ABSTRACT

Title of Dissertation:	Exploring the Use of Cognitive Apprenticeship for Teachers and Students in Science Classrooms
	Yewon Lee Doctor of Philosophy, 2019
Dissertation directed by:	Professor Susan De La Paz Department of Counseling, Higher Education, and Special Education

The primary goal of this dissertation is to explore the use of cognitive apprenticeship (CA) with teachers and students in science classrooms. In particular, studies that make up this dissertation explore ways that teachers can improve the quality of students' written scientific explanations and the supports that teachers need in order to promote such growth in their students. CA is a complex instructional model that is challenging for both teachers and students to use, especially in secondary classrooms. Other reports indicate the potential of CA for teaching disciplinary literacy in history classrooms, but this approach has not often been used to teach scientific writing. This project explores that, in inclusive settings with heterogeneous learners, and in an afterschool program, with students with learning disabilities (LD) and those who are English learners (ELs).

The first part of the work reported here involved a systematic review of the literature on science writing instruction with these populations and with struggling learners. A total of 14 studies (three randomized control trials, nine quasi-experimental, and two single case design studies) that met established criteria as high quality studies were identified and

examined to determine whether researchers were including instructional elements that have been found to be effective for these learners (e.g., cognitive and linguistic supports) and to determine learning and writing outcomes that resulted from the science writing interventions.

The next project focused on an in-depth study of two middle school science teachers who participated in PD that was focused on science writing, culminating in the implementation of a CA on constructing and critiquing explanations for scientific phenomena in writing. The goal in this work was to examine how doing so impacted the teachers' beliefs and their subsequent choice of writing tasks for their science instruction. After this PD, both teachers expressed changes in their beliefs about learners that had lasting effects on their subsequent teaching. They also believed the CA led to improved writing in their students, including their ability to engage in argumentative reasoning. This realization led to changes in other beliefs about their students in general, and about the importance of incorporating writing instruction in class. Ultimately, these changes may have affected the types of tasks they assigned in class. Prior to implementing CA, they assigned writing tasks that were close-ended, but after, they assigned analytical writing tasks like a Claim, Evidence, and Reasoning (CER) that promoted scientific reasoning.

The third project in this dissertation was an intervention study (using single-case design methodology) that focused on teaching middle school students with LD and who are EL to write scientific explanations. The intervention provided cognitive supports such as procedural facilitators to guide students' thinking. In addition, linguistic supports, such as the use of contextualized instruction on text structure, vocabulary, and grammar, and instruction on how language is used in a science was also provided to meet the needs of the sixth- and seventh-grade participants. After delivering instruction using CA (and four weeks later), students produced explanations that were rated as higher in overall quality, grammatical and lexical sophistication, and in the length of their writing. Of importance, they also made substantial gain in causal and mechanistic reasoning, which is central to good scientific writing.

These findings lead us to believe that middle school science teachers who work with students with LD and those who are EL may underestimate their students' ability to write. Contrary to their beliefs, findings from these projects suggest otherwise. Given sufficient and appropriate support such as those afforded by CA, our findings provide tentative support for the conjecture that all students, regardless of their disability status or language needs may be able to improve their reasoning and writing skills in science. CAs can be a powerful vehicle that can transform both teacher practices and student learning outcome.

EXPLORING THE USE OF COGNITIVE APPRENTICESHIP FOR TEACHERS AND STUDENTS IN SCIENCE CLASSROOMS

by

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CHAPTER 1: INTRODUCTION AND OVERVIEW

Problem Statement

Scientists use writing to share scientific findings within a community that shares the same principle for validating findings (i.e., using evidence and experimental procedures). The *Next Generation Science Standards* (NGSS, 2013) propagates such role of scientists in K-12 science education by fostering students' ability to construct and critique arguments and explanations using evidence (National Research Council [NRC], 2013). When constructing and critiquing explanations, students must be able to extract appropriate evidence to justify their claims, which requires sophisticated understanding of the scientific process. Understandably, students struggle with this task and even when they are able to do so, they fail to transfer those ideas into writing. In fact, their challenge in science may be partially attributed to their struggle with writing (see the 2011 *National Assessment of Educational Progress [NAEP]* report). According to this report, only about a third of eighth and twelfth-grade students achieved proficiency or above in writing (NCES, 2012). Moreover, only 1% of students who were English learners (ELs) met proficiency (Beck, Llosa, & Fredrick, 2013). Similarly, students with disabilities also performed significantly lower ($p < 0.001$) than peers without disabilities (NCES, 2012).

Despite these struggles, there has been sparse research on students' disciplinary writing as they engage in scientific practices (e.g., Sampson, Enderle, Grooms, & Witte, 2013; Sandoval & Millwood, 2005). The primary goal of this dissertation is to improve students' abilities to construct and critique written explanations in science by applying a potentially effective method of teaching writing known as Cognitive Apprenticeship (CA). This complex instructional model is challenging for both teachers and students to use. Partly for this reason, CA has not often been applied to teach science writing to struggling writers (i.e., students who are English learners and/or students with LD) despite its well-established effectiveness in domain-general writing instruction. Teachers play a key role in successful implementation of any instruction; therefore, I first sought to explore defining characteristics of effective science writing interventions for students who are ELs and students with LD using examine theoretical models that are relevant for teaching writing to these populations. Second, I explored the level of impact that CA has on teacher beliefs and their future teaching practices. In doing this work, I explain challenges that teachers face when using such complex models and how that affects their beliefs about teaching. Teacher beliefs are relevant because they are powerful predictors for improving student learning. Finally, I designed and implemented a science writing intervention for my target populations. I end this chapter with an overview of my three studies and the potential significance of my research.

Cognitive Apprenticeship

CA is a model of instruction originally designed to help novice learners by making the expert thinking process (i.e., higher order thinking, complex) visible for those who might otherwise struggle with such cognitive processes (Collins, Brown, & Newman, 1988). This instructional model has been found to be effective in teaching domain-general literacy skills (i.e., read and write; Englert, Raphael, Anderson, Anthony, & Stevens, 1991; Graham & Harris, 1989; Harris, Graham, & Mason, 2006) as well as other content areas such as math (Schoenfeld, 1985) and history (e.g., De La Paz et al., 2014; De La Paz et al., 2017); however, in the field of writing research, the same kind of wealth of empirical studies does not exist for teaching disciplinary writing in science

(Englert & Conant, 2002). This instructional model is exceptionally effective because unlike the traditional model of apprenticeship, students develop an ability to apply acquired skills to think and learn independently in diverse learning contexts (Collins, Brown, & Holum, 1991).

Limitations of CA. CA is a model of instruction designed to help novice learners by making the expert thinking process visible for those who might otherwise struggle with such cognitive processes and it has been successfully applied to teach domain-general literacy skills. The model has not been applied more broadly in general education science classrooms to deliver writing instruction because of two reasons. First, successful implementation depends on teachers' content and pedagogical understanding about the content or skill that they teach. CA is an instructional model that allows teachers to guide and scaffold instruction, which means that they need to be able to respond appropriately to their students' learning needs. For teachers to be able to successfully guide instruction, they need to first, understand the content or skill they are teaching, and also ways in which they can scaffold students' learning. Therefore, successful implementation is contingent upon long-term and continuous PD that provides feedback about their instruction and corresponding training on developing literacy skills.

Teachers also need to have "expert knowledge" about the content or skill they are teaching. Knowledge and skills required to write are different from disciplinary core ideas in science. Science teacher education programs traditionally do not offer literacy instruction to candidates. Therefore, many science teachers lack understanding of how to deliver effective literacy instruction. To fill in this gap, we need to help them develop solid understanding of literacy skills, including writing, required to achieve academically in science classrooms. This includes knowledge about different genres in science. Without such knowledge, they will not be able to effectively scaffold learning when delivering writing instruction. For these reasons, application of CA in content-area subjects have been limited, especially in science classrooms.

Stages of SRSD. One form of CA is called *self-regulated strategy development (SRSD*). This teaching model has been validated in more than 50 studies for populations with high-incidence disabilities, English language learners, average learners, and the gifted and talented. SRSD provides a systematic way for teachers to guide students' learning by gradually releasing more responsibilities by transitioning from modeling, collaborative modeling, to independent practice, referred to as stages of instruction. In the earlier stages (i.e., stages 1-3), prior to modeling, teachers first introduce the context of the writing task and different scaffolds (e.g., graphic organizer, mnemonic, self-statement) to help them build foundations in writing. As they transition through the stages, students gain finesse in using strategies (e.g., *IREAD, H2W, POW+TREE*) independent of scaffolds such as graphic organizers. The most helpful feature of this teaching model is the flexibility, which allows teachers to modify stages of instruction to meet the learning needs of diverse learners.

Unlike previous applications of SRSD, the current project will not emphasize self-regulation as part of instruction because the participating students (e.g., middle school students) are older and do not need explicit instruction on self-regulation to monitor their learning. Furthermore, because the current intervention aims to integrate scientific thinking into writing, the intervention will prioritize learning about scientific thinking in addition to writing. These core differences differentiate it from SRSD. Therefore, I utilized CA as the model of instruction instead of SRSD. Furthermore, I will not conduct an additional review of literature on the effectiveness of CA as it has been established as an evidence-based model of instruction.

Teacher beliefs. When using CA, the role of teachers is critical because teachers' teaching practices directly affect students' learning (e.g., Garcia & Guerra, 2004; Miller & Satchwell, 2006; Porter & Freeman, 1986). Researchers used CA-based PD to improve the quality of teachers' science instruction and they found positive effect on their content and pedagogical knowledge, and even their beliefs (e.g., Knight & McNeil, 2016; Lewis, Baker, & Helding, 2015; McNeil et al., 2006; Peters-Burton, Merz, Ramirez, & Saroughi, 2015). Ironically, this literature suggests that teachers' teaching practices remain largely unchanged even after completing CA-based PD. However, a relatively unexplored and potentially powerful predictor that could explain this disconnect is teacher beliefs. There are a variety of theoretical frameworks that relate teachers practices and beliefs (e.g., Fang, 1996; Nespor, 1987). For understanding the role of the CA (in which teachers were implementing a specific curriculum) in teachers' beliefs, we chose Guskey's model (1986, 1989).

In fact, Guskey's (1986; 1989) model provides a way to explain how PD, teacher practices, and teacher beliefs are related. According to his model, PD alters teacher beliefs by transforming their teaching practices. In other words, his model implies a strong causal link between teachers' actual implementation of what they acquired through the PD on their beliefs. Previous studies focused on the role of a PD on teacher beliefs (e.g., Lewis et al., 2015; McNeil et al., 2006; McNeil & Knight, 2013; Peters-Burton et al., 2015) and rarely explored the effect of implementing a CA-based instruction on teacher beliefs. Therefore, this area of research remains untapped despite its potential to unveil helpful information about teacher practices.

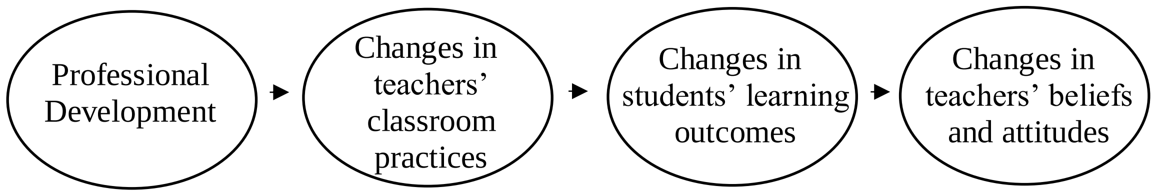

Figure 1. Guskey's (1986; 1989) model for teacher change

Therefore, I adopted Guskey's (1986) model to explore changes in teachers' beliefs, following the implementation of CA-based writing instruction for diverse learners, including students with LD and those who are EL (see Figure 1).

Characteristics of Struggling Writers

As mentioned earlier, the majority of students (about 70%) who appear to be on grade level struggle with writing. These students face additional challenges when writing in a specific discipline such as science if they are unfamiliar with science vocabulary, academic language, and science content (Brigham, Scruggs, Mastropieri, 2011; Scruggs & Mastropieri, 1993). Under normal circumstances, struggling writers rarely engage in planning (De La Paz, 1999) without instruction; thereby produce incoherent texts (De La Paz & McCutchen, 2017). English language learners and students with LD are at higher risk for underachievement in writing (Graham & Hall, 2016). These students come from diverse ethnicity, language, and socioeconomic background (Klingner, Artiles, & Barletta, 2006) yet their shared struggles when learning place them at risk for low education achievement, school dropout, psychological problems, and low self-esteem (Pape, Bjørngaard, Westin, Holmen, & Krokstad, 2011). Despite some apparent similarities, these two subgroups of students have learning needs that require different types of support for them to grow and develop into more capable writers.

Students with learning disabilities (LD). Unlike most typically-developing students and those who are ELs, students with LD face additional challenges in working memory, processing, memorizing, information recall (Taylor & Hord, 2016), and executive functioning (De La Paz, 1999; Graham, Harris, MacArthur, & Schwartz, 1991; Shmulsky, 2003). Difficulties in these areas interfere with their ability to recall and organize information efficiently (Swanson & Siegel, 2001). Therefore, they struggle to recall and organize information simultaneously when writing (Swanson & Siegel, 2001). Due to their challenges with executive functioning, students with LD, like other novice writers, tend to focus primarily on generating content (also described as "knowledge-telling" by Scardamalia & Bereiter, 1987). For example, instead of planning, they list all that they know about a given topic. Consequently, their writing can be incoherent and unclear (De La Paz & McCutchen, 2017; Graham, 1992; Graham, Harris, & Larsen, 2001). Furthermore, their difficulties are magnified by their struggles with foundational writing skills such as transcription, mechanics, and speed (Baker, Gersten, & Graham, 2003; MacArthur & Graham, 1987; Saddler & Graham, 2007; Weintraub & Graham, 1998).

Students who are English learners. Students who are ELs lack command over the English language, which adds an additional layer of challenge when expressing and articulating their ideas (Lee, 2005). Factors contributing to imprecise language use includes a lack of vocabulary knowledge (Lee, 2005) and limited understanding of figurative expressions (Hyland & Milton, 1997). Furthermore, Fang and Wei (2010) asserted that knowledge of academic language is the key to improving students' writing quality and science content knowledge. These students are put at a greater risk due to a lack of exposure to academic content and language (Beck et al., 2013). Consequently, these students may also lack knowledge and experience in using academic language (Fang, 2005). In summary, English language learners struggle in writing in science stems from lack of command over academic language and inadequate vocabulary and science content knowledge.

Theoretical Model

Cognitive process theory. Largely, there are two major theories that could remediate the learning needs of my target population. First is the cognitive process theory (Flower & Hayes, 1980) that focuses on aspects of students' writing development. This is a more traditional theory in writing research that explains students' writing development by focusing on the processes required to transfer ideas into a text (i.e., long-term memory, planning, reviewing, and translating) (MacArthur et al., 2016). This perspective helps us understand the mechanism of writing. Flower and Hayes (1980) further elaborated that one needs to be proficient in the four main cognitive processes to be a good writer: (a) generating ideas, (b) translating ideas into language, (c) turning ideas into written form, and finally, (d) monitoring process in each step (Flower & Hayes, 1980). This perspective offers a plausible explanation for why students with LD struggle with writing as they juggle these cognitive tasks as well as consider using directions to help them. The second while others focus on the context (i.e., setting, purpose and function of language) in which the writing is produced.

Systemic functional linguistics. Systemic Functional Linguistics (SFL; Halliday, 1994) is another theory that can help remediate the needs of my target population. It is a byproduct of the sociocultural theory that views language as a social process that creates and conveys knowledge, contextualizing its use (Halliday, 1994). In application, language follows norms specific to certain discipline because forms of language determine the quality of its delivery. For example, one goal in mathematics is to provide a logical proof whereas in science, it may be to explain a phenomenon (Bailey, 2007). To fulfill their function, mathematicians use more terms that demonstrate logical connections in math while scientists use language that effectively explains a mechanism or a process. Therefore, the form of the language is quintessential to satisfy the primary goal of the writer. Students who are ELs and some who are identified with LD struggle especially with language because they lack an understanding of how to construct appropriate language to communicate ideas. Therefore, this framework has the potential to address the needs of these students by teaching them the forms of language that are most conducive to delivering scientific knowledge (De Oliveira & Lan, 2014).

Summary

Students with LD and those who are EL struggle with foundational writing skills such as transcription, mechanics, and speed (Baker et al., 2003; MacArthur & Graham, 1987; Saddler & Graham, 2007; Weintraub & Graham, 1998), in addition to having other preexisting challenges (i.e., language, executive functioning). These challenges are magnified when asked to produce writing for specific disciplines such as science (Brigham et al., 2011; Scruggs & Mastropieri, 1993). CA is an established evidence-based instructional model for remediating the needs of struggling writers; however, it can be challenging for teachers and students to use and in itself, it lacks attention to science content.

Synopsis of Projects

This dissertation accomplished three aims in an effort to contribute to and expand upon extant research on science writing intervention for struggling learners (i.e., students with LD and those who are EL) and on teacher beliefs. My first aim was to identify elements of science writing intervention that could benefit students with LD and those who are EL through a systematic review of literature. I applied two potentially effective frameworks, cognitive process theory and SFL, to review previous literature on science writing interventions. My second aim was to analyze the effect of implementing an evidence-based instruction, CA, on teachers' beliefs. My final aim was to apply the findings from the systematic review from Chapter 2 to design and implement a science writing intervention for my stated populations of interest.

Significance

The overarching goal of my dissertation was to help struggling writers learn effective ways of thinking and communicating their ideas in science and for teachers to be prepared to instruct them. Three projects investigated the role of CA in teaching science writing for teachers and students, which has not been examined in previous studies. Findings from these projects specifically expand knowledge about effective science writing intervention for students with LD and those who are ELs and its translation into teacher practices. It is my hope that this research can herald further research on science writing intervention for specific populations such as students identified with LD and those who are ELs.

Description of Aims

Aim 1. Synthesize Findings from Current Literature to Identify Components of Potentially Effective Science Writing Intervention for Students with LD and Those Who Are ELs

I conducted a systematic review of existing literature on writing interventions in science to gauge the presence of effective approaches to teaching writing. This synthesis report descriptive findings from methodological findings (e.g., participants, dependent measures, independent variables, research quality) and content findings (e.g., components of effective writing intervention, learning outcome). Based on this review, I highlighted current gap in research, identified components of effective science writing intervention for my target population, and generated recommendations for directions for future research.

Aim 1 Research Questions:

RQ 1: What kinds of learners and writing assignments are included in the extant science writing intervention research?

RQ 2: To what extent do science writing intervention studies include instructional elements that have been found to be effective for students with LD or are EL?

RQ 3: What learning and writing outcomes and effect sizes are reported in this body of research?

Aim 2. Examine the Effect of Implementation of CA-Based Instruction on Teacher Beliefs

Teacher belief is one of the most powerful predictors of their instructional quality and students' academic achievement or growth as a learner. In fact, there has been studies (e.g., Garcia & Guerra, 2004; Miller & Satchwell, 2006; Porter & Freeman, 1986) that highlight the inseparable relationship between teacher beliefs and students' academic achievement. CA-based PD is known to help teachers develop more sophisticated pedagogical and epistemic knowledge and even transform their teaching practices (e.g., Knight & McNeil, 2016; Luft & Hewson, 2014; Peters-Burton et al., 2015). However, the relationship between teachers' implementation of a CA-based instruction on their beliefs is yet to be explored. This project was nested within a larger study that examined the effect of a CA-based PD on students' science writing explanation (De La Paz et al., in review) and it focused on how the implementation of the CA itself influences teachers' beliefs (as informed by Guskey's model in 1986; 1989).

Aim 2 Research Question:

RQ 1: In what ways, if any, does implementation of a CA focus on writing in science lead to changes in teachers' beliefs?

Aim 3. Empirically Determined the Effect of Science Writing Intervention Specifically Designed for English Learners and Students with LD

Based on the findings from a systematic review of literature of current science writing interventions, I designed and evaluated a new type of science writing instruction for my target population using findings from Aim 1. Instruction incorporated these elements and it was delivered using CA model of instruction. This project examined the effect of an innovative science writing intervention on students who are ELs and students with LD.

Aim 3 Research Question:

RQ 1: Do middle school students with LD or are EL show growth in their ability to construct explanations after participating in a cognitive apprenticeship approach to instruction?

A final note to the dissertation reader. The following three chapters are presented as individual papers. As such, titles are provided for each manuscript, and references, tables, and figures are included for each. Language in each chapter is used to acknowledge that the writer of this dissertation is the first author, however the language used to indicate this varies from using "we" to "the first author" or "the second author" based on what was appropriate for each article. Additional material (e.g., abstracts and key words) are not provided here but will be included when submitted for publication. Chapter five will summarize the purpose and major findings from each paper and make recommendations for future research.

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STUDY 1: A SYSTEMATIC REVIEW OF SCIENCE WRITING INSTRUCTION: FINDINGS AND RECOMMENDATIONS FOR STUDENTS WITH LD, WHO ARE EL, OR WHO ARE STRUGGLING LEARNERS

Problem Statement

Writing plays a prominent role in higher education and employment in post-industrialized societies (Graham & Harris, 2006). White-collar employers consider how workers write in hiring and promoting decisions, and 80% of blue-collar workers report writing as part of their job (National Commission on Writing in America's Schools and Colleges, 2004; 2005). Writing has been promoted as a powerful tool for developing communication skills (Santangelo, 2014) and conceptual knowledge (Bangert-Drowns, Hurley, & Wilkinson, 2004; Klein & Boscolo, 2015). Moreover, it helps individuals reflect and evaluate their understanding (Bangert-Drowns et al., 2004; Graham & Perin, 2007).

Writing is a complex task that requires spontaneous coordination of content, mechanics, and organization (Bangert-Drowns et al., 2004), and it is a learned skill that matures only with instruction and practice (Kellogg, 2008). The fact that many students struggle with writing is somewhat expected, given information reported by students across the United States, as revealed in the 2011 *National Assessment of Educational Progress (NAEP)* report. According to NAEP data, only 27% of eighth and twelfth-grade students achieved proficiency in writing (National Center of Educational Research [NCER], 2012). Furthermore, demands for managing the writing process are likely to overwhelm students with learning disabilities (LD) and those who are learning English as an additional language (abbreviated as EL throughout this paper), as these populations of students are typically behind their peers regarding their foundational writing skills (Bangert-Drowns et al., 2004). According to the same NAEP report (NCER, 2012), only 1% of EL scored at or above a proficient level (Beck, Llosa, & Fredrick, 2013). Furthermore, students with disabilities performed significantly lower ($p < 0.001$) than those who were not identified with a disability (NCER, 2012).

