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Disciplinary Literacy and Disciplinary Computational Thinking: Theorizing the Similarities to Support Teachers Learning to Teach Ambitiously

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Abstract

Increasingly, teachers are asked to teach literacy in discipline-specific ways, while also incorporating computational thinking standards into an already full curricula. If teachers are to meet these high standards, we will need to more effectively support their professional learning. In this conceptual piece, I argue that both literacy and computational thinking have much to learn from one another, since they are both discipline-specific social practices. In doing so, I disentangle disciplinary literacy, disciplinary computational thinking, and digital literacies. I then draw upon research in the learning sciences, which has begun to uncover how we might teach teachers to support their students to participate in discipline-specific social practices by leveraging social constructivist, rather than cognitive constructivist, views of learning. I draw upon this body of work to outline four design conjectures for how we might better support teachers' learning about both disciplinary literacy and disciplinary computational thinking.

Keywords: disciplinary literacy, computational thinking, ambitious instruction, teachers' learning, digital literacies

At first blush, literacy and computational thinking could not, perhaps, be more different. And yet, both are foundational social and intellectual practices in which students must learn to participate if they are to meet their own personal and professional goals. School in the United States are recognizing this, and calls for more teachers, in more disciplines, to teach literacy in discipline-specific ways are sounding more loudly (e.g., Shanahan & Shanahan, 2008), even as these same teachers are simultaneously being expected to incorporate computational thinking standards into an already full curricula (e.g., 2018 State of Computer Science Education, 2018).

In this conceptual review of the literature, I argue that,b y conceptualizing literacy and computational thinking as sets of discipline-specific social practices, we can begin to draw upon seemingly disparate bodies of research—especially that coming out of the learning sciences—in order to more effectively design learning opportunities for pre- and in-service teachers. The goal of this paper, then, is to highlight similarities between *disciplinary literacy* and *disciplinary computational thinking,* outlining findings upon which we might draw if we wish to support teachers to teach both disciplinary literacy and disciplinary computational thinking.

In the first half of this paper, I will outline how both literacy and computational thinking are indispensable social and intellectual practices which constitute, and are constituted by, all disciplinary work—hence the opening use of the terms *disciplinary literacy* and *disciplinary computational thinking*. Such views of literacy and of computational thinking as social practices are predicated on a social constructivist view of learning, stemming from Vygotsky (1986), which are primarily concerned not with how individuals construct knowledge through cognition, but rather with the social processes that conspire to afford and constrain participation in a given community's valued social practices (e.g., Lave & Wenger, 1991). In this view, knowledge is "shaped by micro-and macro-cultural influences and evolves through increasing participation within different communities of practice" (Windschitl, 2002, p. 141). Learning disciplinary literacy and disciplinary computational thinking, then, involves an apprenticeship into the communities in which those social practices are made meaningful.

Yet social constructivist theories of learning are just that: theories of learning. They are not theories of teaching. As many have pointed out (Windschitl, 2002; Lave, 1996), teaching and learning are distinct processes, and social constructivist theories of learning require new theories of teaching, which are different than those recommended by a cognitive constructivist theory of learning (e.g., Piaget, 1971). To that end, recent research coming out of the learning sciences has introduced the idea of *ambitious instruction*—a set of instructional stances capable of supporting learning from a social constructivist point of view. Many scholars of ambitious instruction have also worked to develop and theorize a set of andragogies—or ways of teaching adults—for supporting teachers to teach ambitiously (e.g., Ball & Cohen, 1999; Grossman & McDonald, 2008; Grossman et al., 2009; Cohen, 2011; Lampert et al., 2013; Dutro & Cartun, 2016; Kazemi et al., 2016). I draw upon this body of work to outline how research on learning to teach ambitiously can guide us to support teachers' learning about both disciplinary literacy and disciplinary computational thinking.

Disciplinary Literacy as Social Practice

This paper is grounded in sociocultural theories of literacy, which understand literacy, writ large, as a set of practices through which people use language and symbol systems to actively construct meaning in conversation with the expectations and conventions of particular communities, which Gee (2008) has called Discourse communities, and Lave and Wenger (1991; Wenger, 1998) have termed communities of practice. Of course, these theories are distinct, but—for our purposes—they are similar in that they highlight that all forms of language use—in speaking, listening, reading, and writing—are deeply influenced by the work that particular communities aspire to get done (their purpose, or—in Wenger's [1998] words—their "joint work"), by a community's value system, by the conventions of language and tool use that typify these communities, and by an individual's identity within that value system—both the positionings that individuals take up and those that are foisted upon them (Holland et al., 1998).

