sensory tunic of the eye" contains a head (*tunic*), which is premodified by a determiner (*the*), an epithet (*innermost*), and a classifier (*sensory*), and postmodified by a prepositional phrase (*of the eye*).

Despite our efforts, the teachers' lack of confidence in unpacking noun phrases persisted. They noted that while density was "not necessarily a difficult topic", breaking sentences and phrases down into their constituents "has been the hardest thing". As Casey confessed,

> I think one of the challenges that I faced had to do with, again, not feeling as comfortable with the English component of it. For example, when we were doing the sentence combining or we actually did it the other way, too, where they actually wrote the sentences down and there were just some of the terms for the different parts of a sentence, the clause and such that I might not have remembered. I think that was one of the challenges. (Final Interview)

Like Casey, other teachers also expressed their concerns about having enough grammatical knowledge to effectively teach students to tackle density in science language. Toward the end of the PD experience, Brad and Billie felt that deconstructing dense sentences and phrases was, although important, "completely out of my comfort range".

4.4.2.4 Genres

There are six major genres, or text types, in school science: procedure, procedural recount, explanation, report, exposition, and discussion (Fang, 2010). Each of these genres has its own organizational structures and linguistic features that realize the purpose of the genre. Compared to abstraction and density, genre was a relatively easier concept to grasp for the science teachers. During the initial introduction to the topic, the teachers reviewed a matrix from Fang (2010, pp. 106–107) that listed different science genres and their structural and linguistic features. In subsequent PD sessions, the teachers were asked to analyze sample science texts to determine their genres and provide justifications based on their structural and linguistic features. They were able to identify and justify the genres of procedure, recount, report, and explanation, but felt unsure about how to differentiate between discussion and exposition. They drew primarily on their prior knowledge (e.g., purpose of text) and familiarity with text structure to justify their determination of genre types, but rarely mentioned grammatical features specific to each genre. (See also Seah & Silver, this volume).

Overall, the teachers found the work on genre important and useful and were comfortable learning about the concept. They indicated they were willing to try to incorporate it in their teaching. Brad commented:

> I really like genres. … it's important to teach kids what something is saying or the type of writing that it is and the different styles that you see. And they should be able to – you know, if they can identify it, it would probably help them understand it a lot better. (Final Interview)

Patsy also indicated that she found the information about genre useful for working with her biology students, especially when they were working on their science fair projects. In her own words,

> When I started looking at the genres, I thought, 'This has science fair all over it.' And the fact that I could help my students' understanding by having a better concept and better grasp of genres became apparent to me once I saw how many were used. (Final Interview).

4.4.3 Teaching Science Language

Throughout the PD, the science teachers expressed a strong desire to try out the four concepts discussed—technicality, abstraction, density, and genre. Because their understanding and comfort level varied with each of the concepts, they experienced different degrees of success and satisfaction in their endeavors. As a whole, the teachers seemed to experience more success and satisfaction when teaching concepts they knew relatively well and were comfortable with, but more anxiety/frustration and less success when teaching concepts with which they were less familiar and that required stronger grammatical knowledge.

4.4.3.1 Technicality

Of the four concepts, technicality was the most familiar to the teachers. They cited level of comfort, proximity to the strategies they had already been using, and prior knowledge about the importance of technical vocabulary to comprehension as reasons they would use strategies that addressed technicality in science reading. For example, Bette commented, "I knew that vocabulary was huge in science, so that's just something I used to always work with my students on just because I know it's so important from my medical terminology class and just experience before, as a student" (Mid-Term Interview).

Because of the familiarity, the teachers had little trouble envisioning how the strategies discussed in the PD could be a part of their teaching routines. Brad shared how he planned on addressing technicality in his teaching: "I like breaking down the word and doing the suffixes, the roots, and the prefixes; and I think in my journals next year, everyday is going to include breaking down a word from the chapter to help kids understand the vocabulary" (MT-MB-5).