Why Writing is Challenging for Students with LD or are EL

Typically developing students show well-developed executive functioning and working memory (Klein & Boscolo, 2015), which allow them to filter irrelevant information (Kellogg, 2008). Moreover, advanced and mature writers self-monitor each process of writing: (a) planning, (b) translating, and (c) revising (Flower & Hayes, 1980). These writers are able to successfully construct and transmit new knowledge (Klein & Boscolo, 2015). Many students who might otherwise appear to be on grade level are novice writers. Without instruction, these students do not engage in conceptual planning and fail to generate syntactically complex texts (De La Paz & McCutchen, 2017).

Students with LD and those who are EL are at a greater risk for writing difficulties (Graham & Hall, 2016). These students differ in terms of ethnicity, language, and socioeconomic background (Klingner, Artiles, & Barletta, 2006), but as a group, are often at risk for low achievement, school dropout, psychological problems, and low self-esteem (Pape, Bjørngaard, Westin, Holmen, & Krokstad, 2011). Students with LD often have limitations in working memory, processing, memorizing, and information recall (Taylor & Hord, 2016), and may show weakness in executive functioning (Graham, Harris, MacArthur, & Schwartz, 1991; Shmulsky, 2003). Difficulties in these areas interfere with efficient recall and organization of information (Swanson & Siegel, 2001).

Their difficulties in written expression are magnified by struggles with foundational skills such as transcription, mechanics, and spelling (Baker, Gersten, & Graham, 2003; MacArthur & Graham, 1987; Saddler & Graham, 2007; Weintraub & Graham, 1998).

When writing in English-dominant settings such as American schools, students who are EL must gain command over a new language, especially when expected to express their ideas in writing (Lee, 2005). Thus, students who are EL struggle with written communication partially because they have not learned to use appropriate forms of language in science (Beck et al., 2013). A lack of vocabulary knowledge (Lee, 2005) and a limited understanding of ‘nuanced’ expressions (Hyland & Milton, 1997) lead to imprecise language use. A lack of exposure to academic content and experience using language in content areas are other factors that impede clear written communication (Beck et al., 2013; Fang, 2005; Fang & Wei, 2010).

What We Know (and Don’t Know) About Effective Writing Instruction

Two major paradigms dominate research on writing for these two student populations (e.g., Gere, Limlamai, Wilson, Saylor & Pugh, 2019; Newell, Beach, Smith, & VanDerHeide, 2011). Some researchers focus on the cognitive aspect of students’ writing development (i.e., planning, translating, reviewing, and revising) while others focus on the context (i.e., setting, purpose and function of language).

Cognitive process theory. Cognitive models focus on the mental processes that are needed to compose text (De La Paz & McCutchen, 2017); these subprocesses generally include the following: (a) brainstorming and organizing, (b) transcribing or translation, and (c) monitoring and revising a final product. As such the writer is actively constructing ideas. With respect to writing in content areas, Scardamalia and Bereiter

(1987) distinguish further the difference between generating and restructuring information, which is often referred to as knowledge-telling vs. knowledge transformation. These concepts have been the focus of much research on writing and writing instruction since the 1980's when the cognitive processing movement began, and is most often associated as an instructional approach for students with LD.

Today there are many recommendations for teaching writing that can be considered evidence-based for students with LD. Graham, Harris, and Santangelo (2015) identified the following elements as effective: (a) shared writing, (b) goal setting, (c) feedback, (d) foundational writing skills (i.e., handwriting, spelling, sentence construction), (e) content and genre knowledge, (f) vocabulary instruction, and (g) writing process. Gillespie and Graham (2014) found additional elements in their synthesis on writing instruction for students with LD: (a) strategy instruction, (b) goal setting, (c) dictation, (d) process approach, and (e) word processing. The What Works Clearinghouse (WWC, 2010) also identified the self-regulation strategy development (SRSD) model of instruction as an especially effective form of instruction for novice and struggling learners. This form of writing instruction is well researched (c.f. Graham & Perin, 2007).

Sociocultural theory and systematic functional linguistics (SFL). Many researchers look beyond cognition in their explanation of important elements in writing instruction, broadly considering context (Newell et al., 2011). Context includes influences such as environmental factors, previous language experience, cultural norms for language use, and one's primary reason for communication. In particular, SFL researchers advocate that language is constantly shaped through a social process (Halliday, 1994). Based on this perspective, language in a specific discipline follows norms established by a community of experts who use it to share ideas. For example, in science, scientists value scientific explanations because it allows them to provide a mechanistic explanation about a phenomenon (Whittaker, O'Donnell, & McCabe, 2006). These concepts have also been the focus of much research on writing and writing instruction and is now most often associated as an instructional approach for students who are ELs.

A recent review of this literature (Olson, Scarcella, & Matuchniak, 2015) identified the following practices for teaching writing to students who are EL: (a) strategy instruction, (b) modeling, (c) scaffolding, (d) explicit instruction (vocabulary, grammar, text-structure knowledge), and (e) opportunities to practice. These suggestions support students' language development (text structure, vocabulary, grammar). Another promising form of SFL focuses on teaching students about genre. This is prevalent in Australia (Christie & Derewianka, 2008; Martin & Rose, 2005). De Oliveira and Iddings (2014), Harman (2013), Schleppegrell (1998), and Schleppegrell and De Oliveira (2006) have adopted this approach in the United States. In their interventions, teachers accentuated the linguistic structure through (a) deconstruction of the text, (b) joint construction of the text, and (c) independent construction of the text. Reviews such as these are helpful for determining expectations for general writing instruction and are thus summarized in Table 1.

Writing in science classrooms. In addition to writing for general purposes, writing to learn (in) science requires specialized knowledge and skills, because of unique disciplinary demands of science. Over the past five years, the Next Generation Science Standards (NGSS) have initiated significant reforms to K-12 science curriculum, particularly in the practice of scientific argumentation, which comprises both the processes and products of inquiry and evidence-based reasoning about scientific phenomena (National Research Council [NRC], 2013). Even high-stakes standardized science tests require students to construct scientific explanations or arguments (NCER, 2016). Lee, Quinn, and Valdes (2013) summarized that students are now expected to "read, write, view, and visually represent as they develop their models and explanations" (p. 224).

Writing in scientific fields writing has specific linguistic and organizational features that are different from other domain-general writing (Fang, 2005; Halliday, 1989). For example, writing in science is often lexically dense (Fang, 2005). Beyond these features, however, language in science has important functions such as communicating information and constructing and critiquing explanations and engaging in argumentation, and the practices of the NGSS (NRC, 2013) overlap considerably with the Common Core State Standards (CCSS; NRC, 2012) for Literacy (Lee et al., 2013).

Many evidence-based writing instructional interventions exist for students with or without special learning needs and many of these approaches are used by English teachers and special educators (Graham & Perin, 2007). While there is some research in evidence-based writing approaches in science (Sampson, Enderle, Grooms, & Witte, 2013; Sandoval & Willwood, 2005), it has not made its way into classroom practice.

In the ‘80’s writing in science typically involved expository short-answer recall questions, copying from the board, and fill-in-the-blank activities (Applebee & Langer, 2011). These writing tasks don’t require students to plan, organize, and formulate longer or more complex responses. Ultimately, Applebee and Langer (2011) found that teachers did very little to teach students how to write in science classrooms. The problems incorporating writing in science have persisted, despite greater attention to writing-across-the-curriculum (Applebee, 2011). Drew, Olinghouse, Faggella-Luby, and Welsh (2017) surveyed middle and high school teachers who teach specific content (e.g., science, biology, physics, math) and only a third reported assigning written tasks in class. Of those teachers who reported assigning written tasks, a majority reported using "restricted" tasks with low cognitive demand such as step-by-step lab procedures (Kiuhara, Graham, & Hawken, 2009), note-taking, fill-in-the-blank worksheets, lists, and short- answer expository questions (Drew, Olinghouse, Faggella-Luby, & Welsh, 2017). Some of these tasks may support students conceptual understanding, but most do not generally promote analytical thinking and reasoning highlighted by NGSS (NRC, 2013). In summary, teachers of specific content utilize writing minimally and if they do use it, they use it for assessment purposes rather than for thinking and learning (Drew et al., 2017; Kiuhara et al., 2009).

Teachers' reluctance to integrate literacy instruction in science partially comes from a lack of understanding of evidence-based writing instruction in content-area classrooms. Most evidence-based writing approaches are domain-general, such as narratives, opinion essays, and persuasive writing tasks not specific to science (Graham & Perin, 2007). We cannot attribute a lack of productive writing instruction in science and math classrooms solely to teachers' unwillingness to do so, because there is little communication from research to practice about evidence-based science and mathematics writing approaches, although there are research studies that focus on writing (Sampson, Enderle, Grooms, & Witte, 2013; Sandoval & Willwood, 2005). The research community needs to do a better job of bringing evidence-based approaches to writing instruction to practicing teachers.

Moreover, when written, science is often lexically dense (Fang, 2005). According to Halliday (1993) one way to describe scientific writing is by examining informational density, which can be measured in two ways: (a) number of content words per clause, and (b) percentage of the content word over a total number of words. According to Eggins (1994), words can be categorized as content carrying words include "nouns, verbs, adjectives, and adverbs," whereas non-content carrying words would be "prepositions, conjunctions, auxiliary verbs, adverbs, determiners, and pronouns" (Fang, 2005, p. 338). In daily language, there are usually 2-3 content words per clause whereas, in written language, there are 4-6 content words per phrase while scientific writing has 10-13 content carrying words per clause (Halliday, 1993).

Scientific writing is often abstract. According to Veel (1997), abstract expressions help create technical terms that help synthesize and explain abstract concepts or mechanisms that cannot otherwise be captured. Halliday (1998) suggested that one way to make use of abstract expressions is through transforming verbs or adjectives into nouns, or “nominalization” (Fang, 2005, p. 339). To illustrate, the word “grow” can be nominalized into “growth” or “development,” which shifts the focus on explaining the mechanism behind the phenomenon rather than a simple observation (Whittaker et al., 2006, p. 151).

Another feature commonly used to analyze scientific writing is technicality (Fang, 2005). Wignell, Martin, and Eggins (1993) defined technical vocabulary as terms that have specific content-specific meaning. These terms can be adjectives or verbs that contribute to creating meaning in the specialized discipline (Fang, 2005). Most of these terms are low-frequency words that are rarely used outside the discipline because they have a special function of conveying accurate scientific knowledge. Technical terms condense information and help construct a chain of reasoning when presenting scientific explanations (Schleppegrell, 2004). An example might be "frogspawn" or "froglet" when students are expressing ideas related to the life cycle of frogs (Whittaker et al., 2006, p. 151).

Finally, writing in science often has a tone of authoritativeness (Fang, 2005). Science information is inherently accurate and objective and thus, conveyed in an assertive tone to emphasize the objectivity of presented information (Schleppegrell, 2004). Chafe (1982) noted that a writer could establish authoritativeness by refraining from (a) using first person point of view, (b) referencing to own mental processes (e.g., I think), (c) using fillers (e.g., you know, well), (d) using direct quotes (e.g., it says, "I am tired"), and (e) using vague terms (e.g., sort of, stuff). For example, "A large molecular size is expected to retard the compound's rate of diffusion" is an authoritative proposition (as cited in Schleppegrell, 2004, p. 124).

Having linguistic knowledge means that writers are familiar with the written conventions at sub-sentence levels (e.g., spelling, morphology) as well as at the sentence level (Clachar, 1999). Gee (2002) posited that students equipped with adequate linguistic knowledge will develop deeper understandings about science and the nature of science. Understanding linguistic forms requires students to understand the function of language. Therefore, students should learn processes involved in meaning-making to clearly see the connection between the form and purpose of language to develop scientific literacy.

Given these expectations, it is important to identify effective approaches to writing instruction for learning and writing in science classrooms. Gere and colleagues (2019) described writing assignments that are associated with conceptual learning gains in science. According to their review, assignments with clear expectations, those that require interactive writing processes (which draw on sociocultural meanings), and ones that also prompt meaning making and/or metacognition foster deep learning. Unfortunately, the field lacks reviews that explicitly explore writing interventions in science classrooms, and none have been reported for students who experience learning difficulties in school.

Purpose and Significance

One's ability to write well is important in science, yet the field lacks information about how to teach students with LD and who are EL to become proficient writers. Identifying interventions that target their writing needs would help promote their academic and postsecondary success. We hypothesize that cognitive and linguistic elements are likely to be beneficial for these students, and we seek to identify effective instructional elements from the available research (Table 1). Three research questions guided this systematic review:

RQ 1: What kinds of learners and writing assignments are included in the extant science writing intervention research?

RQ 2: To what extent do science writing intervention studies include instructional elements that have been found to be effective for students with LD or are EL?

RQ 3: What learning and writing outcomes and effect sizes are reported in this body of research?

Method

Location and Selection of Studies

We identified studies for this synthesis using a multistep process. First, we looked for writing interventions in a science-learning context. Second, at least one outcome variable measured writing (e.g., writing quality, genre knowledge) or used writing to demonstrate learning (e.g., a science test with short or long responses). Third, we focused on students in K-12 settings because school science writing differs from actual scientific writing (Glen & Dotger, 2013; Yore, Hand, & Florence, 2004). Finally, the student population included students with LD, those who are EL, or studies with struggling learners (e.g., those with low achievers of populations described as of mixed abilities). We conducted a review of literature using multiple research databases, *Education Source, Psych Info,* and *ProQuest* and looked for studies published between 1987 and 2017 in a peer-reviewed journal.

We conducted the search using combinations of the following descriptors: *writing instruction, English learner, learning disabilities, science writing,* and *science education*. We applied Boolean operators (e.g., AND) to narrow the search results by logically linking these terms (i.e., "*English learners," "learning disabilities," "science education," "writing instruction," "explanation," "science writing,"* and "*argumentative writing").* These searches initially yielded 1,000 articles. We reviewed the abstracts of these articles to determine eligibility. After reading all the abstracts derived through the search, we identified eight studies.

We then conducted a hand search of three relevant science journals: *International Journal of Science Education, Journal Research in Science Teaching,* and *Research in*

Science Education. In these three journals, we queried "*writing* and *learning disabilities", "writing* and *English Learners"*, and "*writing* and *disability*". In the *International Journal of Science Education*, the three queries produced 42, 588, and 16 studies; in the *Journal of Research in Science Teaching*, it produced 119, 374, and 65 studies; and finally, *Research in Science Education* produced 25, 148, and 11 studies. After reading all the abstracts derived through the search, we identified six additional studies.

Procedures for Evaluating Quality Indicators of the Studies

We evaluated the quality of each study using well-established standards. We applied the *Council of Exceptional Children's (CEC;* WWC, 2010) quality indicators to evaluate the quality of group experiments and a single case designs (SCD). Each item was rated on a 2-point scale and the average percentage was taken at the end to determine the study quality (i.e., high quality > 70%). A graduate student in special education coded 36% (n = 5) of randomly selected studies after receiving a 2-hour training session prior. According to Cohen's (2016) guideline, a Kappa score of .80 indicates substantial or sufficient agreement between two raters. The Cohen's Kappa coefficient between the two raters was .81.

Results

The systemic review yielded 14 studies (three randomized control trials, nine quasi-experimental-, and two single case design studies, see Table 2). All were identified as high-quality studies. After identifying this set as data, we created a code sheet to identify important characteristics of the studies (participants' grade level, reported ability label, focus of the writing intervention/genre, elements of instruction, duration of intervention, and both descriptive and standardized learning outcomes). The second author initially recorded information for each study using the code sheet. A second rater was trained on the codes. To establish interrater reliability, this second rater coded 36% (five of the fourteen studies) independently. To calculate the percentage of agreement, we determined the total number of agreements and then divided that total by the number of agreements plus disagreements (i.e., the total number of items on the code sheet) for each category. An interrater reliability of 85% was achieved. Our results are organized as findings in response to each research question.

RQ 1: What Kinds of Learners and Writing Assignments are Included in the Extant Science Writing Intervention Research?

Study characteristics. Our pool was varied and several included general education learners as well as students with disabilities (n = 4), students who are EL (n = 5), and students considered low achieving or mixed ability (n = 4); finally one (n = 1) included students with disabilities and EL. Students with disabilities included LD, emotional disturbance (ED), and attention deficit-hyperactivity disorder (ADHD). Students who were ELs were predominantly learners whose first language was Spanish or not specified. Half of the studies included students from grades 3 to 5; the other half specified grades 6 to 12, each with different ranges or contrasts. In other words, most (n = 9) studies included students from multiple grade levels. Only Choi, Notebaert, Diaz, and Hand (2010) reported the outcome for students in each grade level. In many aspects, investigators did not disaggregate the findings based on learner characteristics (e.g., disability, English language learner status, academic performance). Only 5 out of the 10 studies that included students with LD or those who are EL reported outcomes specific to these populations.

Focus and length of writing instruction. Six studies focused on teaching students to write informational texts (n = 5), or on using writing to demonstrate content learning (n = 1). These studies involved younger students (through sixth grade at the upper level). Over half of the investigators focused on argumentation or argumentation and explanation (n = 8). Some studies required an argumentation text structure (e.g., claim, evidence, reason, conclusion) but were presented in the form of a lab report. These interventions were more common with older students. Of interest, the interventions found here ranged from about one hour to one year; with such varied lengths and intensities, no conclusions can be drawn about this element.

We note the types of dependent measures used in the studies as important for reporting outcomes for our third research question. Some researchers provided learning outcomes related to students' clarity of language (Bulgren, Marquis, Deshler, Lenz, & Schumaker, 2013; Rouse, Graham, & Compton, 2017; Wright, Hodges, Zimmer, & McTigue, 2018). Several definitions and coding schemes were apparent in the studies involving argumentation. Some authors gave distinctions between a good and a bad argument based on the quality of the consistency or coherence between research questions, claims, and evidence (e.g., Bulgren et al., 2013; Sampson & Clark, 2009). Many of these researchers (n = 6) followed Toulmin's model (2003) of argumentation, which required students to extend their viewpoints to consider that of their opponents, demonstrated through additional rhetorical moves such as counter arguments, rebuttals, and countered rebuttals (Klein & Samuels, 2010).

Some researchers defined argumentation as including explanation; however, what constituted explanations differed across studies. In general, explanations include a causal mechanism, a description of how the objects are different, and how the causal mechanism influences these objects in terms of these differences (Klein & Rose, 2010; Sampson & Clark, 2009). Causal mechanisms were mentioned often (e.g., Brown, Ryoo, & Rodriguez, 2010; Klein & Rose, 2010; Sampson & Clark, 2009) and was designed to explain what underlies a given phenomenon.

The structure of informational or expository writing was also variable across studies. Benedek-Wood, Mason, Wood, Hoffman, and McGuire (2014) and Lee, Mahotiere, Salinas, Penfield, and Maerten-Rivera (2009) taught students to write an introduction, details, and conclusion. Hebert, Bohaty, Nelson, and Roehling (2018) taught simple description, compare and contrast, and sequence. These investigators privileged factual or scientific knowledge or quality of language.

RQ 2: To What Extent Do Science Writing Intervention Studies Include Instructional Elements That Have Been Found to Be Effective for Students with LD or are EL?

Students with LD. Fully 80% of the science writing intervention studies involving students with LD included a comprehensive writing program that had both cognitive (i.e., process writing, prewriting, strategy instruction, goal setting, procedural facilitators, modeling, and collaborative practice) and linguistic supports (i.e., explicit instruction on text-structure knowledge and opportunities for practice). Generally, instruction was more focused on the writing process (see Table 3). However, most instructional elements supported the writing process, especially when generating and organizing content. There were two types of support during the writing process: (a) strategy instruction and (b) the use of procedural facilitators.

Three teams of researchers used the SRSD form of strategy instruction (Benedek-Wood, Mason, Wood, Hoffman, & McGuire, 2014; Hebert et al., 2014; Mason, Snyder, Sukhram, & Kedem, 2006). Instruction focused on organizing and generating content while writing by explicitly teaching students the writing process: plan, build background knowledge, ask questions and make predictions, revise, and evaluate (Benedek-Wood et al., 2014). Hebert et al. (2018) taught a simpler routine, with four steps: (a) pick your idea, (b) organize your notes, (c) write the topic sentence, and (d) review to check for content and coherence. Students learned the general organization and structure through these parts of writing introduced by Benedek-Wood et al. (2014) and Hebert et al. (2018). In contrast, Bulgren, Marquis, Deschler, Lenz, and Schumaker (2013) used procedural facilitators to teach both the writing process and text structure. Their procedural facilitator contained guiding questions (e.g., "*what is the claim, including any qualifiers?*") that helped generate, organize, and even revise writing. Rouse, Graham, and Compton (2017) provided a simplified version of a procedural facilitator, with only two questions that helped students generate ideas (e.g., "What makes the beam balance?" "What makes it tilt right or left?")

Students who are EL. Instruction for students with EL shared some similarity with that of students with LD (i.e., modeling, collaborative writing, process writing, prewriting, explicit instruction on text-structure knowledge, and opportunities for practice), but Wright, Hodges, Zimmer, and McTigue (2018) accounted for both the cognitive and the linguistic needs of students and most (n = 5) focused exclusively on supporting the linguistic needs. In contrast, researchers focused on establishing clear connections between the form and function of science language (e.g., August, Branum-Martin, Cardenas-Hagan, & Francis, 2009; Hebert et al., 2014; Klein & Rose, 2010; Lee et al., 2009; Sampson & Clark, 2009). Both August, Branum-Martin, Cardenas-Hagan, and Francis (2009) and Lee et al. (2009) focused on teaching specific vocabulary and language (i.e., structure, rhetoric, technical language, nominalizations) that were most effective for conveying scientific knowledge.