Although the idea that literacy is a social practice has been explicated numerous times—and in differing contexts—since the publication of Shirley Brice Heath's (1983) seminal work on the subject, it is worth paraphrasing a short summary here in order to ground readers from multiple disciplines in an example of what, more practically speaking, the statement that literacy is a social practice really means. Since, in the vernacular, literacy is often associated primarily with reading, let us begin there: When people read, they often appear to be engaged in the "same" act: It seems as if they are staring at words or film or infographics or musical scores or lines of code, and it is difficult to access what it is the reader is actively doing. We say that they are, on some level, reading. However, as literacy research repeatedly points out, reading is not reading is not reading (i.e., Heath, 1983; Gee, 2008; Leu et al., 2004; New London Group, 2000; Kress, 2003, etc.). Heath's (1983) ten-year ethnographic study of how children participated in "literacy events," in school and at home and at the grocery store, highlights that community value systems implicitly define what literacy is and how it should be practiced.

Heath found that children from the pseudonymously named Maintown, which was comprised of White families from the middle and upper class, understood reading to be a practice in which they were to listen to a parent reading and, periodically, to answer questions to which the answer was already known. They were also, for example, to make connections between events in books and their own lives, such as what happened at the grocery store. For students in Roadville, on the other hand, in which students were largely White members of the lower middle class, reading a book with a parent was a practice in which students were expected to sit quietly and listen. The tacit value-system related to reading in Roadville was that of respect for authority, and students were expected to listen attentively as though the reading were an important presentation. In Trackton, a largely lower-middle class, African-American community, valued literacy practices were largely oral, focusing on students' generation of spoken text, rather than reading what others had written (Heath, 1983).

This brief example from Heath's work highlights the idea that literacy is a social practice. That is, literacy takes place in specific communities and the ways in which literacy is accomplished are influenced by the expectations, purposes, and value systems of those communities. In Roadville, authority was highly valued, and children were thus expected to avoid interrupting during parental presentations, such as the read aloud. Thus, literacy practices that were valued in Maintown, such as questioning the text, (and indeed are valued in our current research community, e.g., Shanahan & Shanahan, 2012) were not encouraged, because such an interruption might be considered an affront to parental authority. In Maintown, books and stories were valued as connected to all peoples' daily lives, so children were expected to make connections between events in books and those that occurred in children's lives.

More recent work has built upon Heath's (1983) findings, highlighting that, from a social practice perspective, literacy is something that we do, and the way in which we do it is neither culturally determined nor is it entirely idiosyncratic (Gutierrez & Rogoff, 2003; Holland et al., 1998). Instead, the way an individual practices literacy is informed by the values and purposes of particular communities. I will show that the same is true of computational thinking, but first I turn to a few communities that are of particular importance to understanding both literacy and computational thinking in P-12 schools: academic disciplines.

Disciplinary Literacy: How Literacy Practices Differ across Disciplines

The idea of disciplinary literacy builds upon foundational findings from Heath and others that literacy is not something we have or do not have (i.e., we cannot be either literate or illiterate), but is instead something we practice in the context of the communities in which we live and move and, most importantly, accomplish work. The communities in question in disciplinary literacy, of course, are academic disciplines. Central to an understanding of disciplinary literacy is the idea that students must learn to read, write, and think like experts in particular disciplines (Dobbs, Ippolito & Charner-Laird, 2017). Disciplinary literacy does not expect students to be experts, but they are expected to approximate the literacy practices of expert practitioners in a subject area (Shanahan & Shanahan, 2012). Thus, disciplinary literacy rests on sociocultural theory's foundational idea that learning is a change in identity and practice through participation in particular communities of practice (Lave & Wenger, 1991). In classrooms in which disciplinary literacy is taken up, asking students to read is about apprenticing students into the literacy practices that commonly characterize work in particular academic disciplines (Lent & Voigt, 2018; Dobbs, Ippolito & Charner-Laird, 2017): They are to "read like" an historian, a scientist, and so on.