Evidence from observations and interviews showed that the teachers used three of the strategies they had learned from the PD to address technicality in their classrooms: morphemic analysis, concept maps, and vocabulary think charts (Fang, 2010, pp. 52–59). For example, Patsy used the vocabulary think chart to introduce *vestigial organ* to her biology class. She began by putting a copy of the think chart on the overhead and reviewing the process of using the strategy. She then asked students to choose a word for analysis from their reading. One student picked the term *vestigial organ.* Patsy wrote it on board as the target vocabulary and engaged the class in analysis by reading through each probing question on the think chart.

Students started by identifying the word *organ*, noting that it means a collection of similar tissues within the body. Then, they examined *vestigial.* They identified *–ial* to be the morpheme that changed a root word into an adjective; so they assumed the root word must be close to *vest* or *vestige.* One student opened a dictionary and found that the word *vestige* means "a small amount".

Next, students brainstormed words that came to mind when they looked at the word parts in *vestigial organ.* They generated the following list: *footprints*, *imprints*, *organ donor*, and *carbon footprint*. While talking about these words, students connected real-life stories to their ideas, discussing people they knew who had organ transplants or why they thought the idea of a carbon footprint was connected to the concept of *a small amount*, which relates to *vestige.*

Subsequently, students examined the term in context. One student read, "The organs of many animals are so reduced in size that they are just vestiges, or traces, of homologous organs in other species. These vestigial organs may resemble miniature legs, tails, or other structures". Patsy then led the students to paraphrase a definition, writing on the think chart "the mark of something that once existed".

Finally, students used the term *vestigial organ* in a sentence from science. One student remarked, "A theory exists that whale's legs have become vestigial organs.". Another student shouted, "*Animals can exist without vestigial organs.*". A third student said, "The appendix is a vestigial organ because we do not need it to live.".

In closing, Pasty asked students to relate the term to a larger scientific concept, and they responded with this list: *evolution*, *Darwin*, *adaptation*, *survival of the fittest*, *natural selection*, and *modifications.*

4.4.3.2 Abstraction

The teachers believed it was important to address abstraction in science reading, despite their struggle with the concept. Brad, for example, shared in a PD session how he talked about abstraction with his students, saying,

> You know when they [authors] say *cutting down trees* and *deforestation*, they mean the same thing. Now I notice that and I can call it to students' attention when we are reading. I can ask them how they can say a word like *deforestation* or *journey* in another way. (PD Session #5)

Despite this belief, most teachers struggled in their attempts to design and deliver reading lessons that address abstraction. They focused on the lexical structure of a nominalization (e.g., changing a verb or an adjective to a noun) rather than the discursive functions of nominalization (e.g., condensing information, establishing technical taxonomy, creating discursive flow). Moreover, they designed sentence completion exercises without fully understanding the purpose of these exercises. As a result, their exercises resembled traditional cloze tasks or fill-in-the-blank items, failing to address the challenge of abstraction.

For example, Lisa developed a lesson requiring students to change abstract nouns into their verb/adjective forms, or vice versa. She wrote this brief passage on the overhead—*The shark consumes the food. This consumption of the shark involves eating seals and other marine animals.*—and asked students to locate words that were morphologically related. After students identified *consume* and *consumption*, she commented on how scientists change 'action' words into 'thing' words. She called attention to the word endings, explaining how adding -*tion* to *consume* changes the word from a verb to a noun. Next, she gave students a list of words (e.g., *absorb, reflect*, *discover*) and directed them to change these words into nouns. Students completed the worksheet in pairs.

Bette appeared to demonstrate a stronger understanding of how abstraction was used in science writing. When her biology class was studying population growth, she read a passage from the textbook (below) and called students' attention to *the relationship*, asking them to identify what the phrase refers to and what it does to the development of ideas in the text.

> Sea otters are important members of the kelp forest community of America's Pacific Northwest coast. This "forest" is made up of algae called giant kelp, with stalks up to 30 meters long, and smaller types of kelp. The kelp forest provides a habitat for a variety of animals. Sea otters need a lot of energy to stay warm in the cold water, so they eat large quantities of their favorite food: sea urchins. Sea urchins in turn feed on kelp. The relationship along this food chain set the stage for a classic tale of population growth and decline.