The instructional focus was on building students' language skills by teaching text-structures (n = 2), vocabulary (n = 3), and grammar (n = 1). Investigators did this through modeling and the use of model texts; however, each served a different purpose than for students with LD. To illustrate, modeling was used to instruct students on how language constructs meaning in at global and local levels. Investigators demonstrated these through model texts. For example, Klein and Rose (2010) presented exemplar argumentative and explanation texts to highlight features of high-quality writings. These exemplar texts were provided as a way to help students understand a good model for scientific reasoning, communication, organization, and general conventions.

In contrast, Brown, Ryoo, and Rodriguez (2010) modeled the use of language parts (nouns, verbs, adjectives). To disaggregate the science content from language, they taught students the science concepts prior to delivering any writing instruction. Then, they built their instruction on science language by modeling how students could change their original language to that used in science (e.g., nominalization, technical language). So, when students learned to write, they could focus on writing, rather than the content.

Many authors included vocabulary instruction in varying degrees as part of their intervention (e.g., August et al., 2009; Brown et al., 2010; Lee et al., 2009) and took multiple approaches to deliver vocabulary instruction. For example, August et al. (2009) taught students linguistic strategies (i.e., instruction on cognate knowledge, using root words, base words, and affixes) that they can apply when learning new vocabulary words. This team also helped students use science vocabulary words (e.g., analyze, data, organism, cell) through instructing and providing opportunities to practice using those terms to explain and interpret scientific observations.

Low achieving, struggling, and mixed ability writers. Finally, instruction for struggling and mixed ability students commonly used procedural facilitators (n = 3) such as a procedural facilitator (e.g., SWH template; Hand & Keys, 1999). Their procedural facilitators had sections that are traditionally used for laboratory reports: (a) questions or hypothesis, (b) tests or procedures, (c) observations, (d) claims, (e) evidence, and (f) reflection (Akkus, Gunel, & Hand, 2007). However, different authors used it to promote scientific discourse and to deepen science knowledge and collaboration played a key role (Akkus et al., 2007; Hand, Wallace, & Yang, 2004). Students engaged in many discussions to brainstorm, critique, and revise each other's ideas. Second, investigators teaching this group of students found ways to use collaborative practice to challenge students to engage with reasoning using science knowledge, which deepened their conceptual understanding. After modeling the process of writing and providing explicit instruction on text-structure knowledge, these researchers embedded multiple opportunities for practice.

RQ 3: What Learning and Writing Outcomes and Effect Sizes are Reported in This Body of Research?

Here we report the outcomes for each measure and regarding the effects of instructional approaches for each student population (see Table 4 for descriptive results).

Writing measures. Only two teams of researchers (Benedek-Wood et al., 2014; Lee, Mahotiere, Salinas, Penfield, & Maerten-Rivera, 2009) disaggregated the results for specific populations. Others reported findings for all participants, including students with LD and those who are EL, which made it difficult to evaluate effect of the intervention for these particular groups of students. Most studies used researcher-designed science writing assessments.

Some writing intervention studies were evaluated solely based on students' ability to convey scientific information (n = 4). These measures were in a science test format with a written response section where students had to explain, argue, or write about a science topic in a clear and concise language that others can understand (e.g., Akkus et al., 2007; August et al., 2009; Hand et al., 2004; Lee et al., 2009). The only caveat of these tests was that students' understanding of scientific concepts carried equal weight than other writing qualities. Other writing measures (n = 7) were scored for domain-specific dimensions (e.g., organization, reasoning), but there were subtle differences in the scoring criteria across genres. Finally, informational texts were evaluated using a rubric that resembled that of a domain-general writing rubric, which assessed for (a) grammar, (b) spelling, and (c) organization. These rubrics assessed for the presence of topics, details, and an ending, and also the number of science ideas (Benedek-Wood et al., 2014; Rouse et al, 2017).

Writing quality of students with LD. Given the cognitive-based instruction on the structure and process of writing, students with LD wrote better argumentative writings with better organizational structure with higher quality of evidence (Benedek-

Wood et al., 2014; Bulgren et al., 2013). They included more transition words that contributed to the organizational quality of their writing (Benedek-Wood et al., 2014) and generally included claims, evidence, reasoning, and a conclusion (Bulgren et al., 2013). Also, students were able to discriminate good from bad quality of evidence, which helped them include better evidence to corroborate their own reasoning (Bulgren et al., 2013). Students in Herbert et al.'s (2014) study who received instruction of texture structures of informational writings wrote writings that had higher organizational quality, accuracy, and clarity.

Overall, students with LD who received both cognitive and linguistic-based instruction improved in organization (*PND* = 100%; Benedek-Wood et al., 2014), scientific reasoning (*d* = 1.7), and overall clarity of language (Hebert et al., 2014). In fact, Hebert and colleagues (2014) asked students to write three different types of informational texts and they saw improvement in all three including, a simple description (*d* = .66), a compare/contrast (*d* = .61), and a sequence writing (*d* = .94). All but Rouse et al. (2017) identified improvement in students' writings. Students in Rouse et al.'s (2017) study, who only received the support of a simplified procedural facilitator, did not make significant gains in their writing.

Writing quality of for students who are EL. Most students who are EL received explicit instruction on the text-structure, vocabulary, and grammar instruction. Results for students who are EL were mixed for organizational quality, clarity, and the quality of scientific reasoning. August and colleagues (2009), Sampson and Clark (2009), and Wright et al. (2018), and did not find significant gains in the quality of students' argumentative writings after instruction. Brown et al. (2010) and Lee et al. (2009)

identified that students were able to write with better organizational quality (topic, details, and ending), clarity, sentence variety, and syntax.

Overall, students with EL who received linguistic instruction on textual features made notable improvement in writing informational text (*d* > .35; Brown et al., 2010; Lee et al., 2009). Unlike others, Brown et al. (2010) who simply provided students with multiple opportunities to practice using vocabulary and grammatical structures found significant improvement in students' overall writing quality (*d* = .42). On the other hand, findings were mixed for students who received mostly linguistic-based instruction for writing argumentations (*d* < .10; August et al., 2009; Sampson & Clark, 2009; Wright et al., 2018). Improvement in writing informational texts was more consistent than other forms of analytical writings like argumentations.

Writing quality of students with mixed abilities. Students in the mixed group received a balanced approach to writing instruction that supported both their cognitive and linguistic needs. Most of their instructional focus was to build a deeper conceptual understanding while reasoning in science. Therefore, cognitive support in the writing process such as procedural facilitators like the SWH and strategy instruction was common in all four studies. After instruction, students' argumentative (Akkus et al., 2007; Kingir, Geban, & Gunel, 2013; Klein & Rose, 2010), explanation (Klein & Rose, 2010), and informational writing (Mason et al., 2006) improved areas of organization and clarity. Unlike others, Klein and Rose's (2010) found that students made little improvement in argumentative writings. They found that students in the treatment group did not outperform those in the control group. On the other hand, they identified a statistically significant improvement in students' explanation writings (Klein & Rose, 2010). In fact, they saw an increase in causal and mechanistic reasoning in students' writings after treatment. Overall, students with mixed abilities made improvement in argumentation (Akkus et al., 2007; Kingir et al., 2013). Students generally included more parts (e.g., claim, evidence, reasoning) that enhance scientific reasoning and overall writing quality.

Discussion

Students with LD and those who are learning English face some challenges that typically developing students do not experience, as well as other challenges common to all novice writers. Students with LD experience cognitive difficulties that affect planning and organizing content, while students who are EL struggle with written communication partially because they have not learned to use appropriate forms of language in science (Beck et al., 2013; Swanson & Siegel, 2001). As a result, many of these struggling learners significantly underachieve in academic subjects that require them to articulate their knowledge in written form. Unfortunately, we have a very limited understanding of how to best support these students' learning in science classrooms. Thus, the ultimate purpose of this synthesis was to identify elements of effective science writing intervention that can support the needs of all students, including children with LD and those who are EL.

The combination of elements found in science writing intervention were distinct for specific population of students. Instruction for students with LD predominantly used strategy instruction (e.g., SRSD) to teach textual structures and the writing of informational and argumentative writings, which satisfied the cognitive demands of writing. Although instruction provided mostly cognitive support, they also received some instruction on textual structure. All four studies with students with LD found statistically significant improvement on the text-structure and form, reasoning, and understanding of science knowledge, which is consistent with findings from Gillespie and Graham's (2014) meta-analysis. Contrary to the trends in current writing research, investigators did not use SRSD to instruct students other than those with LD.

The SFL-based instruction (vocabulary, grammar, textual structure) was a common approach for delivering writing intervention for students who are EL, who lack exposure to academic language (De Oliveira & Lan, 2014). Most of these investigators explicitly taught students the text-structure, vocabulary, and grammar, common in science writings. Unlike what we found for students with LD, the effects of these interventions were mixed. Some found statistically significant improvements in students' writing qualities and content knowledge, while others found little to no effect. Instruction for other students who are without LD or those who are EL received a balance of cognitive and linguistic supports, which yielded positive outcomes for all students.

Finally, students (regardless of disability or language status) who received both cognitive and linguistic-based instruction demonstrated substantial growth in writing. Students with LD and others without disability or English learning needs made significant improvements after treatment. These two populations of students have distinct learner characteristics, yet they both made gains after receiving a balanced writing instruction with both cognitive and linguistic support. On the other hand, students who are EL, who did not receive much cognitive support in the writing process, made less improvement. When teaching writing in a specific discipline, understanding the genre, including the rhetoric and the structure is essential and our students, regardless of their learning needs, benefit from instruction that provides both cognitive and linguistic supports.

Limitations

This systematic review revealed crucial information about the elements of potentially effective science writing instruction. However, before ending, we acknowledge three methodological limitations. The first is conceptual as studies with younger students focused on teaching concepts through concrete experiences like a lab report or informational writing, whereas older students are expected to engage in deeper levels of analytical thinking. Therefore, as students mature, instruction increasingly focused on analytical outcomes like explanation and argumentation. The problem is that these genres of writing are not comparable because they require different levels of thinking and reasoning and is thus a confound when interpreting the results of this review. For example, students need to write counterarguments and rebuttals, which requires them to adopt a different perspective when writing an argumentation. This is more complex than informational texts that require them to generate ideas about a science topic, which is grounded in recall rather than critical thinking. More complex task may require more intensive support and the effects of the intervention may be less pronounced.

Second, standardized assessments for determining science writing outcomes are not available. Therefore, with such variability in dependent measures, comparisons are difficult to make across studies. Informational, argumentative, and explanations utilize different structures and are scored using different criteria. For example, some researchers scored writing outcomes based on the organizational structure of a given sample, others scored them for the science content, and still others for clarity of language. Moreover, some researchers who assessed argumentation looked for the presence of claim, evidence, and conclusion while others required students to come up with rebuttal, counterarguments, countered rebuttals, and more. Such inherent differences temper the external validity of our findings.

Third, it was difficult to evaluate the effectiveness of each instructional element because the studies reviewed here combined instructional elements. Very few science writing intervention studies include students who are identified with LD or who are EL, or report learning outcomes specifically for each type of learner. With respect to students with LD, most interventions focus on simpler forms of writing, which tend to inflate findings for this subgroup. Needless to say, we need to take the complexity of the writing into account when reviewing our findings because students may have a slower rate of acquisition when learning more complex writings like argumentative or explanations. We need more studies teaching students with LD to focus on argumentation.

To conclude, learning to write in science is a complex task that can require time and practice to learn. The movement for inclusion has led to increased diversity of learners in general education science classrooms, including more students with LD and those who are EL. Although students with LD and those who are EL are have different needs, instructional approaches that combine cognitive and linguistic elements are likely to be beneficial when students are asked to write in science in ways that are important to this domain. This conjecture remains open for investigation.

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Tables

Table 1. Summary of Effective Elements of Writing Instruction for Students with LD or Are EL

Elements	Definition
Cognitive process-based supports	
Dictation (D)	Students write using a transcription tool that records their words into texts.
Process writing (PW)	Activities that are designed to engage students in the process of writing (brainstorming, planning, revising).
Prewriting (P)	Any activities that engage students to plan before they write.
Goal setting (GS)	Students define and work towards a goal that will help motivate and focus their efforts while writing.
Scaffolds using: Procedural facilitation (PF)	This involves providing external supports such as prompts, heuristics, designed to facilitate thinking during the writing process.
Collaborative writing practice (C)	This involves providing cognitive support by collaboratively writing together, which allows students to learn how to organize and think while writing through discussions.
Strategy instruction (SI)	This instruction involves systematically teaching strategies to support students during the writing process (e.g., brainstorming, planning, revising).
Comprehensive writing program (CWP)	Programs that provide both cognitive and SFL-based supports when writing. These programs provide instruction on the writing process as well as the language skills required to write sentences or essays.
SFL-based supports	
Explicit instruction on: Vocabulary (V)	Explicit vocabulary instruction includes modeling the use of vocabulary terms. Students may also learn strategies to better understand the structures of the words itself by looking at root words, prefixes, and suffixes (morphology-based instruction).
Grammar (G)	Grammar instruction focuses on putting together the language parts (nouns, verbs, adjectives, prepositions) to write sentences.
Text-structure knowledge (T)	This instruction involves explicitly teaching students knowledge about the structure and linguistic features (e.g., the use of nominalization, sentence structures) of specific texts, such as science explanations, arguments, and reports.
Modeling (M)	This involves students examining examples of specific types of writing (i.e., science report, argument, explanation, informational) to emulate the forms in these examples in their own writing.
Opportunities for practice (OP)	Language practice refers to opportunities for students to apply learned strategies/skills after or during instruction.

Table 2. Study Characteristics

	Authors	Design	Grade, *n*, academic descriptor(s)	Duration	Type of Writing
1.	Akkus et al., 2007	Quasi	7 – 11; *n* = 187 low, 195 med, 210 high	Not specified	A
2.	August et al., 2009	Quasi	6; *n* = 562 EL, 328 English proficient	10 sessions	I
3.	Benedek-Wood et al., 2014	SCD	5; *n* = 78; (10 students with disabilities)	6 sessions	A
4.	Brown et al., 2010	RCT	5; *n* = 30 EL, 19 English proficient	3-4 hrs.	I
5.	Bulgren et al., 2013	Quasi	6 – 9; *n* = 282; (22 students with LD)	Unknown	A
6.	Hand et al., 2004	Quasi	7; *n* = 93, low, med, high ability	3 months	L
7.	Hebert et al., 2018	RCT	4 & 5, T1, *n* = 32; C, *n* = 29, 70% LD	26 sessions	I
8.	Klein & Rose, 2010	Quasi	5 & 6; *n* = 34, mixed abilities	1-yr	A, E
9.	Kingir et al 2013	Quasi	9; *n* = 62 low, med, high ability	Not specified	L
10.	Lee et al., 2009	Quasi	3; *n* = 2,020 English learners	1-yr	I
11.	Mason et al., 2006	SCD	4; n = 9 (low achieving and with disabilities)	15 sessions	I
12.	Rouse et al., 2017	RCT	4; n = 69 (20% EL and 2 with disabilities)	One hour	P
13.	Sampson & Clark, 2009	Quasi	10-12, *n* = 168 (10% were EL)	4 sessions	A
14.	Wright et al., 2018	Quasi	6-11, *n* = 54, (35% were EL)	8-wks.	A

LD = learning disabilities, EL = English learners, Quasi = quasi-experimental, SCD = Single case design, A = argumentative writing, E = explanation writing, I = informational text, L = lab manual writing, P = Performance assessment (content learning)

Table 3. Elements of Science Writing Instruction

Authors	Elements of Instruction
1. Akkus et al., 2007	PF, T, C, P
2. August et al., 2009	V, C
3. Benedek-Wood et al., 2014	SI, T, GS, M, OP, C, P, PW (CWS)
4. Brown et al., 2010	V, G, OP
5. Bulgren et al., 2013	PF, T, SI, OP, M, C, P, PW (CWS)
6. Hand et al., 2004	PF, P, PW, T
7. Hebert et al., 2018	SI, T, M, OP, C, S, P, PW, GS (CWP)
8. Klein & Rose, 2010	SI, T, G, M, C, P, PW, OP (CWP)
9. Kingir et al., 2013	T, PF, C, PW, P, OP (CWP)
10. Lee et al., 2009	T, OP, V
11. Mason et al., 2006	SI, GS, PW, P, OP, C, M (CWP)
12. Rouse et al., 2017	PW, PF
13. Sampson & Clark, 2009	T, M, C
14. Wright et al., 2018	PF, T, P, PW, OP

D = dictation, PW = process writing, P = prewriting, SI = strategy instruction, GS = goal setting, PF = procedural facilitators, S = sentence starters, M = modeling, V = vocabulary instruction, G = grammar instruction, T = instruction on text-structure knowledge, OP = opportunities to practice, C = collaborative writing, CWP = comprehensive writing programs

Table 4. Writing Quality of Student Subgroups

Participant type/type of scaffolds	Description of Findings
LD	▪ Organizational quality improved (Benedek-Wood et al., 2014; Hebert et al., 2014). Students included more transitions words (*PND* = 100%; Benedek-Wood et al., 2014). ▪ Students adopted text structures that corresponded to the expectations for informational texts. They identified the most effect on sequence text structures (d = .94), followed by simple description (d = .66), and compare/contrast (d = .61; Hebert et al., 2018). ▪ Students also improved in scientific reasoning when evaluating and constructing arguments (*d* = 1.7; Bulgren et al., 2013). ▪ Students' understanding of science content knowledge improved (Benedek-Wood et al., 2014; Mason et al., 2006).
EL	▪ Improvement in organizational quality was small (d = .24; Wright et al., 2018) or insignificant (Rouse et al., 2017). ▪ Brown et al. (2010) and Lee et al. (2009) found moderate (d > .35) effects on students' organizational and overally writing quality, syntax, sentence variety, and vocabulary. ▪ August et al. (2009) and Wright et al. (2018) found that the science writing scores yielded an effect size of .16 and .10, which suggests that the intervention had minimal effects. ▪ The overall quality of argument did not differ significantly, but intervention students did show improvement on explanations (Klein & Rose, 2010). ▪ Less successful groups discussed fewer content-related ideas, were more likely to accept an idea without critical discussion when introduced, relied on less rigorous criteria to evaluate quality of idea, and did not use data until they needed to generate final argument (Sampson & Clark, 2009).
Struggling learners and mixed ability learner groups	▪ Teachers who implemented using SWH had the most improvement (Akkus et al., 2007; Hand et al., 2004). ▪ Students who learned text structure outperformed those who did not on writing science arguments (p < .00; Akkus et al., 2007; Hand et al., 2010; Kingir et al., 2013).

STUDY 2: THE EFFECTS OF A COGNITIVE APPRENTICESHIP ON WRITING IN SCIENCE ON TEACHERS' BELIEFS: PRELIMINARY FINDINGS

At the end of a cognitive apprenticeship (CA) focused on supporting students in writing scientific explanations, a participating teacher revealed her beliefs about using writing for instruction in science.

> *...[T]o write about that* [chemical change phenomena]*, and the reasoning to be like, "A chemical change has one of these five signs. Because my solution went from clear to purple, it's representing one of those signs. Therefore, this must be a chemical change," -- that's a really higher-level thinking skill, where they have to connect multiple pieces together*.

In contrast to beliefs about writing *for assessment* she expressed before she participated in this study, this teacher saw writing as valuable *for instruction*. In this paper, we explore changes in two teachers' tacit and expressed beliefs, and self-reported changes in practice, before and after implementing a CA designed to meet expectations of the Next Generation Science Standards (NGSS; National Research Council [NRC], 2013).

Science education standards promote reforming science education to instill a deep understanding of scientific knowledge and practices to cultivate the next generation of scientists, engineers, and researchers and broader scientific literacy (National Research Council [NRC], 2011). The NGSS (NRC, 2013) supports this vision for scientific proficiency based on a view of science as both a body of knowledge and as way of knowing. Writing plays a prominent role in developing such epistemological understanding of science, as it is instrumental in the professional work of scientists and in practices of science such as constructing and critiquing explanations and arguments and reasoning mechanistically (Bangert-Drowns, Hurley, & Wilkinson, 2004; Fang, 2005;

Ford, 2008; Lee, Quinn, & Valdez, 2013; NRC, 2013; Russ, Scherr, Hammer, & Mikeska, 2008). Writing is not only an effective tool for teaching content knowledge, but it is also a great tool for enhancing students' analytical thinking and scientific reasoning, in particular, using evidence to support a claim (August, Martin, Hagan, & Francis, 2009; Brown, Ryoo, & Rodriguez, 2010; Klein & Samuels, 2010).

Problem Statement

In recent years, there have been efforts to interweave science content with language skills, which has led to heightened expectations for achieving scientific literacy (Lee, Quinn, & Valdes, 2013). To be specific, students are currently expected to "read, write, view, and visually represent information as they develop their models and explanations" (Lee et al., 2013, p. 224). High-stakes standardized science tests also reflect this shift in educational focus as more states are adopting assessments that incorporate questions for constructing written explanations or arguments (National Center for Educational Statistics [NCES], 2012).

Yet, two-thirds of students in the U.S. lack even the most basic academic writing skills (NCES, 2012). What is most concerning about this statistic is that students' struggles with basic academic writing will significantly interfere with their achievement in science (NCES, 2012). There are pockets of populations, students with learning disabilities (LD) and those who are identified as English learners (EL), whose struggles in writing are magnified due to their learner characteristics and traits. In fact, only 1% of students who are EL score at or above proficiency in writing (Beck, Llosa, & Fredrick, 2013) and students with disabilities perform significantly lower ($p < 0.001$) than students without disabilities (NCES, 2012). To meet this goal for scientific literacy for diverse students, ultimately what happens in the classroom is what matters. Quality curriculum, teacher education, and professional development (PD) are thus pivotal in supporting literacy efforts, such as improving students' writing in science.

Although writing can potentially deepen students' conceptual understanding in science (McNeill & Krajcik, 2007), teachers still struggle to incorporate writing to maximize learning in their science classrooms. Ideally, science teachers can learn to infuse literacy instruction as part of their core teaching practices through pre-service teacher education and PD (Lee et al., 2013). However, altering teachers' instructional practices is multifaceted, complex, and often proven to be challenging (Buczynski & Hansen, 2010). Several authors have documented the importance of teachers' choice of tasks as central to instructional practice in science and mathematics education (Biza, Nardi, & Zachariades, 2007; Midgley, Feldlaufer, & Eccles, 1989; Zaslavsky, 2007). It is useful to know how teachers change their beliefs and choice of tasks in response to PD.