Research continues to specify the literacy practices that experts in particular fields rely upon most (e.g., Lent & Voigt, 2018; McConachie & Petrosky, 2010; Lesh, 2011; Wineburg, Martin & Monte-Sano, 2013). In Lent and Voigt's (2018) recent, and popular, book on the subject, the authors adumbrate the ways that practitioners read, write, and think in each of the following disciplines: English, math, science, social studies, art, world language, health, music, and physical education. They could have listed many others. To provide just a few examples of discipline-specific literacy practices, Lent and Voigt (2018) point out that, when mathematicians read, they “isolate information they have been given and look for information they need” (p. 277). They also, “identify patterns and relationships” (p. 277). When mathematicians write, they “seek precision.” In English Language Arts, by contrast, readers read by “finding meaning through literary techniques” and “identifying underlying messages that evolve as theme” (p. 271). When they write, they “understand how to flexibly utilize organization, details, elaboration, and voice to enhance meaning” (p. 272). Historians most frequently contextualize and corroborate textual evidence when they read, attending to who the author was, as well as why and when the author wrote (Lesh, 2011). In short, disciplinary literacy is, “an understanding of the ways in which knowledge is constructed in each content area and how literacy supports that knowledge in discipline-specific ways” (Lent & Voigt, 2018; see also, McConachie & Petrosky, 2010).

A note on differences between content-area literacy and disciplinary literacy. The term *disciplinary literacy* is often used interchangeably with *content-area literacy*, but these are different—and, it turns out, these differences are consequential to the analogy I am building between disciplinary literacy and disciplinary computational thinking. In brief, the idea of content-area literacy stemmed from the hope that, if educators across the content areas worked to better support students’ reading comprehension, then students would—presumably—develop better reading comprehension skills, which would allow them to perform better and learn more in the content areas (Lent & Voigt. 2018; Dobbs, Ippolito & Charner-Laird, 2017). As such, content-area literacy lays out a number of reading comprehension strategies that can be useful across content areas, such as those that typically fall into “one of seven categories of cognitive routines that good readers presumably use fluidly and automatically: making connections, generating questions, visualizing, making inferences, determining importance, synthesizing, and monitoring or fixing up comprehension" (Dobbs, Ippolito & Charner-Laird, 2017, p. 16). In short, content area literacy is about supporting students' general reading comprehension strategies.

Research has shown modest support for these strategy-based approaches, but problems have also arisen: Namely, "content-area reading instruction alone has not produced widespread academic achievement for adolescents, and some secondary teachers and literacy researchers have wondered whether the limits of this instruction prevent it from fully preparing adolescents to meet college and workplace literacy demands" (p. 16). The goal of this paper is hardly to instigate further arguments about the usefulness of either approach—indeed, researchers do not deny that the two might offer useful complementarity (Shanahan & Shanahan, 2008; International Literacy Association, 2017). Instead, the point is that content-area literacy and disciplinary literacy are founded upon very different theoretical bases and indeed have different goals.

In disciplinary literacy, the goal is not necessarily for history students, for example, to learn a host of content-neutral reading comprehension strategies. Instead, the goal is that history students will learn to think like historians—which necessarily entails learning to read and write as historians do. Thus, a U.S. History teacher teaching from a disciplinary literacy standpoint would work not to teach generally applicable comprehension strategies, but would instead "consider how best to model for her students the ways in which she reads historical texts, as a disciplinary insider trained as a historian. She would still be teaching the skills of comprehension, but in ways that are more closely connected to the ways historians think and communicate" (Dobbs, Ippolito & Charner-Laird, 2017, p. 18). Content-area and disciplinary literacy, then, are not interchangeable, and neither—as we shall see—are computer science and computational thinking.

Disciplinary Computational Thinking:

Computational Thinking as a Set of Discipline-Specific Social Practices

The term *computational thinking* is often used interchangeably to mean *computer science* and sometimes confused with *digital literacy*. But computational thinking predates the invention of computers by thousands of years (Erwig, 2017), and so we must differentiate it carefully from both computer science, which is the "study of computers and algorithmic processes, including their principles, their hardware and software designs, their applications, and their impact on society" (Tucker, A., Deek, F., Jones, J., McCowan, D., Stephenson, C., & Verno, A., 2006, n. p.), and digital literacy[1] if we are to support teachers to teach it in authentic and discipline-specific ways. According to the International Society of Technology Educators, and the Computer Science Teachers of America (2011), computational thinking is a "problem-solving process that includes (but is not limited to) the following characteristics:

- Formulating problems in a way that enables us to use a computer and other tools to help solve them.