4.4.3.3 Density

The teachers likewise struggled to integrate the concept of density in their teaching. They had a difficult time identifying long, complex noun phrases in their textbooks. They relied primarily on our support in planning and delivering lessons that addressed density in science texts. For example, Billie felt that many of the sentences in her textbook were simplified. She met with us to go over some sample passages and determined that she needed to use another textbook to look for better examples of sentences with complex noun phrases. Mona had a similar feeling about her physical science textbook. She was concerned that the textbook writers did not use enough 'real' science language in their attempts to make text easier for students to read. She gave the following sentence from a textbook as an example:

> How many different ways have you used energy today? Today, Coral and Buster used a hair dryer or a toaster. If you did, you used energy. Furnaces and stoves use thermal energy to heat buildings and cook.

One solution for the teachers who perceived that their textbooks did not have enough examples of dense sentences was to locate alternative reading materials (e.g., trade books, magazine articles). Because Mona and Billie both taught the same physical science course, they agreed to work together to find some examples to supplement their textbooks.

Another solution we recommended was to look for definitions in the text, as definitions in science (e.g., *Fossil fuels are* *the energy-rich substances formed from the remains of once-living organisms*.) typically contain long noun phrases that pack dense information (Fang, 2021). However, even with definitions, the teachers continued to struggle with identifying complex noun phrases, especially when these phrases were placed in the object (as opposed to the subject) position of a sentence. They were able to pick out simple nouns (e.g., *substances*, *the remains*, *organisms*), but often did not see how these were strung together to form an expanded noun phrase that contains a head with a series of pre- and post-modifiers. As a result, we ended up co-planning and co-teaching many lessons on density with the teachers, helping them search for complex noun phrases, deconstruct these noun phrases, and model coping strategies.

The teachers seemed to consider paraphrasing and sentence combining (Fang, 2010) as useful strategies for addressing density. In paraphrasing, students repackaged the information presented in complex noun phrases and dense sentences in a way that is easier for others to understand. In sentence combining, students integrate two or more simple sentences into one sentence featuring complex noun phrases. They saw these strategies as ways to help students reword dense sentences for better understanding and to write dense sentences that sound more scientific or academic. The teachers reported active student engagement with the sentence combining task, noting that a similar task was also being used in some English Language Arts classes.

Despite our modeling and their willingness to try, most teachers were still not confident in their ability to teach density on their own. Brad and Bette, for example, reported that they tried out several lessons, but did not feel it was making an impact on their students. They hoped to be able to address density next year after more practice.

4.4.3.4 Genre

During the PD sessions, the teachers were introduced to the genre teaching–learning cycle (Derewianka, 1990; Fang, 2010), a heuristic for teaching writing/reading that consists of four phases: preparation, modeling, joint construction, and independent construction. During the preparation phase, the teacher selects appropriate materials related to the focal concept(s) in the curriculum and immerses students in reading these materials. In the modeling phase, the teacher introduces a text model of the target genre and engages students in explicit discussion of the genre in terms of its social purpose, schematic structure, and lexico-grammatical features. In the joint construction phase, the teacher engages students in writing the target genre through collaboration with peers. In the final phase, students write the target genre independently.

In implementing the genre teaching–learning cycle, one key concern shared by the teachers was time. They worried about the amount of time it would take to teach students to write each genre. They also worried about their expertise in genre instruction because they did not see themselves as literacy teachers. As Lisa put it,

> … and back to what you were discussing with modeling, I hadn't heard of this, not being a reading teacher and so getting into modeling in the classroom with the reading strategies to help them – I'm very happy with this, but I'm gonna have to stretch my muscles a good bit to work on some strategies that will work in marine science to do this kind of thing. We're doing teaching reading and we're teaching science and you can still do both, but it requires a huge, greater amount of effort in one sense to go back and learn all the modeling strategies 'cause we're not English teachers. (PD Session #7)

Even though they were concerned about time and their own expertise, they still tried to think of ways they could bring the notion of genre into their classrooms because they saw value in engaging students in learning the genres of science. Bette summarized her feelings about the genre work this way:

> I think that again, this teaching cycle of, you know, the immersion in the different types of genres and the attention to talking about the different, you know, text structures and social purposes and then allowing them to kind of jointly and then independently construct is a powerful model. I think it would take some dedication and some thought, but I think that it's – I think there's a lot of potential there. (Final Interview)

Another issue the teachers raised in their implementation of the genre teaching–learning cycle was whether to introduce one genre at a time or all of the science genres at once. Casey and Lisa indicated they would do one genre at a time to ensure mastery before moving on to the next genre. They focused on the procedure genre because their students were doing a lot of laboratory work in class then and needed to follow procedures. Brad, Mona, and Bette, on the other hand, preferred to introduce all six genres at once because they felt students would do better to see all of the genres and to recognize them across the readings that were used in the classroom. Mona, for example, introduced the genre teaching–learning cycle by telling students "I want to prepare you to read all kinds of science.". She found 25 different articles from various sources and had each student read and analyze one of the articles for its structural and grammatical features.

4.5 Discussion

During the seven-month PD experience, the science teachers developed a basic sense of the specialized features of science language, though they felt more comfortable with technicality and genre than with abstraction and density. They also became more aware of how/why science language poses a challenge to students and felt better prepared to support their students in science reading. Because of the differences in their prior knowledge, experiences, beliefs, motivations, and teaching goals, the teachers demonstrated different degrees of understanding about science language and of success and satisfaction in integrating it into their teaching.

These findings are largely consistent with what previous research has suggested about the challenges of helping teachers develop linguistic expertise for disciplinary literacy instruction (e.g., Fang et al., 2008, 2014). Science teachers were interested in but apprehensive about learning to teach language/literacy in their classrooms; and with support, they were capable of implementing, to varying degrees of success, language/literacy strategies to advance their disciplinary goals. Their success in integrating language/literacy with science depends on not only personal factors (e.g., conception of science, grammatical knowledge, prior training, past learning experience, motivation) but also contextual factors (e.g., school culture, classroom realities, opportunities to learn/share/reflect, level of support from experts/peers/administrators).

With respect to our study, a multitude of factors influenced the ways the seven science teachers learned about science language/reading and applied what they were learning to classroom teaching. We theorize the complexity of their learning in Fig. 4.1. This grounded theory model of how secondary science teachers learned to teach science language/reading consists of three systems of influencing factors, each represented in a big circle—the school culture, the individual, and professional development. The elements within and across the three systems interacted in complex ways to determine the degree of success and satisfaction each teacher experienced during the learning process. At the intersections of these three systems is the *opportunity to talk*, which emerged as the core factor that appeared to account for the greatest influence on the degree to which the teachers experienced success and satisfaction in learning to teach science reading through a functional focus on language. Each system of influencing factors can exist independently or in interaction with the others; therefore, the circles are represented both independently and intertwined. However, it is through the interaction of the systems that the *opportunity to talk*—that is, time for candid discussion, sharing, and reflection among members of a teaching–learning community—is created and in turn the process of learning is impacted. We unpack key factors that impact our teachers' learning below.

One factor that made a positive contribution to the teachers' learning and engagement was their willingness to learn. All seven teachers believed in the importance of language/literacy to science and were motivated to learn about science language in order to better help their students read/write science texts. While they continued to see themselves as science teachers, they recognized the need to engage with language/reading and were willing to take up a task traditionally thought to be English