This paper arose out of a larger project (Levin, Lee, & De La Paz, 2017) in which two middle school teachers, working as a team, received PD on crafting and creating writing tasks to promote students' construction and critique of scientific explanations. They also collaborated with researchers to implement cognitive apprenticeship focused on scaffolding students' written explanations. As part of this project, we interviewed teachers initially, as an evaluation, to gauge the progress of the project and their perceptions of it. Teachers revealed tacit beliefs about writing and reported their practices of supporting student writing, and we became interested in understanding how participating in various stages of the project influenced their beliefs and the nature of tasks they created. There is a large body of literature on teachers' beliefs and how they influence and are influenced by practices or via PD (Desimone, 2009; Fives & Gill, 2015; Guskey, 1986; 1989). Yet, little literature exists regarding how these beliefs are influenced by implementation of a curriculum focused on writing in science, to date (c.f., Zambak, Alston, Marshall, & Tyminski, 2017).

We interviewed the teachers over the two years of initial PD and implementation of the CA. We also administered a test to evaluate teachers' ability to construct and critique scientific explanations in the first year. Finally, we documented their choice of tasks (well documented as a central aspect of teaching practice; Anderson, 2003) before and after implementing the CA, all in the context of understanding their evolving beliefs and choice of tasks as they participated in the two phases of the project. Through the case studies of the two teachers, the following research question guided our qualitative study:

RQ 1: In what ways, if any, does implementation of a CA focus on writing in science lead to changes in teachers' beliefs?

In the sections that follow, we discuss the literature on writing in science instruction and PD to support teachers' practice, our theoretical framework, and the data drawn from the case studies of the two teachers. From our findings we propose a hypothesis about the role of CA on teachers' beliefs and practices that may be tested and refined through larger-N studies as Blazar and Pollard (2018) did when studying teachers' mathematics instruction.

Writing in Science Instruction

Writings in scientific fields writings have common linguistic and organizational features that are different from other domain-general writing (Fang, 2005; Halliday, 1989). For example, writing in science is often lexically dense (Fang, 2005). Beyond these features, however, language in science has important functions such as communicating information and constructing and critiquing explanations and engaging in argumentation, and the practices of the NGSS (NRC, 2013) overlap considerably with the Common Core State Standards (CCSS) for literacy (Lee et al., 2013).

Evidence-Based Writing Strategies in Science Education

Many evidence-based writing instructional interventions exist for students with or without learning needs and many of these approaches are used by English teachers and special educators (Graham & Perin, 2007). While there is some research in evidence-based writing approaches in science (Sampson, Enderle, Grooms, & Witte, 2013; Sandoval & Willwood, 2005), it has not made its way into classroom practices.

In the '80's, writing in science typically involved expository short-answer recall questions, copying from the board, and fill-in-the-blank activities (Applebee & Langer, 2011). These writing tasks do not require students to plan, organize, and formulate longer or more complex responses. Ultimately, Applebee and Langer (2011) found that teachers did very little to teach students how to write in science classrooms. The problems incorporating writing in science have persisted, despite greater attention to writing-across-the-curriculum (Applebee, 2011). Drew, Olinghouse, Faggella-Luby, and Welsh (2017) surveyed middle and high school teachers who teach specific content (e.g., science, biology, physics, math) and only a third reported assigning written tasks in class. Of those teachers who reported assigning written tasks, a majority reported using "restricted" tasks with low cognitive demand such as step-by-step lab procedures (Kiuhara, Graham, & Hawken, 2009), note-taking, fill-in-the-blank worksheets, lists, and short- answer expository questions (Drew et al., 2017). Some of these tasks may support students conceptual understanding, but most generally do not promote analytical thinking and reasoning highlighted by NGSS (NRC, 2013). In summary, teachers of specific content utilize writing minimally and if they do use it, they use it for assessment purposes rather than for thinking and learning (Drew, Olinghouse, Faggella-Luby, & Welsh, 2017; Kiuhara et al., 2009).

Teachers' reluctance to integrate literacy instruction in science partially comes from a lack of understanding of evidence-based writing instruction in content-area classrooms. Most evidence-based writing approaches are domain-general, such as narratives, opinion essays, and persuasive writing tasks not specific to science (Graham & Perin, 2007). We cannot attribute a lack of productive writing instruction in science and math classrooms solely to teachers' unwillingness to do so, because there is little communication from research to practice about evidence-based science and mathematics writing approaches (Sampson, Enderle, Grooms, & Witte, 2013; Sandoval & Willwood, 2005). The research community needs to do a better job of bringing evidence-based approaches to writing instruction to practicing teachers.

PD in Science Writing

Considering teachers' general lack of preparation and confidence in this area it is imperative to provide PD, tasks, and curriculum to support teachers in incorporating writing into science classrooms in ways that align with expectations of NGSS (NRC, 2013). Science teacher education and PD have not played an adequate role in preparing science teachers to incorporate writing. We offered a 2-year PD and followed the teachers for another year to investigate teacher changes. Traditional teacher education programs do not provide adequate training on writing instruction for teacher candidates in content areas other than English (Applebee & Langer, 2011; Drew et al., 2017), and there is a lack of guidance for science teachers to incorporate writing activities that support students' participation in scientific practices as described by NGSS (NRC, 2013). Consequently, science teachers may feel underprepared and reluctant to provide literacy-integrated lessons in class (Gillespie & Graham, 2014; Kiuhara et al., 2009).

We describe our PD focused on science writing, culminating in the implementation of a CA focused on constructing and critique explanations for scientific phenomena in writing. We examine how it impacted the teachers' beliefs and choice of written tasks during science instruction to generate a hypothesis that may be tested with larger-N studies.

Theoretical Framework

There are a variety of theoretical frameworks that relate teachers' practices and beliefs (e.g., Fang, 1996; Nespor, 1987). For understanding the role of the CA (in which teachers were implementing a specific curriculum) on teachers' beliefs, we chose Guskey's model (1986, 1989) (Figure 1), because it conceptualizes how implementation

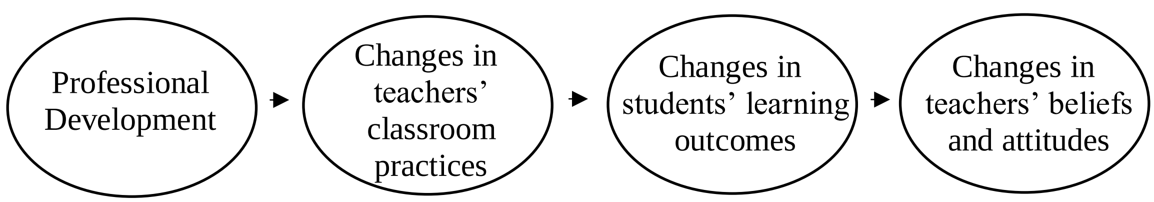

Figure 1. Guskey's (1986; 1989) model for teacher change

of teaching practices can lead to changes in teachers' beliefs, mediated by changes in students' learning outcomes, in our case, the work students produced as a result of a CA-based writing instruction.

To understand the ways in which implementation of CA influence teachers' beliefs and practices, we need to better understand what we might expect. A large literature base now supports a view of teachers as active decision-makers who hold "complex systems of beliefs that influence how they view students, themselves, and science" (Bryan, 2012, p. 427). A wide variety of teachers' beliefs have been described in the literature. Researchers have defined teacher beliefs broadly in six topics: "(a) self, (b) context or environment, (c) content or knowledge, (d) specific teaching practices, (e) teaching approach, and (f) students" (Fives & Buehl, 2012, p. 472). Specific descriptions of teacher beliefs also include teacher self-efficacy (Pajares, 1996), the belief in one's ability to plan and manage a given situation or a task (Bandura, 1997), and teachers' epistemological beliefs about learning and teaching science (Levin, Chumbley, Jardine, Grosser-Clarkson, & Elby, 2018).

To guide our inquiry, we extrapolated information about teachers' beliefs that were *professed* during interviews (Levin et al., 2018). We also learned about teachers' beliefs through making inferences from the way they talked about their practice and the tasks they chose or designed, which were more *tacit.* We believe that these professed and tacit beliefs provide a window into their beliefs (Anderson, 2003). In this inquiry, we primarily explored teachers' expressed beliefs and choice of tasks through interviews. For our purposes, we broadly explored teachers' beliefs as they evolved throughout the study. We did not focus our attention on any particular beliefs, although we hypothesized that we would at least learn something about teachers' beliefs about writing in science, based on the nature of the project.

Methods

Qualitative Case Study Approach

We took a qualitative case-study approach (Baxter & Jack, 2008; Merriam, 1998; Yin, 2003) to understand teachers' beliefs and changes in the design of writing tasks. An exploratory, qualitative case study approach is appropriate for beginning to chart the terrain of changes in teachers' beliefs and choice of tasks and generate new hypothesis for systematic testing in future studies. Our case study approach allows us to draw on a variety of data sources to find patterns both within and across cases that "allows for multiple facets of the phenomenon to be revealed and understood" (Baxter & Jack, 2008, p. 544). While our approach only focuses on two teachers, the longitudinal nature of our study allows us to develop a fuller picture of teachers' beliefs and choice of tasks and the ways in which these may change over time. Similar small-N longitudinal case studies have been useful for generating hypothesis. For example, Danielak, Gupta, and Elby (2014) studied a single undergraduate engineering students' epistemological beliefs and identity drawing primarily on classroom observations and longitudinal interviewing. Through this approach, they proposed a hypothesis about retention of high-achieving students in engineering.

Participants

The participants (Maggie and Kim) in this study both had been undergraduate science majors who subsequently graduated from a Master's program in Science Education at a large public four-year university in the mid-Atlantic region of the United States. Each taught seventh grade science at a middle school in a school district near the university. Maggie and Kim were both white females and the only two full time seventh-grade science teachers at the cooperating school. Of note, they were close colleagues as prior to our PD and CA they collaborated by co-planning their science lessons together, even keeping a calendar to maintain the same pace through the curriculum.

As part of their graduate program, Maggie and Kim had taken a series of science methods course taught by the second author. Although these courses aligned with the expectations of NGSS (NRC, 2013), like most science methods course, they did not go into great depth on disciplinary writing and literacy. Maggie and Kim were both successful well-regarded graduates of the program. Although Maggie and Kim were similar with respect to their educational background, gender, age and ethnicity, and were following the same schedule with similar students, we treated them as separate case studies to detect any potential differences that might be insightful.

In the cooperating school, 52.7% of the overall student population participated in the National School Lunch Program, with 47.5% eligible for free lunch and 5.2% eligible for reduced lunch prices. Nine percent of students at the school were considered as having limited English proficiency, and 13% had identified LD. Maggie and Kim's classes resembled the population of the school.

PD and Curricular Context

To understand the context for exploring the teachers' beliefs and choice of tasks, we need to provide some details of the PD and the CA. The larger study took place over two years. In the first year, we began by trying to understand what writing the teachers incorporated into their classrooms. As it appeared, they primarily used writing for assessment and only for instruction in a limited way, we made efforts to help them learn to incorporate writing during instruction, and in the service of scientific practices.

Focusing on content that the teachers needed to cover in their classes, we helped them to develop ideas for instructional lessons that incorporated writing with a focus on explanation and argumentation. Ultimately, we asked the teachers to construct their own lessons, which we then discussed. These lessons serve as one of our data sources in understanding teachers' prior beliefs and actions.

In the summer between years 1 and 2, teachers participated in two days of PD, and then we met for 60-90 min once every two weeks after school, during the academic year. The initial summer meeting was used to review the benefits in using a CA model of instruction and the research design, and to collaboratively plan an initial set of writing prompts.

In the second year, we implemented the CA, the results of which are described briefly in our findings to contextualize our findings on beliefs and choice of tasks. The CA was designed to guide students through a process of constructing and critiquing explanations, it included a framework and a set of critical questions for teachers to scaffold critiquing explanations for students to use to practice critique. Students took a pre-test and post-test on constructing explanations (Levin et al., 2017) and the Fourth-Edition of the Test of Written Language (TOWL-4; Hamill & Larsen, 2009) and then participated in six mini-lessons in which they constructed and critiqued explanations for natural phenomena that fit within the teachers' curriculum.

Co-designing with the teachers, we developed a set of prompts that asked students to construct and critique explanations for scientific phenomena. For example, one question was *"Why are some lakes made of freshwater and others are made of salt water."* The six lessons followed a CA approach of having teachers first model how to think through constructing an explanation and critique it using questions, then allowing students to construct and critique explanations using the scaffold, and finally to fading out the use of the scaffold. We met during the year to collaboratively assess students' ability to generate additional writing probes and to problem solve issues (e.g., the teachers' preference to adapt a district-wide rubric for the study's purpose and behavioral management issues in one of the classes). In the following paragraph, we briefly summarize the results of effect of the CA on student learning, as they are important for understanding changes in teachers' beliefs and practices.

In the larger study, we evaluated the effects of CA through administering a pre- and posttest on constructing explanations (Hogan & Maglienti, 2001), which we scored using a rubric based on Russ et al.'s (2008) dimensions of constructing mechanistic explanations. Students made substantial gains in making conclusions from given evidence (d = .51), but smaller improvement in "critiquing conclusions" (d = .17). It was difficult for us to make any causal claims about the CA, however, because our single-case design (SCD) study showed little consistent change over time and was particularly flat for students with low-literacy achievement. We speculated that several factors contributed to the inconclusive results of the CA. First fidelity of implementation measures showed that teachers were not following the CA completely, particularly in creating few opportunities for students to discuss explanations and collaboratively critique them. Second, teachers chose to modify our scaffold to match a rubric used by their school, which we argue, diluted the influence of the scaffold.

Data Sources

We drew on several data sources to understand teachers changes in beliefs and choice of tasks over a three-year period. At the beginning of the project, we gave the teachers the same pre-test that we planned to give the students in the CA, to gauge their own epistemological beliefs and practices and abilities to construct and critique explanations. We conducted semi-structured interviews (Glesne & Peshkin, 1991). In the first-year interview, we were primarily collecting data to evaluate the project and were not particularly focused on the teachers' beliefs, so we did not ask specific questions about their beliefs. We asked extensive follow-up questions, in order to avoid asking them directly to comment on the project. What emerged from this interview is that teachers revealed tacit beliefs or expressed beliefs about writing and reported on their practices of supporting student writing, and we became interested in understanding how participating in various stages of the project influenced their beliefs and ultimately changes in the nature of the tasks they created.

Since we learned that we could code for their beliefs from this interview protocol, we used a similar approach in the second- and third-year interviews, so as to not influence their responses. We conducted member checking after the third-year interviews where we directly asked them if we appropriately characterized their beliefs. We interviewed the teachers three times: at the end of the first year, before the CA, after the CA, and one year later, to see if changes we detected between years one and two had persisted (see Appendix A for interview protocol). We audio-recorded and transcribed each interview verbatim (Creswell, 2005). Collecting this data over a period of three years allowed us to analyze how teachers' expressed beliefs and choice of tasks changed as a result of learning about and implementing CA in their classrooms. We collected lessons that they had independently written in the first year and again in the third year, after the CA.

Data Analysis

We scored the teachers' pre-test responses according to a rubric we developed for the larger project (Levin et al., 2017). To analyze their choice of tasks, we analyzed the tasks they produced in the third and first years, focusing on ways in which the tasks could facilitate students' construction and critique. To explore their tacit and expressed beliefs, we analyzed the three years of interviews and considered their choice of tasks.

We analyzed the interview transcripts using HyperResearch software 4.0, a qualitative software for data storage, coding, and theme development. We coded the data using a combined deductive and inductive approach (Maxwell, 2013). We began with deductive codes derived from the literature on beliefs (Bryan, 2012; Fives & Gill, 2015), such as beliefs about writing, which we anticipated. From the data inductively identified codes that were more specific about their beliefs about writing such as, the importance of writing, beliefs about effective instruction, beliefs about the effectiveness of their own instructional approaches, expressed approaches to accommodate students' needs, and their students (e.g., beliefs about students' written abilities, beliefs about students' learning difficulties) during the first year.

The first author approached the data analysis by (1) preliminary exploration of the data by reading the transcripts and writing analytical memos (Saldana, 2015); (2) coding the data, developing inductive codes and segmenting and labeling the text; (3) using codes to develop themes by aggregating similar codes together; and (4) constructing a case study narrative using representative examples. Trustworthiness of the findings was secured by using rich and thick descriptions of the cases, member checking in the third-year interviews, and by reviewing and resolving disconfirming evidence (Creswell & Creswell, 2017; Creswell & Miller, 2000; Stake, 1995).

Results

Comparing teachers' scores on the pre-test with students, their teachers, and science education researchers in an earlier study (De La Paz & Levin, 2018), we found that the participating teachers' responses were more like the science education researchers' than other middle school teachers who had more limited science content background and science teaching preparation. This high performance on the pre-test reflects sophisticated epistemological beliefs about science that are similar to those of scientists (Hogan & Maglienti, 2001). As a result, from the beginning of the project we assumed that the teachers were themselves able to construct and critique explanations that revealed they already held sophisticated epistemological beliefs about science. In the remaining sections of our findings we describe changes in teachers' tacit and expressed beliefs, about students and about writing in science, the changes in practice in the writing tasks they chose and described before and after the CA implementation, and what those changes suggest about teachers' beliefs.

Changes in Beliefs About Students

Our analysis of the first-year interviews, before teachers implemented CA, suggested that both teachers expressed deficit beliefs about students. Maggie, for example, believed her students were "*not really good at evaluating each other on anything,* and recounted her struggles with getting them to write well:

> *It was like a struggle to get them to really elaborate*.

Both teachers' descriptions of their choice of tasks and instructional practices reflected beliefs that their students had such deficits that the teachers could only take "baby steps" in using evidence to make a written explanation or claim about a phenomenon:

> *...So instead of just giving them a prompt with a question and then, asking them to write out their full answer in a paragraph, we would give them um- little questions that led up to a big one. So, it would be like, um- based on this one thing, what's a claim you could make? Okay, now we have this new piece of evidence, what's a new claim you could make? So that we did it in baby steps instead of being like, 'here are twelve pieces of evidence. Use all of those to make a claim.*

Kim also didn't believe her students could construct explanations, focusing on giving them some definitive "rules" for making a claim:

> *...they do a lot better when they have something very concrete like, like, if it has A, B, and C, it's a good claim.*

Teachers had particularly strong deficit beliefs about their students who are English learners. She categorized them with students who she considered "lower level students":

> *...so, some of them knew words right off the bat, you know, that we use every day and we don't even think about it. But then, there are a lot of my ESOL students or my lower level students that just don't use those words or have never heard them before.*

Ultimately, both teachers expressed beliefs that fit with a deficit model of their students, particularly when it came to independently constructing explanations. It appeared that they created small scaffolds, but never faded those scaffolds, which implies a tacit belief that their students could not make progress.

Coding the interviews after the CA implementation we found the teachers developed more positive beliefs about students. Maggie, for example, continued to acknowledge her students' struggles, but she also noted improvements, such as their ability to reason using data:

> *They're good at being like, "Oh the temperature changes by eight degrees, so it must be chemical change."*

Kim even referred to her earlier deficit beliefs when she described what she saw during the CA implementation and discussed how she saw her students' assets:

> *I think that last year I overcompensated for some of my students when I thought that they needed help, but now I've kind of stepped back and seen what they can do, and they were really good this year.*

CA allowed Kim an opportunity to observe what her students can do because it is an instructional model that prompts teachers to gradually release responsibilities for learning. Because teachers move from modeling to collaborative practice, and finally to independent practice (where they do not provide instruction), students apply learned skills and strategies independently. In turn, Kim was able to see what her students could do and she developed more asset-based beliefs about her students. She reported that her students who are English learners (ELs), who she described as struggling learners in the previous year, made huge improvements in science writing.

> *A lot of English learners this year grew a lot. Their writing improved a significant amount.*

The shift to asset beliefs persisted a year after the completion of the CA implementation. While continuing to acknowledge areas of improvement, Kim noted improvements more generally in her students' writing.

> *Now, their writing is pretty good. I mean, there's still students that are struggling, and so we're still practicing, and those students still have a little ways to go, but by now the average student is pretty good with what I want with their seventh grade standards.*

Maggie also described growth in her students' abilities to construct written explanations. Here, she describes an example of how her students construct explanations:

> *I feel like once they get it* (writing out their claims evidence and reasoning), *they're really good at doing all the [arguments]*.

These and other examples of asset beliefs that persisted suggest a contrast from the first year, where they rarely highlighted students' strengths.

Changes in Beliefs About the Functions of Science Writing

The interviews before the CA suggest that Kim and Maggie believed that writing in classrooms was primarily for communication and assessment. Kim, in particular, expressed beliefs regarding the function of writing in teaching as getting students to write the correct answer so they could be assessed by her and on high-stakes tests. In describing the kinds of writing tasks, she used, Kim expressed a preference for close-ended "correct answer" questions that covered factual content covered on her assessments and on high-stakes tests. She also reported that she included more "*structured*" forms of writing like laboratory reports. We inferred from her description of the tasks she chose that she did not believe writing served as a tool for instruction, but rather a tool for communication (i.e., structured laboratory reports) and for simple assessment that was easy to grade (i.e., close-ended questions).

Similar to her colleague, Maggie believed that writing in science class was primarily for communication and assessment and she tied it to a school-wide approach to writing that was explicitly intended to prepare students for high-stakes tests.

...we taught biology where they make them write a lot. So, they're expected to write longer lab reports to prepare them for AP and IB classes.

Thus, even though Maggie did report using writing in instruction, its use in instruction was primarily for practice for Advanced Placement and International Baccalaureate classes and assessments in high school, which ultimately are the lab reports whose function is to communicate information in a prescribed format.