[1] According to Hobbs and Coiro (2018), digital literacy is an "expanded conceptualization of literacy that is responsive to the ongoing changes in information and communication technologies that are part of everyday life" (p. 2). They note that the term is variously defined by a variety of constituents, and that maintaining a level of vagueness in the definition allows them to build relationships and buy-in during teachers' professional development around digital literacy. That said, it is important to note that, even from this broad perspective, digital literacy generally refers to superscreenic activities related to information and communication technologies, whereas computational thinking can take place in plugged or unplugged environments, but is—regardless—very much at the heart of subscreenic work.

- Logically organizing and analyzing data
- Representing data through abstractions such as models and simulations
- Automating solutions through algorithmic thinking (a series of ordered steps)
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources
- Generalizing and transferring this problem solving process to a wide variety of problems" (Operational Definition of Computational Thinking for K-12 Education, 2011, n. p.)

Computational thinking is often spoken of in terms of four common elements: pattern recognition, algorithms, decomposition, and abstraction (e.g., Jocius & Joshi, 2019). As both ISTE and CSTA point out, all of these aspects exist in various forms across disciplines. Consider the following table, available on ISTE and CSTA's joint website, which highlights that the PRADA framework names a series of skillsets, strategies, or practices that can be used across any number of disciplines:

[Insert Table 1 about here.]

Of course, computational thinking has typically been understood as foundational to fields such as computer science, mathematics, and engineering (Wing, 2006), much as literacy has historically been understood as existing within the limited purview of Language Arts and English classes. However, the table above highlights that computational thinking, like literacy, can be found across a number of disciplines. One computer scientist noted that, working with 'educators from multiple diverse disciplines meant learning to 'disconnect computational thinking from computer science'" (Barr & Stephenson, 2011, p. 51). Computer scientists, of course, practice computational thinking, but they do it in ways specific to their discipline much as the literary critic reads, but does so in particular ways.

It is also notable and relevant that, like disciplinary literacy practices, computational thinking practices both shape—and are shaped by—the communities in which they are enacted. Put more directly: Aspects of the PRADA framework become different in more and less fundamental ways as they are selected for use according to different standards and for different purposes within differing disciplinary communities. Recognizing motifs in English Language Arts, for example, certainly requires that one recognize patterns, but this is different than recognizing the patterns that constitute a fractal in mathematics, which is still different from recognizing a pattern in computer science. By thinking about computational thinking as disciplinary, we allow ourselves to recognize (and teach) the ways that expert practitioners in a number of disciplines actually take up computational thinking.

These examples highlight the ways that computational thinking is a social practice, because it is taken up by members of particular communities of practice according to the value systems and joint work of those communities—students of literature recognize patterns in terms of motifs in order to analyze fiction for overarching themes; mathematics students recognize patterns in order to find more parsimonious means of solving problems, and computer science students recognize patterns in order to write algorithms. In the next section, I consider another central aspect of social practices: They mediate—and are mediated by—the tools that characterize particular communities of practice (Gee, 2008; Wertsch, 1998; Holland et al., 1998).

The Relationship between Tool Use and Social Practice

In the case of both computational thinking and literacy, the particular tools with which humans undertake their respective social practices afford and constrain—and, indeed, create—

these social practices. Tools are among the defining aspects of particular communities of practice (Wenger, 1998). For example, in Wertsch's (1998) oft-cited explication of some of sociocultural learning theory's foundational claims, he offers an example of the pole vaulting community as a well-defined community of practice. In non-technical terms, their joint work was to use a communally agreed-upon pole with which those who identified as pole vaulters might jump over a regulation-sized stick, which was of a size and height that—again—the pole vaulting community of practice had determined. However, at one point, some members of the pole vaulting community began to use poles constructed of a new material. Wertsch describes the controversy that ensued. There were arguments within the community about what counted as pole vaulting, given the new materials, and—indeed—who should be included and who ostracized based upon their embrace of the new tool and whether or not, essentially, the practices in which these members were engaged could rightfully be understood as pole vaulting. Eventually, Wertsch notes, the community itself was redefined, because the new innovation altered, to varying degrees, what counted as that community's most central and valued work.