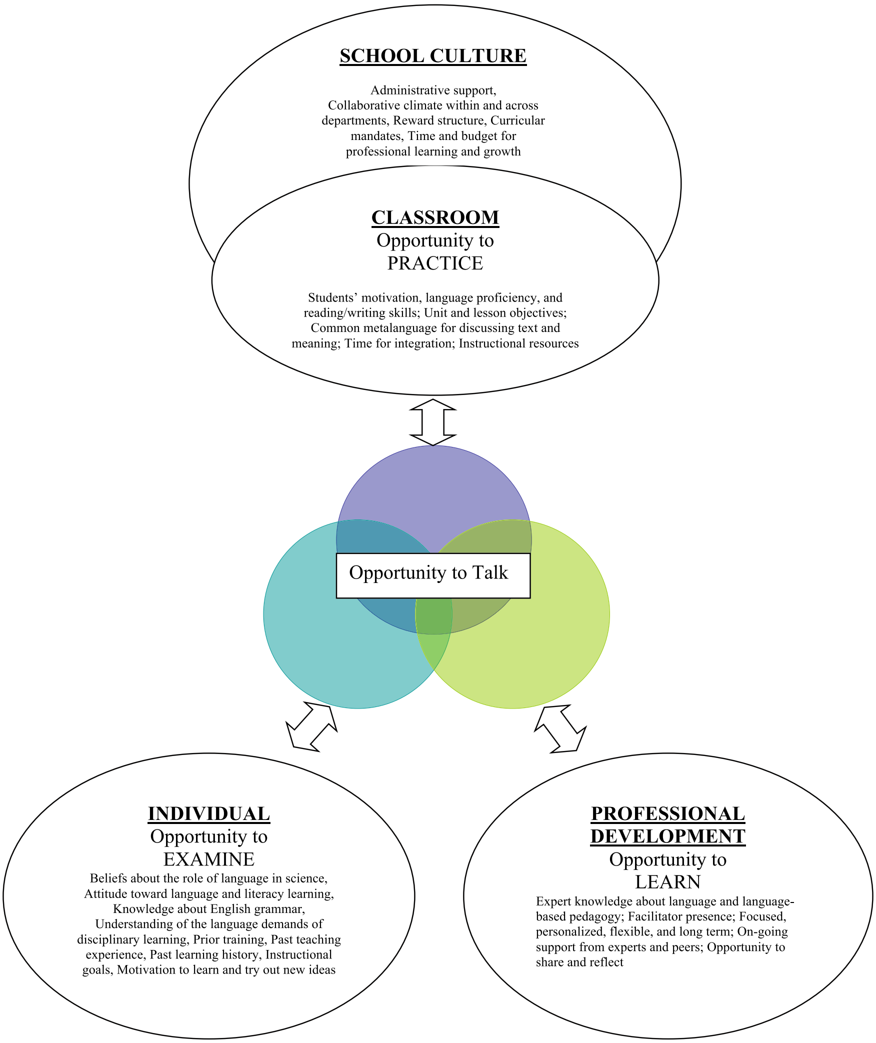

Fig. 4.1 Grounded theory model of teacher learning about science language/reading

teachers' responsibility. They were eager to learn new information and implement new ideas in their classrooms. Even when the PD was over, they expressed a desire to continue learning, sharing, and trying out new ideas and strategies. They were also interested in exploring ways of collaborating with other members in their department so that they could disseminate the knowledge they had gained through the PD. This finding suggests that the science teachers were keen to understand how to address the language and literacy needs of their students. It challenges popular depictions of content area teachers as disinterested in or even resistant to literacy learning (c.f., Moje, 2008) and support the recommendation that teacher educators reframe how they view the willingness of secondary teachers to learn about disciplinary literacy practices (Siebert & Draper, 2008).

Another factor that likely facilitated the teachers' language/literacy learning is the support they received through the PD experience. Our PD fostered a learning community in which peer collaboration and candid conversation were encouraged. The teachers seemed to be particularly appreciative of the opportunity to talk about their learning and their practice during the PD meetings. They valued the time to listen to one another sharing ideas and reflecting on what they were learning and practicing. They enjoyed the time they spent together to plan lessons and to tell stories about their implementation of new ideas and strategies. The opportunity to talk with and listen to peers also built the teachers' confidence, making them less fearful of failure and more willing to take risks. This contributed to their feeling comfortable experimenting with new ideas, which in turn increased their confidence to practice what they were learning in their own classrooms. It showed the benefits of creating learning spaces where teachers felt safe to talk about and try out new practices.