After implementing the CA, both teachers' beliefs about the role of writing expanded, from a tool for communication and assessment to include beliefs about the function of writing for instruction, to improve reasoning and metacognition. Kim believed that critiquing each other's writing helped students develop metacognitive skills that enhance their ability to critique their own ideas:

> *But when they look at someone else's to evaluate they're- 'oh well, obviously, that's wrong. Obviously, you should have done this' and I'm- 'guy's that's what I think when I look at your paper. They, they- I think that has just helped them grow in that reflective, metacognitive way of looking at their writing…*

Maggie's beliefs about writing also expanded over time, as revealed in the tasks she chose. She described the value in having students writing explanations, noting in particular that explanation and argumentation goes *"hand in hand"* with writing.

...it would make sense to me if you learn how to write [explanations] *then you learn how to critique.*

Importantly, both teachers did not abandon their beliefs about the importance of writing for assessment and communication, but the nature of what they began to notice and assess (in the ongoing, everyday sense of the word) changed. A quote from Kim describes what the teachers came to believe was worth assessing:

A lot of them when they were going through their writing, you got to see more of that cause and effect in their thinking, which was great to see.

A year after delivering the CA, teachers retained these beliefs about writing instruction and believed writing played a key role in helping students engage in explanation and argumentative reasoning. In many cases we inferred teachers tacit, or unexpressed, beliefs through their descriptions of their own instructional practices. The teachers adopted a claims-evidence-reasoning (CER; McNeil & Karjcik, 2012) approach to supporting written explanations and engaging in explanation and argumentation and both teachers reported investing time in teaching students to write explanations and arguments in class.

More generally, the teachers came to believe that writing was a valuable tool for reasoning, as Maggie described in the quote that opened this paper.

...[T]o write about [chemical change phenomena], *and the reasoning to be like, "A chemical change has one of these five signs. Because my solution went from clear to purple, it's representing one of those signs. Therefore, this must be a chemical change," that's a really higher-level thinking skill, where they have to connect multiple pieces together*.

Thus, after the CA implementation, both teachers demonstrated an expansion in beliefs about the functions of writing, from communication and assessment, to explanation argumentation and reasoning in general. This change was also evidence in their choice of tasks and reported instructional practices preceding and after the CA implementation.

Changes in Choice of Writing Tasks

Before teachers implemented CA, their choice of writing tasks was not very systematic. When asked about their instructional approaches, they did not ascribe to using any specific instructional approach nor did they mention reserving any time for writing instruction. In that first year, as we describe in our methods section, we made efforts to help the teachers learn to incorporate writing during instruction. We helped them to develop ideas for instructional lessons that incorporated writing with a focus on constructing and critiquing explanations and arguments and then asked them to construct their own lessons. In one of the lessons, the task they designed corresponded to their beliefs (see Figure 2). In this task, students were asked to formulate and choose the best explanation or “claim” made about a science phenomenon (i.e., population change). Although they did make efforts to encourage students to construct and critique each other’s proposed explanations (in this case, their claims), the teachers had the whole class brainstorm together the “everything you remember” about the relationship between population and pollution. As shown below, the “claim” that they had students make really led logically to only one correct answer. Thus, although the teachers wanted students to critique each other’s claims, there was little diversity in the claims and very little opportunity for students to disagree and argue.

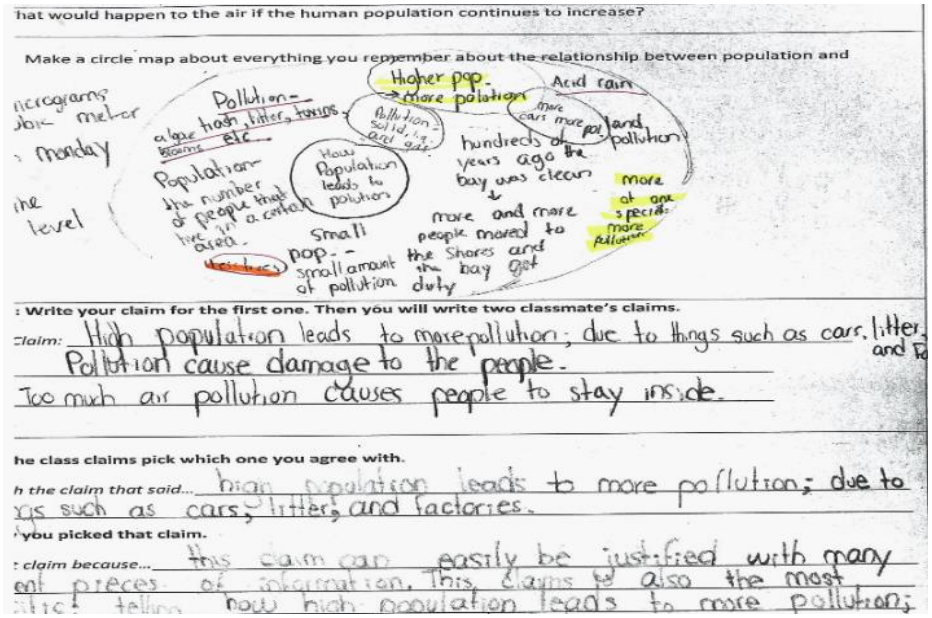

Figure 2. Population change task, developed during year 1

By contrast, after the CA implementation, the teachers independently continued using the claims, evidence and reasoning approach and integrated it into their usual practice. Now they focused more on creating tasks that allowed students to construct diverse explanations and critique them. For example, they had students conduct an investigation where light was shown through different filters to shine on different color objects. Rather than have the students construct a traditional lab report, as they described in earlier interviews, they made the conclusion to their existing labs a "scientific explanation" that students had to construct using a claims-evidence-reasoning framework (Figure 3). Since the students had collected their own data, there were a variety of findings which led to a variety of responses. This created opportunities for students to construct, critique, and argue about explanations, practices which were not as well-supported by their choice of tasks before the CA.

Conclusion:

What can you conclude about your investigation? Write a scientific explanation describing the relationship between light and the color of an object.

Claim: ____

____

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Evidence: ____

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Reasoning: ____

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Figure 3. Teacher-designed worksheet from Year 3 (2018)

Anderson (2003) showed how teachers' choice of tasks reflect teachers' beliefs. We also found that changes in teachers' beliefs aligned with changes in their instructional practices. As the teachers' beliefs about the functions of writing changed from communication and assessment to promoting reasoning, and from deficit to asset models of students, the teachers invested more instructional time creating opportunities for students to construct, critique, and argue about explanations. Even a year after the PD concluded, teachers maintained this practice and embedded it throughout their instruction, regardless of how demanding the pacing of the curriculum was.

Discussion

In this study, we explored two teachers' beliefs and changes in the tasks they chose before and after they implemented a CA focused on writing scientific explanations for phenomena. Our findings suggest that before participating in our PD and implementing the CA, Maggie and Kim expressed deficit beliefs about students and expressed beliefs about writing as appropriate in science classes primarily for communication and assessment. After the CA implementation, we found that they began to see beyond their students' deficits, focused more on what students *could* do, and gave them more challenging tasks. Applying Guskey's model (1986; 1989) to the CA implementation, we developed a hypothetical conceptual framework:

Based on our findings, we hypothesize that the implementation of the CA contributed to changes in the teachers' beliefs and influenced the tasks they chose. The fundamental question is *how* simply implementing a designed curriculum with a CA approach to constructing and critiquing explanations could impact teachers' beliefs and practices. After all, the CA intervention itself was not conclusively effective in improving students writing (Levin, Lee, & De La Paz, 2017).

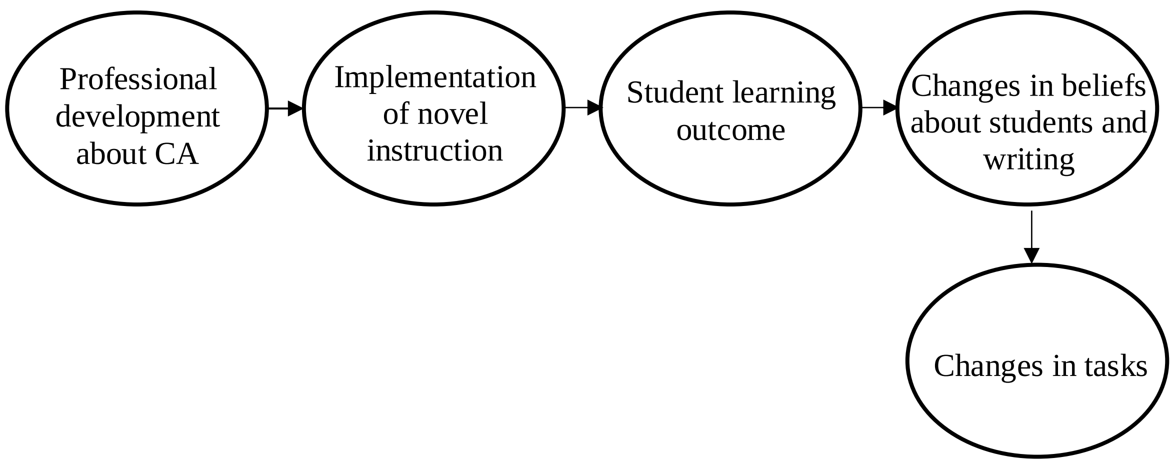

Figure 7. Adapted Guskey's model (1986; 1989)

We suggest that as the teachers worked with us to design prompts and saw the results of the CA by collaboratively examining students writing with us, and providing feedback to students, they noticed aspects of their students' work that suggested (a) that writing could be productively used for reasoning and (b) that their students could construct and critique explanations. In other words, we suggest that by attending to the substance of the students' written work the teachers were *more sensitive* to their students' success qualitatively than our quantitative measures could pick up. A large body of work shows that teachers' beliefs, are influenced by, and influence, what they attend to in students' thinking (Robertson, Scherr, & Hammer, 2016).

Implications for Research and for Teacher Education

Recognizing the role of teacher education and PD on teachers' quality of instruction, we conducted this qualitative study with hopes of providing insights into the mechanisms of changes in teachers' beliefs. Making long-term changes in teachers' instructional practices can be difficult to initiate and harder to maintain. We also know from previous literature that teacher beliefs influence practice (Fang, 1986; Fives & Gill, 2015; Guskey, 1986; 1989). It is therefore possible that participating in the implementation of a CA (or even other designed interventions) can impact teachers' beliefs, which may ultimately influence their practices.

Unlike quantitative research, in qualitative case study research we do not seek external validity and attempt to make generalizations (Creswell & Creswell, 2017). Instead, we commonly raise hypotheses that we propose merit greater research. We are currently following other teachers who are implementing a similar intervention, and we hope to test and refine this hypothesis. It may hold up over many cases that a CA focused on written explanation and argument influences teachers' beliefs in general, or we may find that it influences different teachers in different ways, or that it doesn't influence some teachers' beliefs at all. We may learn that well-developed epistemological beliefs about science, which the pre-test task showed that Maggie and Kim held, is necessary for teachers to benefit from the experience of implementing the CA.

For teacher education, our results suggest that, in accordance with our adaptation of Guskey's model (1986; 1989), engaging in new and innovative practices can impact teachers' beliefs, which can impact future practices. We do not propose however, that teacher education programs or teacher PD primarily focus on having teachers implement prescribed curricula. Rather, we see how the gradual release of responsibility model of CA allowed teachers many opportunities to focus on the substance of the students' work, as we discussed it during the implementation. This has implications for teacher education and PD. It suggests that we should facilitate opportunities for teachers to review and analyze students' work, ideally in collaboration with others.

Limitations

Although this study revealed an interesting dimension of teacher change, it comes with limitations. First, our primary data source came from teacher interviews. Teacher interviews can only assess teachers' expressed and tacit beliefs, which may not be unitary, and may be influenced by the interview or the context of the questions (Levin et al., 2018).

On a different note, we acknowledge some constraints that came from using Guskey's (1986, 1989) model as a lens to explore our research questions. Although his model is well-supported through research, it provides a slightly over-simplified explanation for teacher change. External factors might have also contributed to changes in teachers' expressed beliefs.

As we alluded to it earlier, teachers' experiences and knowledge may affect our findings. In addition to having sophisticated epistemological beliefs about science, Maggie and Kim were in their fourth year of teaching by the end of the study and were no longer preoccupied by their need to learn entry level skills such as classroom management. They were well-respected in the school and they had begun to collaboratively focus on clarifying learning goals. As a result, they may have developed better understanding better of students' learning needs, and consequently, became better at facilitating student learning.

The school district also may have exerted an influence. From the beginning of the project, the school district encouraged teachers to use the CER framework. This may have contributed to the more ambitious and challenging tasks that we saw in the third year, as the teachers better understood how to use the framework in science. We assert, however, that the *way* in which the teachers used the CER showed increased attention to the value of students constructing diverse explanations and not simply reiterating a correct claim. This suggests that beyond just implementing the CER approach for explanation construction, teachers embraced it, in part, because they saw how it could support students in scientific practices of critique.

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Appendix A:[1]
Interview Protocol

1. Tell me how your teaching has developed since you first met Dan and Susan last fall?

2. Has your approach to including writing in science changed over the course of this year?

3. How has your teaching changed this year as a result of this professional development?

4. What kinds of changes have you noticed in students' writing over the course of this year?

5. Which do you think is more important for students to learn – how to construct explanation or how to critique explanations? Why?

6. How did you scaffold students' abilities to construct explanations?

7. How did you scaffold students' abilities to critique explanations?

8. Do you have any suggestions for Susan and Dan? What kinds of supports would you like for teaching writing in science?

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[1] This is the protocol from year 1 and year 2. In the final year, we asked more generally about their writing instruction in class, without specific reference to critiquing written explanations.

STUDY 3: TEACHING STUDENTS WITH LD AND THOSE WHO ARE EL TO COMPOSE SCIENTIFIC EXPLANATIONS

Students in the 21st century need adequate written proficiency to succeed in schools. This ability becomes increasingly important for secondary students' learning because writing becomes a tool for acquiring knowledge (Brown, Ryoo, & Rodriguez, 2010; Graham & Perin, 2007; Rijlaarsdam, Couzijin, Janssen, Braksma, & Kieft, 2006). This places large demands on students as writing is a complex task that requires both cognitive, meta-cognitive abilities, and linguistic skills and knowledge (Fang, 2005; Schleppegrell, 1998; Troia, 2006). Students who struggle with foundational writing skills are consequently at risk for success in school (Brown et al., 2010; Rijlaarsdam et al., 2006).

Writing to learn in science has received greater attention in the last 10 years (Bangert-Drowns, Hurley, & Wilkinson, 2004; Rouse, Graham, & Compton, 2017) and is timely, given reforms to science instruction (National Research Council [NRC], 2012) and writing (Common Core State Standards, 2010). The Next Generation Science Standards (NGSS—National Rsearch Council [NRC], 2013) and underlying Framework for K-12 Science Education (NRC, 2012) describe a vision of proficiency in science based on a view of science as both a body of knowledge and as way of knowing. Learning science, in this view, involves developing more sophisticated understandings of (a) disciplinary core ideas (DCIs) and (b) cross-cutting concepts (CCCs) of science deeply integrated with (c) deep engagement in scientific and engineering practices (SEPs) —three dimensions.

DCIs are the conceptual knowledge that is commonly thought of as science content: the major conceptual ideas in physical sciences; life sciences; earth and space sciences; and engineering, technology, and applications of science. CCCs are ideas that bridge disciplinary boundaries, uniting disciplinary core ideas throughout science and engineering. These include, for example, "Cause and Effect: Mechanism and Explanation" which highlights the primary activity of science as explaining causal relationships and the mechanisms by which they are mediated. SEPs are aspects of scientific inquiry—the activities in which professional scientists and engineers engage when they apply their existing knowledge to exploring new questions and solving problems. These practices include, among others, "Constructing Explanations" and "Engaging in Argumentation from Evidence."

Students as young as in Grades 3-5 are expected to explain observed relationships using data and evidence and to support an argument with data. Middle school expectations include standards such as MS-LS1-4, From Molecules to Organisms: Structures and Processes: "Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants respectively." And, the NGSS include the practice of obtaining, evaluating, and communicating information, which describes that students at all grade levels should be able to communicate scientific and technical information in written form.

Teaching Science Explanations

Explanation writing is one type of writing that promotes deeper understanding of the science content, together with arguments, lab reports, and informational texts (Lee, Quinn, & Valdes, 2013; NRC, 2013). Previous research suggests that explanations are more difficult to write than other writings like a lab report or an informational text because it involves a higher level of analytical thinking (Fang, 2005). For this reason, this genre of writing, along with argumentations, is a part of both the literacy and science learning standards (Common Core State Standards [CCSS], 2010; Lee et al., 2013; NRC, 2013). Students struggle to produce high-quality science explanations because of the cognitive and language demands required to produce this type of analytical writing. However, this is a relatively new field of writing research that has recently received more attention with a growing demand for scientific literacy, so there are only a few studies on it, to date.

According to Russ, Scherr, Hammer, and Mikeska (2008), a high-quality science explanation is one that is causal and mechanistic. Causal explanations clearly define cause-and-effect relationships that are observed in scientific phenomenon. A high-quality science explanation would include specifications of the causal relationship such as mechanistic details that elaborate on the underlying process. Russ and colleagues (2008) asserted that a good mechanistic explanation would include details such as: (a) properties of entities, (b) organizations of entities and activities, (c) comparisons and generalizations, and (d) examples. The main goal of our intervention was grounded on Russ et al.'s (2008) constructs for high-quality science explanations.

In our study, we focused on teaching scientific explanations. We presented students with a home science experiment and prompted them write an explanation. This procedure did not establish or assess students' initial level of conceptual knowledge. Therefore, students' explanations were hypotheses rather than grounded in scientific evidence; however, the goal of our intervention focused on students' ability to engage in scientific reasoning.

Challenges for Novice and Struggling Writers

Engaging students in writing that is integrated with scientific practices presents challenges for middle school students. First, data from the United States' National Assessment of Educational Progress (NAEP) on writing suggest that a mere quarter of 8th and 12th graders are proficient writers who show mastery of fundamental knowledge and skills (NCES, 2012).

In contrast, over half of the students in each of these grades demonstrate basic writing skills, and 20% more write below basic proficiency levels. Second, even when emphasized in science, writing is not taught in ways authentic to science – students rarely engage in the kinds of writing that scientists do (Carter, Ferzli, & Wiebe, 2007; Sampson, Enderle, Grooms, & Witte, 2013).

Contemporary science frequently involves teams of researchers working together to explore, describe, and explain generalized patterns of events in nature that stress physical causality (Dunbar, 2000). As such, written language is an integral part of science: it provides a way for doing science and for constructing claims (Yore, Florence, Pearson, & Weaver, 2006). Finally, novice and struggling writers often have difficulty discerning the underlying goals and purposes of writing tasks (Ferretti, MacArthur, & Dowdy, 2000), and without experience engaging in scientific practices through writing they are likely to have limited understanding of the text structures and linguistic devices that are particular to this genre.

Students with learning disabilities (LD) experience additional, specific difficulties that negatively affect their writing performance (National Joint Committee on Learning

Disabilities [NJCLD], 1990). They often have limitations in working memory, processing, memorizing, and information recall (Taylor & Hord, 2016), and may show weakness in executive functioning (Graham, Harris, MacArthur, & Schwartz, 1991; Shmulsky, 2003). Difficulties in these areas interfere with efficient recall and organization of information (Swanson & Siegel, 2001). Their difficulties in written expression often result in shorter texts that contain multiple grammatical and spelling errors and are lacking important organizational qualities (Graham, Harris, & Santangelo, 2015). Relative to peers, they construct syntactically simple sentences that are lower in overall quality (Saddler, 2011). Further, data from the United States' National Assessment of Educational Progress (NAEP) on writing suggest that students with disabilities perform at significantly lower levels ($p < 0.001$) than those without a disability on national writing exams such as the National Assessment of Educational Progress (NCER, 2012).

Students who are English learners (ELs) must gain command over a new language, especially when expected to express their ideas in writing (Lee, 2005). A lack of vocabulary knowledge (Lee, 2005) and a limited understanding of 'nuanced' expressions (Hyland & Milton, 1997) lead to imprecise language use. A lack of exposure to academic content and experience using language in content areas are other factors that impede clear written communication (Beck, Llosa, & Fredrick, 2013; Fang, 2005; Fang & Wei, 2010). Students who are EL tend to construct simpler sentences with inappropriate word choices, resulting in writing that can be difficult to understand (Beck et al., 2013) with significantly lower subsequent teacher ratings than their peers (Silverman et al., 2015). Finally, these students provide fewer elaborations in their written responses (Beck et al., 2013; Lee, Mahotiere, Salinas, Penfield, & Maerten-Rivera, 2009). These challenges may underlie the reported NAEP findings that only 1% of EL scored at or above a proficient level (NCER, 2012).

Successful Models of Literacy Instruction

Cognitive apprenticeship (CA; Brown, Collins, & Duguid, 1989) is a promising model of instruction for teaching students complex tasks like writing. CAs make expert thinking and literacy practices visible to novices through teachers' modeling. As students gain practice in the new ways of reading, thinking, and writing, less modeling is required, but regular feedback is still needed to support learning so that students are able to use these thinking and literacy practices independently. Brown and colleagues (1989) envisioned that CAs could focus on complex, higher-order thinking and make visible heuristic strategies used by experts. This instructional model has been found to be effective in teaching domain-general literacy skills (and has been identified as the Self-Regulated Strategy Development model of instruction; Graham & Harris, 1989; Harris, Graham, & Mason, 2006) as well as other content areas such as math (Schoenfeld, 1985) and history (e.g., De La Paz et al., 2014; De La Paz et al., 2017); however, in the field of writing research, the same kind of wealth of empirical studies does not exist for teaching disciplinary writing in science (Englert & Conant, 2002).

We know even less about effective approaches to teaching scientific writing with students who are cognitively and/or linguistically diverse. Thus, the primary goal of our study was to explore the benefits of this approach to intervention for students with LD or are EL. The results of a literature synthesis (Author, 2019) led us to develop a CA that provides both cognitive and linguistic supports for such students to be able to compose scientific explanations. In addition to following CA (and SRSD) guidelines to scaffold the cognitive processes that underlie effective writing, we added contextualized and explicit supports on language to meet the needs of students who were EL. We anticipated that this would be helpful, at least for the students with LD in this study as these are widely viewed as evidence-based approaches to writing instruction (What Works Clearinghouse, https://ies.ed.gov/ncee/wwc/PracticeGuide/22). We then added a focus on teaching specific features relevant to science writing (e.g., nominalizations), and provided multiple opportunities to respond through contextualized lessons where students learned to deconstruct exemplar science texts and practiced constructing their own explanations. We anticipated that this would be helpful, at least for the EL participants in this study as explicit language-based instruction has been effective in teaching the structure and use of academic English (Brisk, Hodgson-Drysdale, & O'Connor, 2010; De Oliveira & Lan, 2014; Hodgson-Drysdale, 2014).