Tool Use and Literacy as a Social Practice

Those who study literacy can attest to the ways that technological innovation has recently—and, indeed, since the dawn of the written word—brought about new conceptions of what it means to be literate. Since the 1990s, entire movements have sprouted around new literacies, multimodal literacies, and digital literacies—to name just a few—in light of new technological advances (ex. Leu, 2004; Hull & Schultz, 2002; Kress, 2003; The New London Group, 2000; Lankshear & Knobel, 2006).

Of course, even before the advent of computers and then the internet, technology has had deep implications for literacy: Socrates perhaps infamously claimed that writing, which was itself a central technological advancement, would be detrimental to human knowledge because it would limit dialogue (Plato, 1952). The reciprocal relationship between the invention of the printing press and an explosion in literacy practices, even if not necessarily expressed in those terms, has long been part of academic parlance. To provide one of an untold number of more recent examples, scholars have written about the ways that reading comprehension practices are influenced by the structure of the internet: Indeed, it is a central premise of New Literacy Studies that the internet "makes new social practices possible, with technologies such as instant messaging, social networks, blogs, wikis, and email, among others" (Leu et al., 2014, p. 2). In this view, there are at least five "processing practices" in which students engage as they participate in online research and comprehension, such as reading to define important questions and to locate information, to critically evaluate online information, to synthesize information, and reading and writing to communicate online information (Leu et al., 2014, p. 3). These practices are differentiated from comprehension practices in offline, school-based contexts, where students are more likely to be given a purpose for reading and to construct meaning through only a single text. Thus, social practices, such as reading comprehension, are always tightly intertwined with the technologies through and with which they are performed.

However, Street (1984) highlights that literacy is not determined by the technologies through which it is made available: Instead, literacy, is "more than just the 'technology' in which it is made manifest…it is a social process in which particular socially constructed technologies are used within particular institutional frameworks for specific social purposes" (Street, 1984, p. 97). This brings us back to the world of disciplinary literacy, which would stipulate that literacy practices differ not only in terms of the tools available for use, but also according to the expectations and conventions of the community of practice in which people practice literacy.

Street (1984) directs our attention to the idea that "particular socially constructed technologies" are "used within particular institutional frameworks for specific social purposes." Thus, if we take academic disciplines to be "particular institutional frameworks," which they certainly are (Cole, 1998), then we must also consider that these disciplines construct technologies in particular ways. Put more succinctly, individuals participate not only in online reading and offline reading practices, but—more specifically—in scientific reading practices in particular genres in on and offline spaces. In short, a scientist accessing a confidential data set from an online server will read her Excel spreadsheet in a far different way than a literary critic will read the daily poem that shows up in his inbox on a Tuesday morning, although both are participating in online disciplinary literacy practices. Thus, tools are situated within communities of practice. They afford and constrain literacy practices, but they do not determine them.

Tool Use and Computational Thinking as a Social Practice

In the same way, computational thinking is a social practice which is undertaken and made meaningful within the bounds of particular communities of practice, and those communities of practice are characterized by particular forms of tool use. Experts in the field of computational thinking continue to point out that computational thinking predates the invention of computers or the internet, and that computational thinking can and should be conducted in both "plugged" and "unplugged" spaces (e.g., Papert, 1980). In other words, computational thinking requires neither electricity nor keyboards nor wi-fi: "Consider folding a paper airplane, driving to work, cooking a meal, or even DNA transcription…these are all examples of computation" (Erwig, 2017, p. viii). Each of these is an example of computational thinking, because it involves the systematic decomposition of steps into a reproduceable algorithm that can be used in another situation to solve the same problem—we can use the same set of steps to create another paper airplane or to make more meatballs. Indeed, I note with some fascination that we might exchange Street's (1984) use of the term *literacy* for *computational thinking* and say that computational thinking is "more than just the 'technology' in which it is made manifest…it is a social process in which particular socially constructed technologies are used within particular institutional frameworks for specific social purposes" (1984, p. 97)[2]. Thus, computational thinking is, like literacy, a social practice that mediates and is mediated by disciplinary communities of practices and their attendant tools.