In addition to the support during the PD meetings, we also provided support to the teachers when they were in 'the trenches'. On a regular basis, we observed the teachers in their classrooms and sometimes assisted with teaching, providing feedback and encouragement. We were flexible with our role as facilitator in their classrooms. For example, whereas Brad and Bette liked us to come and do demonstration lessons in their classrooms, Lisa preferred that we observed her in a more traditional manner. Patsy, on the other hand, liked to consult with us during the lesson. She would lead the lesson, with us sitting in the back of the classroom watching. She would often ask us to elaborate on or demonstrate how to use a particular strategy when she felt stuck. In short, the teachers had individual responses to the level of support they required or wanted when attempting to integrate new ideas or strategies into their teaching.

Another accommodation we made in our role as facilitator was to allow each teacher to decide what to integrate and how to integrate based on what they were learning from the PD. The teachers sometimes struggled to find ways to integrate what they were learning with the curriculum they were using. Even though they were learning about science language/reading during the PD, thinking about how to use the newly acquired knowledge in their classroom teaching presented a new set of challenges. To address the implementation challenges, we met with the teachers individually to help them find connections between what they were learning in the

PD and what they were teaching in their curriculum and suggested ideas for making the integration. These one-on-one meetings eased the teachers' anxiety and made the task of integration less intimidating.

Two other aspects of our PD program likely helped increase the teachers' buy-in and sustain their interest and engagement. One has to do with the PD content. The teachers valued the discipline-specific information we provided, noting the benefits of being able to focus on just science language/reading rather than content area literacy more broadly. They reported that having access to expert knowledge and flexible scaffolding helped them see the important roles language plays in shaping knowledge and influenced their buy-in to the ideas presented in the PD sessions (cf. Fang et al., 2008). The second aspect about our PD program is that the teachers were all from the same content area working in the same school. This helped create a close-knit community where learning and application co-occurred and that promoted the concurrent construction of what Cochran-Smith and Lytle (1999) referred to as three essential and interrelated dimensions of professional knowledge about teaching and learning—that is, knowledge-for-practice (e.g., knowledge imparted by instructor and textbook), knowledge-in-practice (e.g., knowledge gained through reflection about and critique of one's own experience in the field), and knowledge-of-practice (e.g., knowledge gained through deliberate inquiry).

The school climate also had an impact on the teachers' commitment to learning. The seven science teachers were part of a school where continuous professional development was valued and actively promoted, as evidenced in the various department-wide study groups that had already been established prior to our project. In addition, the school principal showed her support for our project by visiting the science teachers' department meeting and encouraging them to participate in our PD project.

Besides the school climate, the classroom environment played an important role in the teachers' learning. The science teachers' commitment to the PD resulted in part from the needs they saw in their students to improve science reading. They were concerned about their students' lack of motivation and/or proficiency to read science. The teachers' commitment to the PD was likely also influenced by their perception of the PD's impact on student learning (c.f., Guskey, 2002). They reported that when their students were engaged and successful with a new strategy they introduced, it helped them see how a focus on language in science could support their students' science reading, writing, and learning. This, in turn, reinforced their dedication to the PD project.

Despite their motivation and willingness to participate in our PD, the science teachers did face some significant challenges in their learning about science language/reading and in applying what they were learning to their teaching practice. Chief among these challenges is the teachers' scant knowledge about the English grammar—its systems, forms, and functions—and the resulting lack of a linguistic metalanguage that is essential for engaging students in productive talks about language/text and meaning. Although the teachers were aware that language is a barrier to science reading, their understanding of the challenge was initially confined to scientific terminology. They had considerable difficulty identifying language patterns beyond the word level, struggling in particular with learning to teach abstraction and density, two concepts that involve understanding of language at the phrase and discourse levels. They also tended to focus on linguistic forms but neglect their discursive functions when teaching language in science.

Another factor that inhibited the teachers' learning was time. They found it challenging to add language/literacy instruction to their already packed curriculum. They felt that more time would have helped them feel more successful in their planning and implementation. They said they needed more structured time to plan lessons with the support of their fellow teachers and the facilitator to make appropriate connections between the new ideas and their existing curricula. They wanted more time to talk and share with their peers during the PD about what they were learning and how they were applying their new knowledge in their classrooms. They expressed a willingness/eagerness to stay for at least an extra hour during each PD session. They also wanted more time for feedback and support during their classroom implementation, noting that more time to practice in the classroom and receive feedback from peers would have helped them to continue using what they were learning in their teaching.