The Current Study

This study was designed to give academically, culturally and linguistically diverse middle school students guidance to construct written explanations in science. We examined the use of CA to teaching sixth and seventh grade students with LD or who were identified as EL to write science explanations. In addition to the above hypotheses, we anticipated that our approach would contribute to the following for all participants: (a) enhanced organization and clarity of language, as shown by better descriptions and specifications of entities and activities, and (b) an improved ability to produce explanations that are causal and mechanistic, with descriptions of the properties of entities and activities, comparisons, generalizations, and organization (Russ et al., 2008).

The following research question guided this study:

RQ1: Do middle school students with LD or are EL show growth in their ability to construct explanations after participating in a cognitive apprenticeship approach to instruction?

Method

Setting and Participants

Students received the science writing intervention as part of an afterschool program, which supplemented their school science curriculum called the Investigating and Questioning our World through Science and Technology (IQWST; Krajcik, Reiser, Sutherland, & Fortus, 2012). Three middle school students with LD (one girl and two boys) and three who were identified as EL (one girl and two boys) from an urban school in the mid-Atlantic region of the United States participated in this study. The average age for the six students was 13 years and 8 months. Each participant met the federal definition for having LD or qualified as an EL. We administered the *Test of Written Language—Fourth Edition* (TOWL-4; Hamill & Larsen, 2009) to screen for foundational writing difficulties (e.g., basic vocabulary, syntax, spelling). In general, many wrote run-on or fragmented sentences but were able to construct simple sentences; however, they had little genre knowledge about narratives. A summary of student characteristics is presented in Table 1.

Students with LD. Three students (Chris, Steven, and Donoria, all pseudonyms) were receiving special education services for LD. English was their primary language, and they all had at least one Individualized Education Program (IEP) goal in reading and writing. Chris, an African American boy, was 12 years and 8 months old at the start of the study. On the *Woodcock-Johnson Psychoeducational Battery-Fourth Edition* (*Woodcock Johnson-IV*; Schrank, Mather, & McGrew, 2014), he scored approximately four years below age level in both reading and writing. Despite his aspirations to become a scientist in the future, he finds reading and writing required in school to be challenging. His homeroom teacher commented that compared to his peers, Chris experiences difficulties organizing and planning for projects. Even when he is given a simple assignment, he frequently forgets to complete all sections.

Steven, another African American male student, was 12 years old and 9 months old at the start of the study. On the *Woodcock Johnson-IV* (Schrank et al., 2014), he read at a second-grade level and wrote at a third-grade level. In addition to learning goals in writing and reading comprehension, he also had phonics and fluency-related goals. He scored the lowest in both subtests in TOWL-4 and his teachers reported that he does not enjoy writing. Teachers stated that Hero, a school-wide positive behavior support system, keeps him engaged and motivated during writing activities in classrooms. She mentioned that he generally “does the minimum” to pass the class. Unfortunately, that was not the case for this year as he was failing a few classes, including English language arts. So, he is required to attend Summer School.

Taylor, an African American girl, was 13 years and 9 months old at the start of the study. On the *Woodcock Johnson-IV* (Schrank et al., 2014), she read at a second-grade level and wrote at a third-grade level. In addition to learning goals in writing and reading comprehension, she also had phonics and fluency-related goals. Her teachers described her as a motivated learner who “tries to do her best.” Her homeroom teacher also reported that Taylor was a responsible student who always turned in her assignments. Unfortunately, her struggles with reading and writing affect her academic performance in school and she received a failing grade in English the year before this study began.

English learners. Three students (Sarah, David, and Tom) were receiving pull out ESOL services for at least three times a week. Sarah, an Asian American girl, was 11 years and 4 months old at the time of the study. She stated her hopes are to become a popular youtuber one day that specializes in "do it yourself (DIY)" art projects. She reportedly stayed up at night to make home art like posters and collages, enjoyed reading, but disliked writing. Her teachers explained that her struggles were more noticeable when writing longer compositions like essays. They reported that her essays are often off-tangent and disorganized. They described her writing as a "stream of consciousness," without a clear purpose.

David, a Hispanic male student, was 12 years and 6 months old at the start of the study. He stated that he loved to play sports and aspired to be an engineer when he grows up. Yet his teachers reported that David often neglected to reread his own writing. So, his writing was viewed as incoherent or choppy. He reportedly enjoyed math but did not like to write in class and found it quite challenging.

Tom, a male student from Iran, was 12 years and 5 months old at the start of the study. He transferred to the school a few months ago and was adjusting to the new school environment. Despite the novelty, his teachers reported that he was an enthusiastic learner who asked a lot of questions in class, but because his first language is not English, he struggled to form questions at times. When completing in-class activities, his teachers noted that he often ran out of time to complete many tasks. A part of the reason is his lack of vocabulary knowledge. They reported that they see him use his electronic dictionary to talk, write, and read.

Experimental Design

The effects of the science writing intervention were evaluated using a multiple-probe, multiple-baseline design (Shadish, Cook, & Campbell, 2002). We assigned one student with LD and another who was an EL using their standardized scores on the TOWL-4 as a matching variable to create pairs who could participate together in instruction. This ensured that students in each instructional group had comparable foundational writing skills. We then randomly assigned the order that each pair moved from baseline to instruction. As a result, Chris and Sarah were in the first small group, David and Steven were in the second, and Tom and Taylor, were in the final instructional grouping.

The six students were administered a series of baseline probes, then instruction, followed by a series of posttest probes, finally maintenance probes. During baseline, posttest, and maintenance phases, each participant was asked to write an explanation within 15 minutes on a given writing prompt. Paper and pencil were provided. Students watched a corresponding video for the prompt in all probes. Once a stable baseline was established, defined as consistent performance on the measure of causality, we introduced them to the novel writing instruction. Only when the first group of students demonstrated improvement and the second group of students maintained a stable baseline did the instruction for the second group of students begin, and so on for the third group of students. The first, second, and third group wrote five, seven, and eight baseline science explanations, respectively. During posttest, the first, second, and the third group completed seven, six, and five science explanation probes, respectively. Four weeks after revising instruction, each student completed three maintenance science explanation probes.

The primary variable of interest was the quality of causal and mechanistic reasoning. Causal and mechanistic reasoning was defined by the number of details students include about the processes or the entities that cause the phenomenon. The number of mechanistic details were counted and scored, graphed, and used for analysis. Subsequent instruction was contingent on mastery of content covered in each session, defined as 80% improvement on causal and mechanistic reasoning. Intervention ended when students reached the mastery level. Maintenance prompts was given 4 to 8 weeks after instruction ended, under the same conditions.

Description of the Intervention

The intervention “packages” both cognitive and linguistic components through a CA, which has been successful for both populations (De La Paz & Sherman, 2013). Scientific explanations describe a mechanism, which require words that mediate the cause and effect relationships between variables such as entities and activities (De La Paz & Levin, 2017; Russ et al., 2008). Quality mechanistic explanations include nouns, predicates, adjectives, and prepositional phrases to construct. CAs used in disciplinary writing facilitate learning through five phases of instruction: (a) prepare students to learn, (b) model, (c) support student’s practice, provide more challenging forms of practice, and (e) independent practice (De La Paz et al., 2017).

In the first phase of instruction, the first author clearly defined the lesson objectives and built background knowledge about science writing to prepare students to learn. Then, in the second phase, she made disciplinary thinking in science visible by thinking out loud while using multiple scaffolds to help me write such as a procedural facilitator. Our procedural facilitator (see Figure 1) comprised of questions that guided students' thinking when writing explanations. In application, students were first asked to think about the observed phenomenon, then they were asked to think about the variables that may have caused it. Finally, they were asked to generate ideas about the underlying process or the mechanism that may have led to the phenomenon.

In the following phase, students learned to apply this approach to think and reason in a highly structured learning environment where their learning was constantly scaffolded through on-going discussions. When students demonstrated a reasonable improvement from baseline (e.g., writing an explanation including at least two mechanistic details), she allowed them multiple opportunities to practice writing while gradually fading out the scaffolds and support. Finally, in the last phase, students wrote science explanations independent of any support.

She also embedded contextualized language instruction to introduce features of science language throughout the lessons. The focus of this language instruction was to write with clarity and precision in conveying causal and mechanistic explanations. The first author deconstructed exemplar texts to discuss the use of nouns, verbs, adjectives, and prepositional phrases in high-quality science explanations. For example, she examined how prepositional phrases like "on top of" describes the organizational relationship between entities or how adjectives like "quickly" described attributes about the mechanism. Then, she modeled ways to use language to convey clear and precise, causal and mechanistic relationships. As part of guided practice, she had students deconstruct exemplar texts by identifying how different parts of language were used. Finally, she had students practice writing explanations while providing appropriate scaffolds, until they were ready to write independent of her support.

General Procedures

Materials. Prior to the study, two middle school science teachers were asked to rate a pool of potential prompts for the study based on difficulty or the level of mechanistic reasoning in constructing an explanation, and some prompts were eliminated accordingly. A final pool of 24 science explanation prompts were available.

Writing prompts. All the writing prompts were presented using the same format: "Write an explanation about the given phenomenon" as used in Klein and Rose's (2010) study. Students were first asked to watch a short (1-3 minute) video of a home science experiment from a website (youtube.com). An example of the selected video includes a packet of ketchup moving inside a bottle of water or a straw going through an uncooked potato. We administered the same writing prompts at a given point to all participants so that the participants responded to the same prompt at a given time (e.g., the posttest prompts for the first group of students and the final baseline prompts for the second group of students were the same).

Instructional procedures. Students received 30-min instructional sessions at least two times a week, using a CA form of instruction. Students were taught a specific strategy for writing science explanations. First, the first author demonstrated a short science experiment (e.g., placing a heavy textbook on top of the eggs) and delivered a corresponding writing instruction. Shortly after the brief science demonstration, she introduced a specific way of thinking and planning when writing a science explanation using a procedural facilitator (i.e., cue cards). The cue cards contained prompts for generating causal and mechanistic explanations and for clarifying language (e.g., adding details about mechanisms). We created a second tool that was shown to students in the form of a rocket (see Figure 2) to help them evaluate and revise their writings and to self-monitor their writing progress. It contained an abridged version of the following prompts, highlighting crucial parts: (a) What do you want to explain, (b) How did the variables or things cause the phenomenon? (c) Did you clearly describe the entities and activities? (d) Did you clearly describe the organization of entities and activities?

Lesson 1: Activating background knowledge. Then, she introduced features of high-quality science explanations and the scaffolds and discussed with the student the importance of learning the tools to become better writers. She showed examples of high-quality science explanations, highlighting the clarity of language in the essays by discussing the use of nouns, verbs, adjectives, and prepositions in the writing sample that contributed to the clarity of the explanation. The first author also discussed features of examples and nonexamples using the rocket as a rubric by asking students to evaluate the quality of science explanations of three writing samples. A nonexample was shown as a contrast and students were asked to think about ways to improve it using the rocket. When finishing the discussion of all the writing samples, students were given two of his or her science explanations collected during the baseline phase and practiced evaluating it using the rocket as a way to track their progress with the help of the first author.

Lesson 2: Modeling. The first author modeled using the cue cards in Figure 1 by generating ideas, drafting, and editing by establishing writing quality (e.g., clear and precise language) and quantity goals (e.g., including mechanistic details). Prior to modeling writing a science explanation, she conducted a brief science experiment where she added two cups with water with different colors of food dye (e.g., blue and yellow) and different amounts of sugar (i.e., six teaspoon and one teaspoon), causing them to separate into two layers. After modeling, the first author also modeled evaluating the writing using the rocket by checking all the criterion on the progress-tracking chart. To conclude the lesson, students were asked to complete a contextualized language activity where they identified language parts that contributed to the clarity and precision of the writing. They were also asked to write about a natural phenomenon (e.g., the leaves changing color, the weather changing) using clear and precise language.

Lessons 3 and 4: Guided practice. The goal of the second phase of instruction was for students to engage in the thinking and the writing process collaboratively, allowing them opportunities to practice applying what they have learned from previous lessons. The first author reviewed the scaffolds and the features of a high-quality science explanation with each pair and asked questions to check their understanding. Then, she conducted a series of science experiments similar to the one she did on the previous lesson. During these lessons, the first author practiced using the cue cards to generate the content and draft a science explanation with the students. After drafting the explanations, students were also guided to use the rocket to check their writings together by recording the number of criteria they met on the progress-tracking chart. At the end of these lessons, students completed a contextualized language activity that asked students to identify language parts that contributed to the clarity and precision of writing.

Lessons 5 and 6: Independent practice. The first author instructed students to write an explanation without the cue card on the fifth lesson and without any scaffolds on the subsequent session. We faded out the scaffolds as they were expected to work independently in preparation for completing written responses to posttreatment writing probes. After students constructed science explanations, the first author asked students to evaluate their essays on the progress-tracking chart.

Treatment Fidelity

To ensure that instruction was delivered as intended, we developed a checklist that described core instructional practices. The instructor checked off each step as it was completed. All the instructional lessons were audio recorded, and an undergraduate student who was blind to the study listened to 25% of the audio-recorded lessons selected at random and documented the fidelity of treatment. He checked off the steps on the checklist as they were completed and found that 97% of the practices were completed as intended.

Scoring Procedures

We used several writing product measures to evaluate the effect of the science writing intervention. Each writing sample was analyzed for length, causal and mechanistic reasoning, grammatical and lexical sophistication, and holistic writing quality to examine both the form and content of students' writings. Two students (one undergraduate and one graduate) who were unfamiliar with the study (goals for instruction, phase of instruction, participants' learning characteristics) independently scored 25% of the sample for the causal and mechanistic reasoning and grammatical and lexical sophistication, and both students scored the holistic variable (with the undergraduate scoring 25% for reliability), to provide unbiased ratings. We calculated interrater reliability using intraclass correlation (ICC) coefficient on absolute agreement.

We also asked students about their satisfaction in an interview after the intervention was completed.

Writing Product Measures

Length. Length is an index for writing productivity. All essays were scored for length using the word count feature of Microsoft Word.

Causal and mechanistic reasoning. The presence and quality of causal and mechanistic reasoning was scored using a rubric developed by De La Paz and Levin (2017). The rubric examined the quality of a causal explanation that provided mechanistic details relating to the entities (things that play roles in producing the phenomenon) and the activities (various processes in which these entities engage) based on Russ and colleagues' (2008) constructs (see Figure 3). Students were awarded points for the presents of these mechanistic details, with a maximum score of 7. The reliability of scoring was .957.

Grammatical and lexical sophistication. Grammatical and lexical sophistication is measured by examining the degree to which responses included specific content words, different words, syntactic complexity, and depth of elaboration. We used a rubric developed by De La Paz and Levin (2017; see Figure 4). Reliability was .985.

Holistic writing quality. A graduate and an undergraduate student who were unfamiliar with the purpose, design, and students in the study independently scored the quality of each student's writings that were typed and identifying information was removed, with any grammar or mechanical errors corrected. We created a holistic rubric, adapting one by De La Paz and Levin (2017), modifying it from an evaluation of an argument, to one of a written explanation (see Figure 5). Scores ranged from 1 to 6, representing the reader's general impression of the overall quality. Each rater was asked to consider the ideas and development of the essay, its organization, coherence, as well as quality of sentence structure and vocabulary. Two or more criteria for each of these traits were provided in representative samples (1, 3, 5) as anchor points for scoring. Average scores were reported for agreed upon or resolved scores; in addition, the interrater reliability (intraclass correlation) for holistic quality was .979.

Social Validity

The students were asked to respond to a series of questions to determine how well participants believed the strategy worked and what they liked and did not like about it. We also asked in ways they benefited from the intervention and if they would use it in the future.

Results

We report findings separately for students with LD and those who are EL. The average scores during baseline, posttest, and maintenance for each student is presented in Table 2 and the average for each population is in Table 3. A summary of the effect size for each writing product measure is presented in Table 4. Figures 6 and 7 presents a graph of students' performance on causal/mechanistic reasoning and holistic writing quality.

Writing Product Measures

Length. During baseline, students with LD wrote longer (M = 26.30) explanations than those who are EL (M = 22.23). This pattern was reversed after instruction as students who are EL (M = 55.10) wrote more than those with LD (M = 51.19). However, students with LD showed more improvement after instruction (τ = .89) than those who are EL (τ = .83). The students with LD (Chris, Steven, and Taylor) wrote on average 26, 15, and 25 words before instruction and 67, 49, and 49 after. On average, the student who are EL (Sarah, David, and Tom) wrote 33, 23, and 23 words during baseline and 63, 51, and 49 words after instruction. Both groups of students wrote slightly less during maintenance, but this average was still substantially more than during baseline. Chris, Steven, and Taylor wrote 52, 39, and 53 words and Sarah, David, and Tom wrote 41, 54, and 34 words. On average, students with LD and those who are EL wrote 43 and 48 words on the maintenance probe.

Causal and mechanistic reasoning. On average, all students wrote recounts rather than explanations before treatment, resulting in an average score ranging from 0 to 1 (Figure 6). After instruction, they wrote explanations with mechanistic details that demonstrate the underlying processes of the observed phenomenon, resulting in higher average scores. During baseline, students with LD and those who are EL wrote mostly recounts of the phenomenon, obtaining average scores of .57 and .67 for causality. The students with LD appeared to benefit from instruction upon visual analysis. Chris, Steven, and Taylor scored on average .80, .50, and .71 before instruction, demonstrating stable baseline trend. Then, they scored 5.71, 5, and 5.20 post-instruction, which did not overlap with the baseline data.

Tau-U analysis demonstrated that their causal and mechanistic reasoning improved substantially after instruction (τ = .97). After instruction, students who are EL (M = 5.30) wrote explanations that contained slightly more mechanistic details than those with LD (M = 4.77). On average, Sarah, David, and Tom scored .6, .83, and .29 during baseline with a steady trend, and they scored 4.71, 5.20, and 5.20 after instruction. Visual inspection demonstrated no overlap between baseline and post-instruction data. Students who are EL wrote comparable explanations before the intervention and they all made comparable improvements after instruction. Tau-U analysis showed that their causal and mechanistic reasoning improved substantially after instruction ($\tau = .99$). All students maintained an improved quality of causal and mechanistic reasoning four weeks later. The students with LD made a slight improvement during maintenance (M = 5) and those who are EL scored slightly worse than immediately after instruction (M = 4.78).

Grammatical and lexical sophistication. During baseline, students wrote one-sentence responses, which often lacked clarity (e.g., “it” or “thing”). After instruction, they used more specific terms (e.g. “baby oil,” “hydroxide,” “chemical reaction”) in their writings. During baseline, students with LD and those who are EL wrote one-sentence responses, obtaining average scores of 1.05 and 1 on grammatical and lexical sophistication. After instruction, students with LD (M = 3.19) wrote explanations that were slightly more complex than those who are EL (M = 2.79). On average, the students who are EL scored 1, 1, and 1 during baseline and 3.57, 3, and 2.8 after instruction. Although instruction did not focus on sentence construction, the students who are EL improved substantially after instruction on grammatical and lexical complexity ($\tau = .96$). All students continued to show improved levels during maintenance. Students who are EL made a slight improvement (M = 3.01) and those with LD scored slightly worse (M = 3.00).

Holistic writing quality. During baseline, students with LD and those who are EL did not often respond to the prompt, resulting in average scores of 1.74 and 1.77 on this measure (Figure 7). After instruction, students with LD (M = 4.39) wrote explanations that were similar to that produced by those who are EL (M = 4.62). The students with LD scored on average 4, 5.2, and 1.43 before instruction and 5, 4.33, and 4.67 post-instruction. Consistent with our findings from visual analysis, Tau-U supported that they demonstrated significant improvement after instruction (τ = .92). On average, the students who are EL scored 1.8, 2, and 1.43 during baseline and 4, 5.2, and 1.43 after instruction. Upon visual analysis, we found that their baseline data did not overlap with the post-instruction and maintenance data. Tau-U analysis also demonstrated that they made substantial improvement on the holistic writing quality after instruction (τ = .93). All students maintained improved levels of holistic writing quality two weeks after instruction ended. Students with LD made a slight improvement (M = 4.67) and those who are EL scored slightly worse than immediately after instruction (M = 4.33).

Social Validity

All students believed they benefited from the writing instruction. Taylor indicated that she would like to keep using the rocket to help check her writing in the future. Chris and David both aspires to become a scientist or an engineer and they believed that the cue cards were very helpful in helping them think like one. All six students said that they especially enjoyed the science experiments that were built into the program. They indicated that they wanted to continue being part of the writing program and asked to join if I intended to offer one in the following year.

Discussion

The primary purpose of this study was to evaluate the effects of instruction that was designed to improve academically, culturally, and linguistically diverse middle school students' abilities to construct scientific explanations. Although students with LD and those who are EL experience different learning challenges and have distinct learner characteristics, we hypothesized that all would benefit, as they were all novices when it came to scientific reasoning and struggled with language use in science classrooms. Our intervention was designed to meet these challenges by providing both cognitive and linguistic supports.

We designed a procedural facilitator (i.e., cue cards) that prompted students to: (a) think about what they want to explain, (b) explain how different things caused the phenomenon, and to (c) clearly define the entities and the activities involved in the explanation. We also provided contextualized language activities that deconstructed the language parts (nouns, verbs, adjectives, and prepositions) used to convey scientific ideas. Students' learning was guided through phases of instruction including, modeling, collaborative practice, and independent practice to ensure mastery of taught strategies and skills.

After receiving instruction, both students with LD and those who are EL wrote more causal and mechanistic details to explain a phenomenon. These modifications enhanced the clarity of their ideas. To write explanations that encapsulate this, they no longer could write responses that were only a sentence long. In fact, they had to write more complex sentences that can convey causal relationships. So, they wrote longer and grammatically and lexically more complex forms of writing. As a result, we found a substantial improvement in the holistic writing quality, which is harder to detect than the other analytic writing product measures we examined. These findings are consistent with De La Paz and colleagues' (2017) study showing that cognitive apprenticeship model of instruction can improve students' disciplinary (historical) writing. Our study is notable as it is the first CA to show improved disciplinary (scientific) writing, and it is the first to show such improvements in the writing of students with LD and who are EL.