Ambitious Instruction:

A Developing Theory of Teaching for Social Constructivist Theories Of Learning

As I have outlined, then, both disciplinary literacy and disciplinary computational thinking are founded on social constructivist views of learning, but teaching and learning are distinct processes (Windschitl, 2002; Darling-Hammond, 1996; 2016). Hence, particularly in math and science education, the field is working to understand the implications for teaching of

[2] In reciprocal fashion, a computer science textbook notes that the "essence of computation is the transformation of representation" (Erwig, 2017, p. 3), which sounds eerily like a semiotic understanding of literacy: the transformation of symbols, which are—by definition—representations, into meaning (e.g., Kress, 2003). Erwig (2017) later adds that computation is a systematic and decomposable process through which representations can be manipulated (p. 24). We might debate the extent to which literacy is a systematic process, but anyone familiar with the idea of phonemic segmentation can tell you that literacy involves decomposition. In the same vein, Grover and Pea (2013) point out that diSessa pioneered the term computational literacy, which has largely been supplanted by Wing's (2006) use of the term computational thinking: "Although the phrase and notion of *computational thinking* now seems to be preferred over *computational literacy*, in research and practice today the two phrases are often used interchangeably" (p. 39).

social constructivist theories of learning. They have called this instructional stance *ambitious instruction* (e.g., Windschitl, 2002).

Broadly, *ambitious instruction* is characterized by an epistemological stance that assumes knowledge is alive with inquiry, interpretation, and argumentation, not a set of inert properties to be acquired (Lampert & Graziani, 2009; Cohen, 2011). In other words, ambitious instruction takes a social constructivist stance on knowledge. As such, ambitious instructors position students as sensemakers capable of interacting with ideas using the tools and practices of a discipline (Lampert et al., 2013; McDonald, Kazemi & Kavanaugh, 2013). In ambitious instruction, students are:

> routinely asked to apply knowledge in diverse and authentic contexts, to explain ideas, interpret texts, predict phenomena, and construct arguments based on evidence, rather than to focus exclusively on the acquisition of predetermined “right answers” (Windschitl, 2002, p. 137).

Thus, ambitious teachers co-participate with students in a “risky quest for knowledge” (Darling-Hammond, 2016, p. 86). To partner with students in this risky quest, teachers must simultaneously adapt to the contingencies of the classroom, discover what students are “thinking, puzzling over, feeling, and struggling with,” and respond to that thinking in ways that support disciplinary inquiry (Darling-Hammond, 2016). From this perspective, the function of schools is to “create the social contexts (zones of proximal development) for mastery and the conscious awareness of the use of cultural tools (e.g., language and technologies of representation and communication) so that individuals can acquire the capacity for higher-order intellectual activities” (Windschitl, 2002, p. 141).

In a passage that will resonate particularly with those interested in disciplinary literacy and disciplinary computational thinking, Windschitl (2002) explains that, from a social constructivist perspective, the role of the teacher is to act as a disciplinary expert, apprenticing students to the social practices of the discipline:

> [Teachers] become representatives of canonical science, mathematics, or history in the classroom. As such, they are disciplinary practitioners who must model intellectual skills and dispositions for students and thus engage them in scientific, mathematical, or historical discourse. Students participate in activities relevant to the discipline, using tools commonly available to practitioners as they carry on their work. Tools are seen as powerful mediators of learning. They include language itself, computers, diagrams, maps, math symbols—anything that can facilitate the co-construction of knowledge among learners (Roth, 1995; Wertsch, 1991). (Windschitl, 2002, p. 141)

What Windschitl (2002) describes here are the underpinnings of disciplinary literacy, and—I argue—of disciplinary computational thinking, although he does so prior to Shanahan and Shanahan's (2008) landmark publication outlining disciplinary literacy (Dobbs, Ippolito, Charner-Laird, 2017) and before Wing's (2006) seminal piece on computational thinking.