4.6 Conclusion

Science is "a unique mix of inquiry and argument" (Yore et al., 2004, p. 347). Language plays an essential role in construing and shaping science knowledge and argument. An understanding of science language is, thus, critical to supporting students in developing science literacy. Science teachers are best positioned to undertake this work because of their content expertise (Fang, 2014). However, they need considerable support in developing the linguistic expertise—i.e., knowledge about the forms, structures, logic, functions, and meanings of lexico-grammatical choices and familiarity with a linguistic metalanguage for engaging students in productive conversations about text (Fang, 2020)—that will help them better understand what it is that makes science texts challenging to read for students and explicate to students how language choices make meaning in science. Such support can be provided through professional development programs. To be effective, these programs need to be long term, discipline specific, focused, and flexible. They also need to provide ample opportunities for discussion and sharing and for connecting learning with teaching. Furthermore, they need to recognize and respond to the many individual and contextual variables that facilitate or inhibit the development of knowledge for, in, and of practice. Only until then can we truly empower teachers to make positive changes and improve student learning.

Acknowledgements The research reported in this chapter was supported by the National Academy of Education's Adolescent Literacy Predoctoral Fellowship, funded by the Carnegie Corporation of New York. Any opinions, findings, conclusions, or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the sponsoring/funding agencies. We thank the seven science teachers for their participation in and their principal for her support of the research project.

References

Allen, J. (1999). *Yellow brick roads: Shared and guided paths to independent reading* (pp. 4–12). Stenhouse.

Beers, K. (2002). *When kids can't read—What teachers can do*. Heinemann.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher, 33*(8), 3–15.

Cervetti, G., Barber, J., Dorph, R., Pearson, D., & Goldschmidt, P. (2012). The impact of an integrated approach to science and literacy in elementary school classrooms. *Journal of Research in Science Teaching, 49*(5), 631–658.

Chen, Y., Hand, B., & McDowell, L. (2013). The effects of writing-to-learn activities on elementary students' conceptual understanding: Learning about force and motion through writing to older peers. *Science Education, 97*(5), 745–771.

Cochran-Smith, M., & Lytle, S. (1999). Relationships of knowledge and practice: Teacher learning in communities. In A. Iran-Nejad & P. D. Pearson (Eds.), *Review of research in education* (Vol. 24, pp. 249–305). American Educational Research Association.

Creswell, J. (2007). *Qualitative inquiry & research design: Choosing among five approaches*. Sage.

Derewianka, B. (1990). *Exploring how texts work*. Primary English Teaching Association.

Desimone, L., & Garet, M. (2015). Best practices in teachers' professional development in the United States. *Psychology, Society, and Education, 7*(3), 252–263.

Fang, Z. (2005). Scientific literacy: A systemic functional linguistics perspective. *Science Education, 89*, 335–347.

Fang, Z. (2006). The language demands of science reading in middle school. *International Journal of Science Education, 28*(5), 491–520.

Fang, Z. (2008). Going beyond the Fab five: Helping students cope with the unique linguistic challenges of expository reading in intermediate grades. *Journal of Adolescent and Adult Literacy, 51*(6), 476–487.

Fang, Z. (2010). *Language and literacy in inquiry-based science classrooms, grades* (pp. 3–8). NSTA Press.

Fang, Z. (2013). Learning to teach against the institutional grain: A professional development model for teacher empowerment. In X. Zhu & K. Zeichner (Eds.), *Preparing teachers for the 21st century* (pp. 237–250). Springer.

Fang, Z. (2014). Preparing content-area teachers for disciplinary literacy instruction: The role of literacy teacher educators. *Journal of Adolescent and Adult Literacy, 57*(6), 444–448.

Fang, Z. (2020). *Using functional grammar in English literacy teaching and learning*. Foreign Language Teaching and Research Press.