Limitations

The current intervention does not take into account the school curriculum. Because school science requires students to support explanations with factual and conceptual knowledge, further improvements in the accuracy of students' explanations would be dependent upon integrating this form of instruction with science content. This was not feasible due to the inherent restrictions of an afterschool program. Another limitation inherent to SCD is sample size. Further research is needed with more students with LD or those learning English. Finally, the field lacks standardized measures (writing prompts) in science. Because we created the writing prompts in the current study, we are not fully able to rule out topic effects.

Conclusions

The movement for inclusion led to increased diversity of learners in general education science classrooms, including more students with LD and those who are EL. Our findings suggest the importance of helping teachers to use CA to teach novice and struggling learners to deconstruct the language used in science, and to explicitly instruct them how to write scientific explanations. Finally, effective writing instruction does not need to take up a significant amount of instructional time. Students in the current study made substantial improvements to their science explanations after an average of six to ten, 30-minute lessons. We believe our findings may be interpreted as providing initial evidence that a cognitive apprenticeship is a promising model of instruction to support academically, culturally, and linguistically diverse middle school students' construction of written scientific explanations.

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Tables

Table 1. Participant Information

Name	Sarah	Chris	David	Steven	Tom	Taylor
Age (in months)	11 years, 4 months	12 years, 8 months	12 years, 6 months	12 years, 9 months	12 years, 5 months	13 years, 9 months
Grade	6	7	7	7	7	7
Gender	F	M	M	M	M	F
Identification	EL	LD	EL	LD	EL	LD
TOWL Subtest 6	Average	Average	Average	Below Average	Average	Average
TOWL Subtest 7	Poor	Poor	Below Average	Very poor	Below Average	Poor
PARC Reading	653 (level)	669 (level 1)	712 (level 2)	689 (level 1)	681 (level 1)	694 (level 1)
ELA Grade 2017-2018	64	69	69	66	73	64

M = male, F = female, EL = student who is an English learner, LD = student with learning disabilities, ELA = English language arts, PARCC = Partnership for Assessment of Readiness for College and Careers, TOWL = Test of Written Language

Table 2. Average Scores for Each Measure at Baseline, Posttest, and Maintenance

Student	Length	Causality	Syntax	Holistic
Sarah				
Baseline	33.00	.6	1	1.8
Posttest	62.57	4.71	3.57	4
Maintenance	41.33	5.67	3	5
Chris				
Baseline	26.4	.80	1	2.2
Posttest	67.29	5.71	3.43	4.86
Maintenance	51.67	5.33	3	4.33
David				
Baseline	23.33	.83	3	2
Posttest	51	5.2	1	5.2
Maintenance	54	4.67	3	4.33
Steven				
Baseline	15	.5	3	1.67
Posttest	48.6	5	1	4.2
Maintenance	38.67	4.67	2.8	4.67
Tom				
Baseline	22.57	.29	1	1.43
Posttest	40	4.4	2.8	4.4
Maintenance	34.33	4.67	3	4.67
Taylor				
Baseline	25.29	.71	1.14	1.43
Posttest	49.4	5.2	3	4.8
Maintenance	53.33	4.33	3	4

Table 3. Average Scores for Students with LD and Who Are EL

Populations	Length	Causality	Syntax	Holistic
Students with LD				
Baseline	26.30	.57	1.05	1.74
Posttest	51.19	4.77	3.19	4.39
Maintenance	43.22	5	3	4.67
Students who are EL				
Baseline	22.23	.67	2.79	1.77
Posttest	55.10	5.30	1	4.62
Maintenance	47.89	4.78	3.01	4.33

Table 4. Effect Sizes (τ) for Each Dependent Measure

	Length	Causality	Syntax	Holistic
Students with LD	0.8925	0.9748	0.9622	0.917
Students who are EL	0.834	0.9937	0.9558	0.9342

Figures

Figure 1. Cue Cards

1	**What are you trying to explain?** Describe what you are trying to explain based on what you saw in the experiment.
2	**Cause and Effect** What are the variables that are involved? Identify things that could have caused the phenomenon.
3	**Cause and Effect** How do these variables lead to the phenomena? Explain how these variables CAUSED the phenomenon. Is there a clear caused-and-effect explanation in your writing?
4	**Clear and Precise Language** Did I clearly identify what I am trying to explain? Did I clearly identify the variables (name, place, or thing)?
5	**Clear and Precise Language** Am I describing where the variables are in relation to one another?
6	**Clear and Precise Language** Did I clearly explain how the variables CAUSED the phenomenon?

Figure 2. Science Rocket

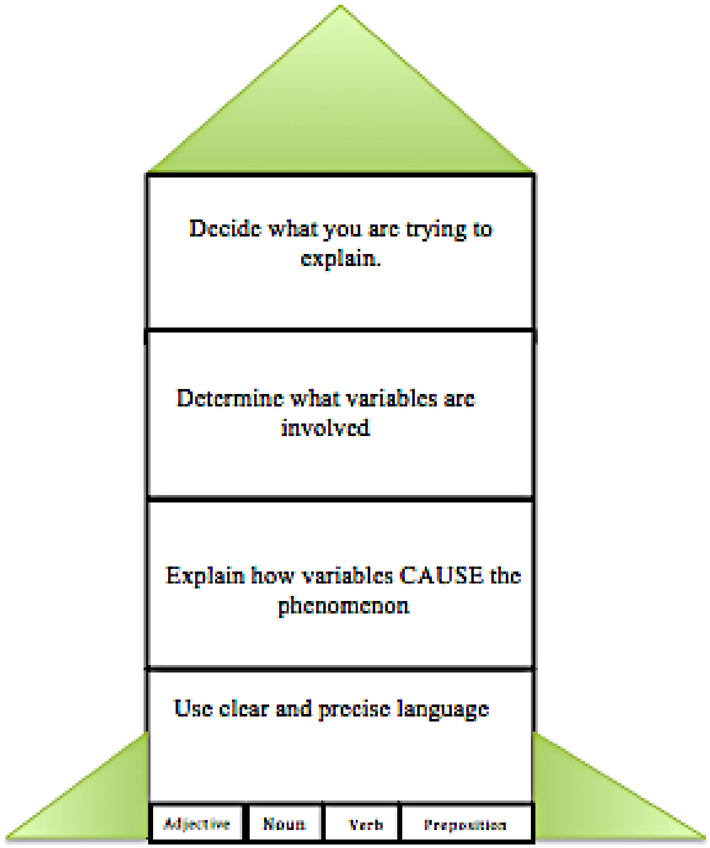


Figure 3. Causal Mechanistic Reasoning Measure

Score	Description
0	Student vaguely describes the phenomenon or writing is unrelated to the science video.
1	Student clearly describes the phenomenon using one of the following but lacks an explanation: • Specific properties of entities • Organization relationship of entities and/or activities • Some form of comparison or generalizable statement • An example
2	Explanation is non-mechanistic or teleological, anthropomorphic, magical, or "theological" types of thinking.
3	Explanation is mechanistic but **does not** mention the following to explain a mechanism (specific properties of entities, organization relationship of entities and/or activities, some form of comparison or generalizable statement or an example)
4	Explanation is mechanistic with at least one of the following for both mechanisms: • Specific properties of entities • Organization relationship of entities and/or activities • Some form of comparison or generalizable statement • An example
5	Explanation is mechanistic with at least two of the following for both mechanisms: • Specific properties of entities • Organization relationship of entities and/or activities • Some form of comparison or generalizable statement • An example
6	Explanation is mechanistic with at least three of the following for both mechanisms: • Specific properties of entities • Organization relationship of entities and/or activities • Some form of comparison or generalizable statement • An example
7	Explanation is mechanistic with at least four of the following for both mechanisms: • Specific properties of entities • Organization relationship of entities and/or activities • Some form of comparison or generalizable statement • An example

Figure 4. Grammatical and Lexical Sophistication Measure

Score	Lexical Sophistication	Grammatical Sophistication
	▪ Specific words are of higher value, as is the diversity (how many different words are used). ▪ Longer words = proxy for lexical sophistication ALSO factor in the element of diversity of words, so don't count repeated words.	▪ Syntactic complexity = e.g., the type of sentence. Compound = coordinating conjunctions (FANBOYS). Complex = subordinating conjunctions (e.g., unless, because, although, if then) that joins a dependent clause to a main clause. ▪ Number of sentences = depth of elaboration
0	▪ Vocabulary is inappropriate or in error. ▪ Expresses an incomplete thought.	*I think why it happen because*
1	▪ Appropriate but basic vocabulary that lacks specificity (i.e., missing relevant and/or important vocabulary), or shows repetition in word use. ▪ Writes one sentence: simple/compound/complex.	*Purebred dogs have more health problems, because they have less variation of traits.*
2	▪ Appropriate vocabulary with some specificity (i.e., at least one relevant and/or important concepts); one word (whether about science concept or not) is at least 7 letters long. ▪ Writes more than one sentence – mix of simple, simple & compound, simple & complex sentences.	*The nervous system had sent impulses to the brain to flop around, and by the time the fish's head is cut off, the nerve impulses are already back to the spinal cord. The result is the fish flopping around for longer after the head is cut off.*
3	▪ Appropriate vocabulary with some specificity (i.e., at least 2 relevant and/or important concepts); 2-3 words (science concepts or not) are at least 7 letters long. ▪ Writes more than two sentences and the structure must include compound/ complex elements.	*Some lakes are made of freshwater and some are made of salt water depending on when the water comes from. For a lake to be fresh water, the water may come down from rain or melted snow or creeks/streams where water has very low salinity. Salt water lakes get water from places where there may be more salinity, such as near a salt mine, acid rain, and/or sometimes man-made lakes.*
4	▪ Appropriate vocabulary with some specificity (i.e., at least 2 relevant and/or important concepts); 5 or more words (whether about science concepts or not) are at least 7 letters long. ▪ Writes more than three sentences and the structure must include compound/complex elements. .	*Saltwater fish die in a freshwater ecosystem because of many reasons. Salt in water is an example of diffusion. This causes the water to be denser. Fish are used to the dense environment, which is not in fresh water. Also, fish may have a different spot on the food chain in the fresh water. This may cause the fish to have more predators and/or less prey.*

Figure 5. Holistic Writing Quality Measure

Score	Description
1	**Prompt is not addressed** Seems silly or tangential or no discernable idea/unintelligible idea. There is a confused or incoherent discussion of the subject.
2	**The essay is difficult to follow** Demonstrates partial understanding of the underlying concepts. The explanation has some important elements but presents sentences non-sequentially or randomly and lacks transitions and/or topic sentences.
3	**The essay is clear, but undeveloped** Demonstrates partial understanding of the underlying concepts. The ideas are consistent but are underdeveloped. As a result, the explanation is less coherent. There is little organization. There are few transitions, or they are weak and/or illogical. The explanation may be a single or a few sentences.
4	**The essay is clear, but with little development in persuasiveness or structure** Demonstrates understanding of the underlying concepts. The response answers the prompt, though ideas may seem incomplete. Overall, the explanation has a clear and logical structure, and the sentences are unified. Some sentences may be disorganized and/or inconsistently integrated. Transitions may be implicit, if present at all.
5	**The essay is clear and purposeful, with some lapses in persuasiveness or structure** Demonstrates understanding of the underlying concepts. The response answers the prompt, though ideas may seem incomplete. Overall, the explanation has a clear and logical structure, and the sentences are unified.
6	**The explanation is clear, purposeful, and well structured** Demonstrates understanding of the underlying concepts. The response makes accurate connections between claim and evidence. The ideas are coherent and build a complete explanation. Overall, the explanation has a clear and logical structure, and the sentences are unified.

Figure 6. Causal/Mechanistic Thinking Results

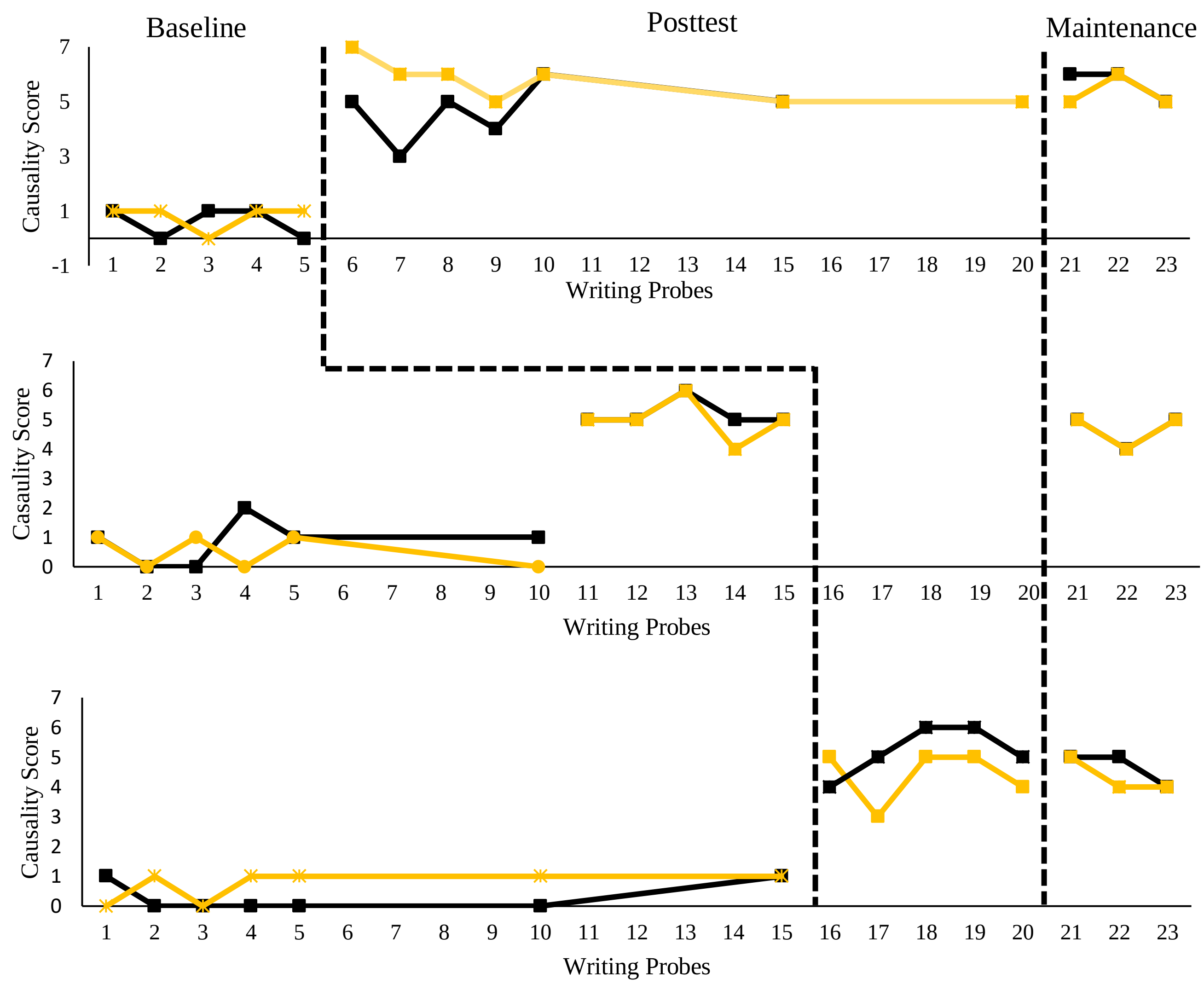
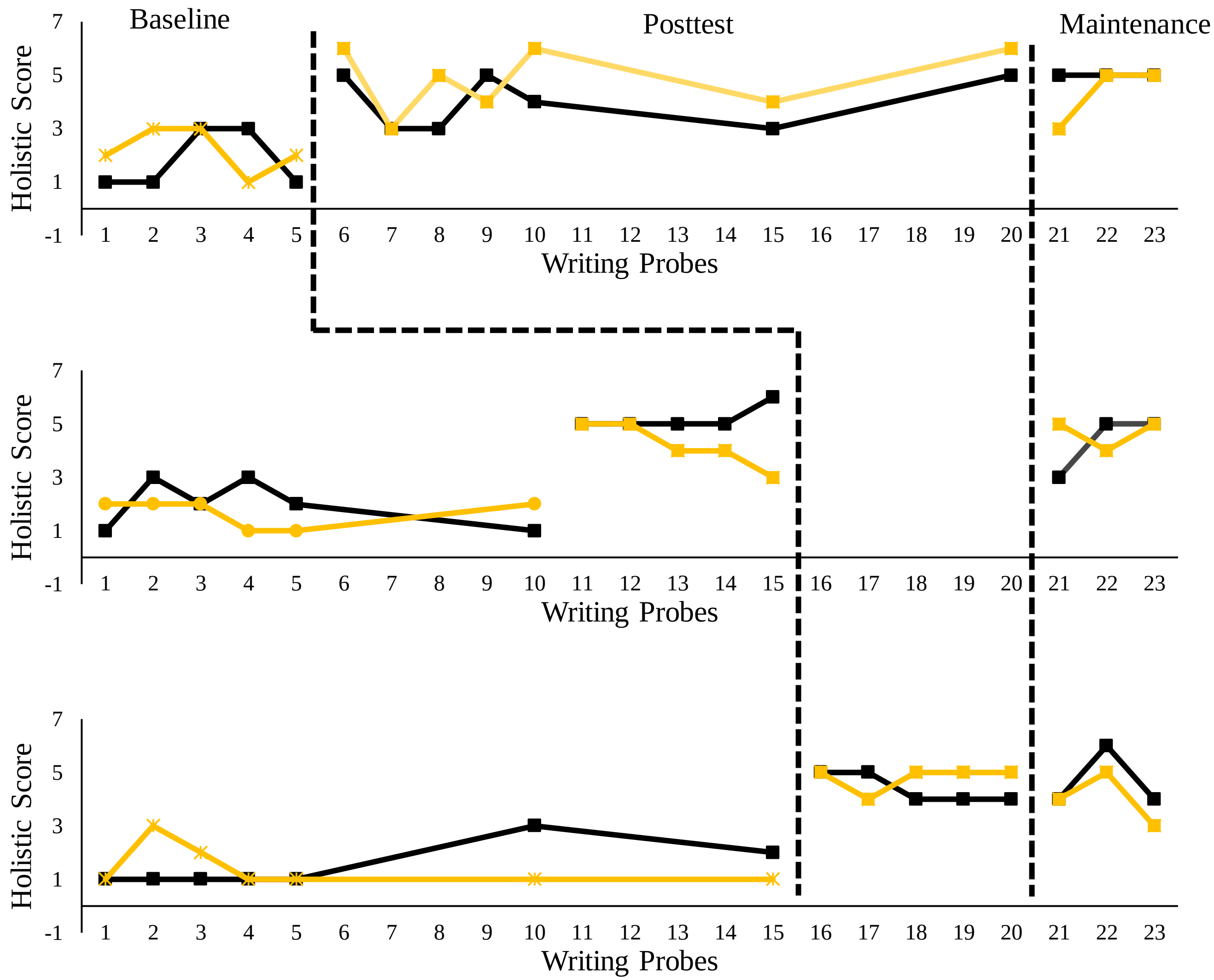


Figure 7. Holistic Writing Quality Results



CHAPTER 5: DISCUSSION AND IMPLICATIONS

This dissertation included three studies that broadly explored science writing instruction for students with LD and those who are EL. We first explored existing studies on science writing instruction in Chapter 2 and completed a formal synthesis of the available research. Then, in Chapter 3, we explored how cognitive apprenticeships can affect teachers' beliefs. Finally, Chapter 4 provides the results from an intervention study, using instructional elements that were based on findings from Chapter 2, with six students with LD and those who are EL This chapter begins with a summary of findings from each chapter, followed by a discussion of the broader implications on students, science teachers, and language and literacy researchers.

Summary of Findings

Effective Writing Intervention for Students with LD and Those Who Are EL

Although students with LD and those who are EL experience different learning challenges, they share some struggles when writing. One of those struggles is in understanding the language used in science classrooms or in academic settings, in general. We conducted a systematic review of 14 quantitative studies to identify elements of science writing instruction that could benefit each or both populations of students. Our pool was varied and several included general education learners as well as students with disabilities (n = 4), students who are EL (n = 5), and students considered low achieving or mixed ability (n = 4); finally one (n = 1) included students with disabilities and EL. Students with disabilities included LD, ED, and ADHD. Students who were ELs were predominantly learners whose first language was Spanish or not specified. Half of the studies included students from grades 3 to 5; the other half specified grades 6 to 12, each with different ranges or contrasts. Most (n = 9) studies included students from multiple grade levels. In many aspects, investigators did not disaggregate the findings based on learner characteristics (e.g., disability, English language learner status, academic performance). Only 5 out of the 10 studies that included students with LD or those who are EL reported outcomes specific to these populations.

A total of 80% of the science writing intervention studies involving students with LD included a comprehensive writing program that had both cognitive (i.e., process writing, prewriting, strategy instruction, goal setting, procedural facilitators, modeling, and collaborative practice) and linguistic supports (i.e., explicit instruction on text-structure knowledge and opportunities for practice). Generally, instruction was more focused on the writing process. However, most instructional elements supported the writing process, especially when generating and organizing content. There were two types of support during the writing process: (a) strategy instruction and (b) the use of procedural facilitators.

Three teams of researchers used the SRSD form of strategy instruction. Their instruction focused on organizing and generating content while writing by explicitly teaching students the writing process: plan, build background knowledge, ask questions and make predictions, revise, and evaluate. Hebert et al. (2018) taught a simpler routine, with four steps: (a) pick your idea, (b) organize your notes, (c) write the topic sentence, and (d) review to check for content and coherence. Students learned the general organization and structure through these parts of writing. In contrast, Bulgren et al. (2013) used procedural facilitators to teach both the writing process and text structure. Their procedural facilitator contained guiding questions (e.g., "*what is the claim,* *including any qualifiers?*") that helped generate, organize, and even revise writing. Rouse and colleagues (2017) provided a simplified version of a procedural facilitator, with only two questions that helped students generate ideas (e.g., "What makes the beam balance?" "What makes it tilt right or left?").