What is striking here is not who published these ideas first—but rather their marked similarities: This view dovetails substantially with research from those who practice and study disciplinary literacy (Lent & Voigt, 2018; Gabriel & Wenz, 2017; Hinchman & O'Brien, 2019) in terms of its call for teachers to model for students how to participate in the disciplinary practices in which scientists, mathematicians, and historians, to name only a few, commonly participate. Students must also be asked to participate in these practices using the tools that characterize each discipline, and by participating in authentic disciplinary inquiry (see also, Lent

& Voigt, 2018; Monte-Sano et al., 2017; Dobbs, Ippolito, Charner-Laird, 2017; Shanahan & Shanahan, 2008; 2012).

Given that both disciplinary literacy and disciplinary computational thinking are underpinned by social constructivist conceptualizations of learning and ambitious understandings of instruction, we might begin to understand how to design opportunities for teachers' professional learning about disciplinary literacy and disciplinary computational thinking by studying and drawing lessons from research on teachers' learning about ambitious instruction. In the following sections, I discuss major findings from research on how teachers learn to teach ambitiously, interweaving these findings—where possible—with findings from the developing literatures on supporting teachers' learning about disciplinary literacy and what I am calling disciplinary computational thinking[3]. In this way, I aim to lay some groundwork for understanding how teachers can be supported to apprentice students into particular, socially constructed literacy and computational thinking practices in the context of their content-area or disciplinary instruction.

How Can Teachers Be Supported to Teach Disciplinary Literacy and Disciplinary Computational Thinking Ambitiously?

Based upon a conceptual synthesis of the literature, as well as my own work, which has focused on supporting teachers to teach ambitiously in middle school mathematics, writing in and out of the English Language Arts, and in disciplinary computational thinking, I highlight several central precepts (Author, 2015; 2016; under review). Among them are that learning to teach ambitiously requires teachers to:

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[3] Research on how teachers teach computational thinking is more scarce than is research on disciplinary literacy. This is why research in disciplinary literacy is more frequently referenced in these sections.

- have access to a coherent and ongoing system of job-embedded instructional supports
- participate in job-embedded collaborative inquiry
- investigate and enact particular teaching practices
- develop a professional vision of disciplinary concepts and practices

A Coherent and Ongoing System of Job-Embedded Instructional Supports

As research continues to investigate the ways that teachers can be supported to take up ambitious forms of instruction, findings are converging on an important point: support for teachers' learning about ambitious instruction must be continuous, ongoing, and embedded in teachers' daily work if it is to support teachers' changes in practice (Jackson et al., 2018; Wilson & Berne, 1999; Hawley & Valli, 1999; Ball & Cohen, 1999). As disciplinary literacy authors Lent and Voigt (2018) put it, "Going down the same path we have gone in the past with professional development initiatives that aren't embedded or based on continuous learning will cause us to stumble and, inevitably, take us away from our most important destination—increased student learning" (p. 11). Instead, teachers must have access to continuous, job-embedded professional support in which teachers collaborate meaningfully with experts and peers in ways that are close to the daily work of teaching (Jackson et al., 2018).

Jackson and her colleagues (2018) describe a teacher learning system, which includes "pull-out" professional development—single or multi-day workshops that happen outside the school building. However, they—along with a broad consensus in the teacher learning research (Jackson et al., 2018; Dobbs, Ippolito & Charner-Laird, 2017; Wilson & Berne, 1999; Hawley & Valli, 1999; Ball & Cohen, 1999)—insist that pull-out professional development cannot stand alone if teachers are to take up ambitious instructional practices. Instead, they highlight the need for classroom level supports, such as co-teaching and modeling by an instructional coach or teacher leader (see also, Gibbons & Cobb, 2017), as well as teacher learning activities designed to be embedded in teachers' school-based collaborative work (see also, Author, 2017). Similarly, those who have studied teachers' professional learning about disciplinary literacy recommend "combining professional learning structures to create an effective framework" for teachers' learning (Dobbs, Ippolito & Charner-Laird, 2017). Research on supporting teachers to teach ambitiously highlights inquiry-focused teacher workgroups as essential to supporting teachers' learning.