Fang, Z. (2021). *Demystifying academic writing: Genres, moves, skills, and strategies*. Routledge.

Fang, Z., Lamme, L., Pringle, R., Patrick, J., Sanders, J., Zmach, C., Charbonnet, S., & Henkel, M. (2008). Integrating reading into middle school science: What we did, found, and learned. *International Journal of Science Education, 30*(15), 2067–2089.

Fang, Z., & Schleppegrell, M. (2008). *Reading in secondary content areas: A language-based pedagogy*. The University of Michigan Press.

Fang, Z., & Schleppegrell, M. (2010). Disciplinary literacies across content areas: Supporting secondary reading through functional language analysis. *Journal of Adolescent and Adult Literacy, 53*(7), 587–597.

Fang, Z., Sun, Y., Chiu, C., & Trutschel, B. (2014). Inservice teachers' perception of a language-based approach to content area reading. *Australian Journal of Language and Literacy, 37*(1), 55–66.

Fang, Z., & Wei, Y. (2010). Improving middle school students' science literacy through reading infusion. *Journal of Educational Research, 103*(4), 262–273.

Guskey, T. (2002). Professional development and teacher change. *Teachers and Teaching, 8*(3/4), 381–391.

Halliday, M. (1998). Things and relations: Regrammaticising experience as technical knowledge. In J. Martin & R. Veel (Eds.), *Reading science: Perspectives on discourses of science* (pp. 185–235). Routledge.

Halliday, M. (2006). Some grammatical problems in scientific English. In J. Webster (Ed.), *The language of science: Vol. 5 in the collected works of M.A.K. Halliday* (pp. 159–180). Continuum.

Lee, O., & Buxton, C. (2013). Teacher professional development to improve science and literacy achievement of English language learners. *Theory into Practice, 52*, 110–117.

Moje, E. (2008). Foregrounding the disciplines in secondary literacy teaching and learning: A call for change. *Journal of Adolescent & Adult Literacy, 52*(2), 96–107.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies Press.

Norris, S., & Phillips, L. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education, 87*, 224–240.

Osborne, J. (2002). Science without literacy: A ship without a sail? *Cambridge Journal of Education, 32*(2), 203–218.

Patterson, A., Roman, D., Friend, M., Osborne, J., & Donovan, B. (2018). Reading for meaning: The foundational knowledge every teacher of science should have. *International Journal of Science Education, 40*(3), 291–307.

Romine, B., McKenna, M., & Robinson, R. (1996). Reading coursework requirements for middle and high school content area teachers: A U.S. survey. *Journal of Adolescent & Adult Literacy, 40*, 194–198.

Saul, E. (2004). *Crossing borders in literacy and science instruction: Perspectives on theory into practice*. International Reading Association.

Seah, L. (2016). Elementary teachers' perception of language issues in science classrooms. *International Journal of Science and Mathematics Education, 14*(6), 1059–1078.

Seah, L., & Silver, R. (2020). Attending to science language demands in multilingual classrooms: A case study. *International Journal of Science Education, 42*(14), 2453–2471.

Siebert, D., & Draper, R. (2008). Why content-area literacy messages do not speak to mathematics teachers: A critical content analysis. *Literacy Research and Instruction, 47*(4), 229–245.

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (2nd ed.). Sage.

Tovani, C. (2000). *I read it, but I don't get it: Comprehension strategies for adolescent readers*. Stenhouse Publishers.

Watson, R., & Manning, A. (2008). Factors influencing the transformation of new teaching approaches from a programme of professional development in the classroom. *International Journal of Science Education, 30*(5), 689–709.

Wellington, J., & Osborne, J. (2001). *Language and literacy in science education*. Open University Press.

Yore, L., Bisanz, G., & Hand, B. (2003). Examining the literacy components of science literacy: 25 years of language arts and science research. *International Journal of Science Education, 25*, 689–725.

Yore, L., Hand, B., Goldman, S., Hildebrand, G., Osborne, J., et al. (2004). New directions in language and science education research. *Reading Research Quarterly, 39*, 347–352.