Instruction for students with EL shared some similarity with that of students with LD (i.e., modeling, collaborative writing, process writing, prewriting, explicit instruction on text-structure knowledge, and opportunities for practice), while others accounted for both the cognitive and the linguistic needs of students and most (n = 5) focused exclusively on supporting the linguistic needs. In contrast, some researchers focused on establishing clear connections between the form and function of science language. They focused on teaching specific vocabulary and language (i.e., structure, rhetoric, technical language, nominalizations) that were most effective for conveying scientific knowledge.

Their instructional focus was on building students' language skills by teaching text-structures (n = 2), vocabulary (n = 3), and grammar (n = 1). Investigators did this through modeling and the use of model texts; however, each served a different purpose than for students with LD. To illustrate, modeling was used to instruct students on how language constructs meaning in at global and local levels. Investigators demonstrated these through model texts. For example, Klein and Rose (2010) presented exemplar argumentative and explanation texts to highlight features of high-quality writings. These exemplar texts were provided as a way to help students understand a good model for scientific reasoning, communication, organization, and general conventions.

In contrast, Brown and colleagues (2010) modeled the use of language parts (nouns, verbs, adjectives). To disaggregate the science content from language, they taught students the science concepts prior to delivering any writing instruction. Then, they built their instruction on science language by modeling how students could change their original language to that used in science (e.g., nominalization, technical language). So, when students learned to write, they could focus on writing, rather than the content.

Many authors included vocabulary instruction in varying degrees as part of their intervention and took multiple approaches to deliver vocabulary instruction. For example, August et al. (2009) taught students linguistic strategies (i.e., instruction on cognate knowledge, using root words, base words, and affixes) that they can apply when learning new vocabulary words. This team also helped students use science vocabulary words (e.g., analyze, data, organism, cell) through instructing and providing opportunities to practice using those terms to explain and interpret scientific observations.

Finally, instruction for struggling and mixed ability students commonly in three studies used procedural facilitators such as a procedural facilitator (e.g., SWH template). Their procedural facilitators had sections that are traditionally used for laboratory reports: (a) questions or hypothesis, (b) tests or procedures, (c) observations, (d) claims, (e) evidence, and (f) reflection (Akkus et al., 2007). However, different authors used it to promote scientific discourse and to deepen science knowledge and collaboration played a key role. Students engaged in many discussions to brainstorm, critique, and revise each other’s ideas. Second, investigators teaching this group of students found ways to use collaborative practice to challenge students to engage with reasoning using science knowledge, which deepened their conceptual understanding. After modeling the process of writing and providing explicit instruction on text-structure knowledge, these researchers embedded multiple opportunities for practice.

Overall, students with LD who received both cognitive and linguistic-based instruction improved in organization (*PND* = 100%), scientific reasoning (*d* = 1.7), and overall clarity of language. In fact, Hebert and colleagues (2014) asked students to write three different types of informational texts and they saw improvement in all three including, a simple description (*d* = .66), a compare/contrast (*d* = .61), and a sequence writing (*d* = .94). All but Rouse et al. (2017) identified improvement in students' writings. Students in Rouse et al.'s (2017) study, who only received the support of a simplified procedural facilitator, did not make significant gains in their writing.

Given the cognitive-based instruction on the structure and process of writing, students with LD wrote better argumentative writings with better organizational structure with higher quality of evidence. They included more transition words that contributed to the organizational quality of their writing and generally included claims, evidence, reasoning, and a conclusion. Also, students were able to discriminate good from bad quality of evidence, which helped them include better evidence to corroborate their own reasoning. Students in Herbert et al.'s (2014) study who received instruction of texture structures of informational writings wrote writings that had higher organizational quality, accuracy, and clarity.

Most students who are EL received explicit instruction on the text-structure, vocabulary, and grammar instruction. Results for students who are EL were mixed for organizational quality, clarity, and the quality of scientific reasoning. Many did not find significant gains in the quality of students' argumentative writings after instruction. Brown et al. (2010) and Lee et al. (2009) identified that students were able to write with better organizational quality (topic, details, and ending), clarity, sentence variety, and syntax.

Overall, students with EL who received linguistic instruction on textual features made notable improvement in writing informational text ($d > .35$). Unlike others, Brown et al. (2010) who simply provided students with multiple opportunities to practice using vocabulary and grammatical structures found significant improvement in students' overall writing quality ($d = .42$). On the other hand, findings were mixed for students who received mostly linguistic-based instruction for writing argumentations ($d < .10$). Improvement in writing informational texts was more consistent than other forms of analytical writings like argumentations.

Students in the mixed group received a balanced approach to writing instruction that supported both their cognitive and linguistic needs. Most of their instructional focus was to build a deeper conceptual understanding while reasoning in science. Therefore, cognitive support in the writing process such as procedural facilitators like the SWH and strategy instruction was common in all four studies. After instruction, students' argumentative, explanation, and informational writing improved areas of organization and clarity. Unlike others, Klein and Rose's (2010) found that students made little improvement in argumentative writings. They found that students in the treatment group did not outperform those in the control group. On the other hand, they identified a statistically significant improvement in students' explanation writings. In fact, they saw an increase in causal and mechanistic reasoning in students' writings after treatment. Overall, students with mixed abilities made improvement in argumentation. They generally included more parts (e.g., claim, evidence, reasoning) that enhance scientific reasoning and overall writing quality.

Findings showed that studies including students with LD incorporated more cognitive supports that satisfy the demands of writing required to plan, organize, and revise, such as the procedural facilitator or strategy instruction. Studies that included students who are EL, who lack exposure to academic language, provided more linguistic-based instruction on vocabulary, grammar, and textual structures. Students with LD and those who are EL both benefitted from a balanced writing instruction with both cognitive and linguistic support. In fact, students who are EL, who did not receive much cognitive support in the writing process, made less improvement than the rest of the students. When teaching writing in a specific discipline, understanding the genre, including the rhetoric and the structure is essential and our students, regardless of their learning needs.

Effects of Long-Term PD on Science Teachers

Science teachers are responsible for determining the success of educational reform movements by deciding whether and how to attempt innovative teaching practices. Traditionally, science teachers lack training in delivering literacy lessons. In Chapter 3, I explored how a long-term PD on CA, a particular approach to writing instruction, influenced teacher beliefs and practices. The long-term PD that was part of a larger project focused on the implementation of CA. As teachers implemented CA-based writing instruction, their beliefs about students and the value of writing changed gradually over the years. These changes in beliefs, subsequently, affected their choice of tasks and reported instructional practices. Of note, resulting changes were sustained a year after the PD ended.

Our analysis of the first-year interviews, before teachers implemented CA, suggested that both teachers expressed deficit beliefs about students. Maggie, for example, believed her students were "*not really good at evaluating each other on anything*", and recounted her struggles with getting them to write well. Both teachers' descriptions of their choice of tasks and instructional practices reflected beliefs that their students had such deficits that the teachers could only take "baby steps" in using evidence to make a written explanation or claim about a phenomenon. Kim also didn't believe her students could construct explanations, focusing on giving them some definitive "rules" for making a claim.

Teachers had particularly strong deficit beliefs about their students who are English learners. She categorized them with students who she considered "lower level students". Ultimately, both teachers expressed beliefs that fit with a deficit model of their students, particularly when it came to independently constructing explanations. It appeared that they created small scaffolds, but never faded those scaffolds, which implies a tacit belief that their students could not make progress.

Coding the interviews after the CA implementation we found the teachers developed more positive beliefs about students. Maggie, for example, continued to acknowledge her students' struggles, but she also noted improvements, such as their ability to reason using data. Kim even referred to her earlier deficit beliefs when she described what she saw during the CA implementation and discussed how she saw her students' strengths when writing. CA allowed Kim an opportunity to observe what her students can do because it is an instructional model that allows teachers to gradually release the responsibilities for learning. To elaborate, teachers provides instruction in phases, from modeling to collaborative or supported practice, and finally to independent practice. Instead of continuing to scaffold and facilitate learning, teachers are encouraged to allow students to build their own skills to apply learned skills and strategies independently. This could have been momentous in helping teachers develop more asset-based beliefs about their students.

She also reported that even her students who are ELs, who she described as struggling learners in the previous year, made huge improvements in science writing. The shift to asset beliefs persisted a year after the completion of the CA implementation. While continuing to acknowledge areas of improvement, Kim noted improvements more generally in her students' writing. Maggie also described growth in her students' abilities to construct written explanations. These and other examples of asset beliefs that persisted suggest a contrast from the first year, where they rarely highlighted students' strengths.

The interviews before the CA suggest that Kim and Maggie believed that writing in classrooms was primarily for communication and assessment. Kim, in particular, expressed beliefs regarding the function of writing in teaching as getting students to write the correct answer so they could be assessed by her and on high-stakes tests. In describing the kinds of writing tasks, she used, Kim expressed a preference for close-ended "correct answer" questions that covered factual content covered on her assessments and on high-stakes tests. She also reported that she included more "*structured*" forms of writing like laboratory reports. We inferred from her description of the tasks she chose that she did not believe writing served as a tool for instruction, but rather a tool for communication (i.e., structured laboratory reports) and for simple assessment that was easy to grade (i.e., close-ended questions).

Similar to her colleague, Maggie believed that writing in science class was primarily for communication and assessment and she tied it to a school-wide approach to writing that was explicitly intended to prepare students for high-stakes tests. Thus, even though Maggie did report using writing in instruction, its use in instruction was primarily for practice for Advanced Placement and International Baccalaureate classes and assessments in high school, which ultimately are the lab reports whose function is to communicate information in a prescribed format.

After implementing the CA, both teachers' beliefs about the role of writing expanded, from a tool for communication and assessment to include beliefs about the function of writing for instruction, to improve reasoning and metacognition. Kim believed that critiquing each other's writing helped students develop metacognitive skills that enhance their ability to critique their own ideas. Maggie's beliefs about writing also expanded over time, as revealed in the tasks she chose. She described the value in having students writing explanations, noting in particular that explanation and argumentation goes *"hand in hand"* with writing. Importantly, both teachers did not abandon their beliefs about the importance of writing for assessment and communication, but the nature of what they began to notice and assess (in the ongoing, everyday sense of the word) changed. A quote from Kim describes what the teachers came to believe was worth assessing.

A year after delivering the CA, teachers retained these beliefs about writing instruction and believed writing played a key role in helping students engage in explanation and argumentative reasoning. In many cases we inferred teachers tacit, or unexpressed, beliefs through their descriptions of their own instructional practices. The teachers adopted a claims-evidence-reasoning (CER) approach to supporting written explanations and engaging in explanation and argumentation and both teachers reported investing time in teaching students to write explanations and arguments in class. More generally, the teachers came to believe that writing was a valuable tool for reasoning. Thus, after the CA implementation, both teachers demonstrated an expansion in beliefs about the functions of writing, from communication and assessment, to explanation argumentation and reasoning in general. This change was also evidence in their choice of tasks and reported instructional practices preceding and after the CA implementation.

Before teachers implemented CA, their choice of writing tasks was not very systematic. When asked about their instructional approaches, they did not ascribe to using any specific instructional approach nor did they mention reserving any time for writing instruction. In that first year, as we describe in our methods section, we made efforts to help the teachers learn to incorporate writing during instruction. We helped them to develop ideas for instructional lessons that incorporated writing with a focus on constructing and critiquing explanations and arguments and then asked them to construct their own lessons. In one of the lessons, the task they designed corresponded to their beliefs. In this task, students were asked to formulate and choose the best explanation or "claim" made about a science phenomenon (i.e., population change). Although they did make efforts to encourage students to construct and critique each other's proposed explanations (in this case, their claims), the teachers had the whole class brainstorm together the "everything you remember" about the relationship between population and pollution. As shown below, the "claim" that they had students make really led logically to only one correct answer. Thus, although the teachers wanted students to critique each other's claims, there was little diversity in the claims and very little opportunity for students to disagree and argue.

By contrast, after the CA implementation, the teachers independently continued using the claims, evidence and reasoning approach and integrated it into their usual practice. Now they focused more on creating tasks that allowed students to construct diverse explanations and critique them. For example, they had students conduct an investigation where light was shown through different filters to shine on different color objects. Rather than have the students construct a traditional lab report, as they described in earlier interviews, they made the conclusion to their existing labs a “scientific explanation” that students had to construct using a claims-evidence-reasoning framework. Since the students had collected their own data, there were a variety of findings which led to a variety of responses. This created opportunities for students to construct, critique, and argue about explanations, practices which were not as well-supported by their choice of tasks before the CA.

Anderson (2003) showed how teachers’ choice of tasks reflect teachers’ beliefs. We also found that changes in teachers’ beliefs aligned with changes in their instructional practices. As the teachers’ beliefs about the functions of writing changed from communication and assessment to promoting reasoning, and from deficit to asset models of students, the teachers invested more instructional time creating opportunities for students to construct, critique, and argue about explanations. Even a year after the PD concluded, teachers maintained this practice and embedded it throughout their instruction, regardless of how demanding the pacing of the curriculum was.

Effects of the Science Writing Instruction for Students with LD and identified as EL

The science writing instruction study that is presented in Chapter 4 was designed to improve the quality of written science explanations of students with LD and those who are identified as EL. We developed and evaluated an intervention that packaged both cognitive and linguistic supports to help students write causal and mechanistic explanations in science. Procedural facilitator (i.e., cue cards) helped students to generate relevant ideas when writing science explanations (e.g., think about what they want to explain). I also provided contextualized language activities that deconstructed the language parts (nouns, verbs, adjectives, and prepositions) used to write science explanations, which helped students recognize features of high-quality explanations. These components were delivered using CA, where learning was guided through phases of instruction including, modeling, collaborative practice, and independent practice to ensure mastery of taught strategies and skills. My findings indicate that while students initially wrote recounts of the phenomenon, after instruction, their explanations included more causal and mechanistic details. Students also wrote longer sentences that were more grammatically and lexically complex. As a result, the holistic writing quality improved across all participants.

During baseline, students with LD wrote longer (M = 26.30) explanations than those who are EL (M = 22.23). This pattern was reversed after instruction as students who are EL (M = 55.10) wrote more than those with LD (M = 51.19). However, students with LD showed more improvement after instruction (τ = .89) than those who are EL (τ = .83). The students with LD (Chris, Steven, and Taylor) wrote on average 26, 15, and 25 words before instruction and 67, 49, and 49 after. On average, the student who are EL (Sarah, David, and Tom) wrote 33, 23, and 23 words during baseline and 63, 51, and 49 words after instruction. Both groups of students wrote slightly less during maintenance, but this average was still substantially more than during baseline. Chris, Steven, and

Taylor wrote 52, 39, and 53 words and Sarah, David, and Tom wrote 41, 54, and 34 words. On average, students with LD and those who are EL wrote 43 and 48 words on the maintenance probe.

On average, all students wrote recounts rather than explanations before treatment, resulting in an average score ranging from 0 to 1. After instruction, they wrote explanations with mechanistic details that demonstrate the underlying processes of the observed phenomenon, resulting in higher average scores. During baseline, students with LD and those who are EL wrote mostly recounts of the phenomenon, obtaining average scores of .57 and .67 for causality. The students with LD appeared to benefit from instruction upon visual analysis. Chris, Steven, and Taylor scored on average .80, .50, and .71 before instruction, demonstrating stable baseline trend. Then, they scored 5.71, 5, and 5.20 post-instruction, which did not overlap with the baseline data.

Tau-U analysis demonstrated that their causal and mechanistic reasoning improved substantially after instruction ($\tau = .97$). After instruction, students who are EL ($M = 5.30$) wrote explanations that contained slightly more mechanistic details than those with LD ($M = 4.77$). On average, Sarah, David, and Tom scored .6, .83, and .29 during baseline with a steady trend, and they scored 4.71, 5.20, and 5.20 after instruction. Visual inspection demonstrated no overlap between baseline and post-instruction data. Students who are EL wrote comparable explanations before the intervention and they all made comparable improvements after instruction. Tau-U analysis showed that their causal and mechanistic reasoning improved substantially after instruction ($\tau = .99$). All students maintained an improved quality of causal and mechanistic reasoning four weeks later. The students with LD made a slight improvement during maintenance ($M = 5$) and those who are EL scored slightly worse than immediately after instruction (M = 4.78).

During baseline, students wrote one-sentence responses, which often lacked clarity (e.g., “it” or “thing”). After instruction, they used more specific terms (e.g. “baby oil,” “hydroxide,” “chemical reaction”) in their writings. During baseline, students with LD and those who are EL wrote one-sentence responses, obtaining average scores of 1.05 and 1 on grammatical and lexical sophistication. After instruction, students with LD (M = 3.19) wrote explanations that were slightly more complex than those who are EL (M = 2.79). On average, the students who are EL scored 1, 1, and 1 during baseline and 3.57, 3, and 2.8 after instruction. Although instruction did not focus on sentence construction, the students who are EL improved substantially after instruction on grammatical and lexical complexity (τ = .96). All students continued to show improved levels during maintenance. Students who are EL made a slight improvement (M = 3.01) and those with LD scored slightly worse (M = 3.00).

During baseline, students with LD and those who are EL did not often respond to the prompt, resulting in average scores of 1.74 and 1.77 on this measure. After instruction, students with LD (M = 4.39) wrote explanations that were similar to that produced by those who are EL (M = 4.62). The students with LD scored on average 4, 5.2, and 1.43 before instruction and 5, 4.33, and 4.67 post-instruction. Consistent with our findings from visual analysis, Tau-U supported that they demonstrated significant improvement after instruction (τ = .92). On average, the students who are EL scored 1.8, 2, and 1.43 during baseline and 4, 5.2, and 1.43 after instruction. Upon visual analysis, we found that their baseline data did not overlap with the post-instruction and maintenance data. Tau-U analysis also demonstrated that they made substantial improvement on the holistic writing quality after instruction (τ = .93). All students maintained improved levels of holistic writing quality two weeks after instruction ended. Students with LD made a slight improvement (M = 4.67) and those who are EL scored slightly worse than immediately after instruction (M = 4.33).

Implications for practice

What Do Teachers Need to Know?

There are several implications for science teachers in general education classrooms. The movement for inclusion led to increased diversity of learners in general education science classrooms, including more students with LD and those who are EL. Science teachers are at the frontline to assess, design, and implement lessons that are effective for all students, including these populations of students. Findings from the intervention study reported here indicate that both subpopulations benefitted from language instruction, when supported with cognitive tools.

However, researchers must consider what teachers need to know in order to deliver such forms of science writing instruction. To deliver effective writing instruction, teachers need to be able to deconstruct the language used in science to explicitly instruct students about how to write about science content. In particular, they need to have a clear understanding of the linguistic features such as the textual structure involved when generating and organizing the content. This is especially important when teaching genres that are more analytical such as explanations and argumentation.

Effect of CA on Teachers

Science teachers are called to prepare students for scientific literacy. Yet, many feel unprepared to deliver the much-needed language instruction in class. Consequently, many students continue to struggle to write in class and often, it affects their ability to learn in class. Researchers need to think about ways to better prepare science teachers in order to match the diverse learning needs of their students. One way to address this issue is through a long-term PD focused on implementing writing instruction. CA, in particular, allows teachers to foster independence in students when completing sophisticated tasks like constructing and critiquing scientific explanations. In our study, these experiences led to enduring changes in two participating teachers' beliefs and practices. Using a CA to deliver disciplinary writing instruction appears to be a promising way to promote students' critical thinking and reasoning skills in students.

Caveats of Using CA in Science Classrooms

CA is a model of instruction designed to help novice learners by making the expert thinking process visible for those who might otherwise struggle with such cognitive processes and it has been successfully applied to teach domain-general literacy skills. The model has not been applied more broadly in general education science classrooms to deliver writing instruction because of two reasons. First, successful implementation depends on teachers' content and pedagogical understanding about the content or skill that they teach. CA is an instructional model that allows teachers to guide and scaffold instruction, which means that they need to be able to respond appropriately to their students' learning needs. For teachers to be able to successfully guide instruction, they need to first, understand the content or skill they are teaching, and also ways in which they can scaffold students' learning. Therefore, successful implementation is contingent upon long-term and continuous PD that provides feedback about their instruction and corresponding training on developing literacy skills.

Teachers also need to have "expert knowledge" about the content or skill they are teaching. Knowledge and skills required to write are different from disciplinary core ideas in science. Science teacher education programs traditionally do not offer literacy instruction to candidates. Therefore, many science teachers lack understanding of how to deliver effective literacy instruction. To fill in this gap, we need to help them develop solid understanding of literacy skills, including writing, required to achieve academically in science classrooms. This includes knowledge about different genres in science. Without such knowledge, they will not be able to effectively scaffold learning when delivering writing instruction. For these reasons, application of CA in content-area subjects have been limited, especially in science classrooms.

Future Directions for Research

Defining the Language of Science

There is not one universal feature and structure for science writings across literature and the most challenging task in this field of writing research is in defining academic language. Scientific writing is challenging to define because it interweaves scientific practices such as reasoning and critiquing with linguistic features (syntax, sentence structures, vocabulary). So, as a community of researchers, it would be helpful to determine some consensus about the characteristics of each genre and what constitutes high quality exemplars. Such a common understanding will help improve scientific literacy outcomes in our students.

Aligning the Intervention with School Curriculum

Disaggregating content from writing instruction helped us identify writing instruction that works. Based on our understanding of effective writing instruction looks like, future research should explore how to integrate approaches such as the one described here with content-based instruction. We anticipate that such programs will require a comprehensive science literacy intervention that supports inquiry-based learning (as recommended by NGSS, 2013). Attempting such programs are likely to improve the depth and accuracy of students' writings and be more applicable for teachers to use in science classrooms.

Conclusion

Our goal as educators and education researchers in the 21st century is to foster learners who are scientifically literate. Science teachers need to be well-equipped to serve the needs of all students to realize this goal, including students with LD and those who are EL. Collectively, our work shows that a CA is a promising model of instruction to support both science teachers and the academically, culturally, and linguistically diverse students who they teach to construct written scientific explanations. As a nation, we need to explore and invest in efforts such as those explored here to will unlock the full potential of academically, culturally, and linguistically diverse students.