Job-embedded Inquiry as a Support for Professional Learning

The main structure upon which Dobbs and her colleagues (2017) draw, in their comprehensive study of a professional learning initiative focused on disciplinary literacy, is teacher workgroups, because they are ongoing, regular, and job-embedded opportunities for teachers to collaborate on problems of practice. However, like Jackson and her colleagues (2018) and Lent and Voigt (2018), Dobbs and her colleagues (2017) warn of the pitfalls of the oft-employed professional learning communities (PLCs; DuFour & DuFour, 2004), in which teacher "collaboration" is too often reduced to "required weekly meetings" in which teachers are asked to participate in compliance exercises involving standardized test data (Dobbs, Ippolito & Charner-Laird, 2017). As Lent and Voigt put it:

> The formulaic standardization of PLCs left little room for authentic, recursive professional literacy learning, and often teachers weren't given opportunities to wrestle with and find solutions to the teaching and learning challenges they faced in their own classrooms and schools (p. 12)

Thus, research on the development of ambitious instruction—and research specific to disciplinary literacy—highlights that teachers' collaborative learning needs to be part of a continuous, coherent system that is centered in professional learning grounded in teachers' practice (Cobb et al., 2018).

This body of work highlights that, if such instruction is to be both intellectually rigorous and equitable, we must take seriously that ambitious teaching is inherently situated, context-dependent work in which the specific cultural and academic histories of particular students, as well as the discipline in which teaching takes place, require teachers to make near-constant professional decisions about how students' thinking might be made visible, when to model their own thinking for students, and how to use strategies like these in tandem in order to apprentice students toward more sophisticated performances of disciplinary thinking (e.g., Author, under review; Author, 2019; Philip et al., 2018; Jackson et al., 2018; Kazemi et al., 2016; Lampert et al., 2013). In other words, a set of stagnant precepts about how to enact particular teaching strategies, offered in a decontextualized workshop setting, will not help teachers to make sense of those practices with respect to key aspects of ambitious instruction—students, teaching, and content (Cohen, 2011; Author, 2015; Horn, 2020).

Research on supporting teachers' learning about disciplinary literacy concurs, noting that teachers need opportunities to "tailor what they learn to the specific students in their classrooms" (Dobbs, Ippolito & Charner-Laird, 2017, p. 29). In this view, teachers' collaborative inquiry processes should be based in a problem of practice, such as a group of English teachers in Dobbs and her colleagues' (2017) study, who asked, "I have been working on teaching my students to link evidence to arguments, but I'm finding that more than half of them are still struggling with more basic reading and comprehension. How can I balance the need to shore up those more basic foundational skills and work on developing disciplinary literacy skills at the same time?" (p. 34).

Although such groups can be difficult to implement well (e.g., Author, 2017), the benefits of teacher-led, collaborative inquiry are many and have been well-described in the literature (Louis, Marks & Kruse, 1996; Grossman et al., 2000). Those who study teachers' learning about disciplinary literacy, in particular, have highlighted that collaborative communities focused on inquiry into instruction in disciplinary literacy can support teachers' increased individual and collective efficacy, increased teacher knowledge, as well as increased motivation and engagement (Lent & Voigt, 2018). These findings are particularly important because, as Lent and Voigt (2018) point out, teachers' collective efficacy has been earmarked as a central factor in influencing students' learning (Hattie, 2016 as qtd. in Lent & Voigt, 2018, p. 22), and because teachers' self-efficacy in both disciplinary literacy and disciplinary computational thinking, as well as their knowledge of both, may be low (Angeli et al., 2016; Tovani, 2004; Shanahan & Shanahan, 2008; Hinchman & O'Brien, 2019). By centering professional learning about ambitious instruction in teachers' collaborative inquiry, teachers take up the learning practices they are teaching their students, which is a key aspect of high quality professional support for teachers (Borko, 2004): They participate in inquiry-oriented problem-solving (Windschitl, 2002).

Participate in Investigations and Enactments of New Instructional Practices

Twenty years ago, Ball and Cohen (1999) highlighted that, in order to learn to teach ambitiously, teachers should learn about practice in the context of their professional practice. Since then, their work, along with that of a number of scholars in teacher education (i.e., Grossman et al., 2009; Grossman & McDonald, 2008; Lampert et al., 2013; etc.) has taken this credo seriously, working to develop andragogies capable of supporting teachers to learn how to teach ambitiously in the context of their professional practice. Ongoing and carefully theorized work coming out of the Core Practices Consortium continues to highlight that teachers' professional learning is enhanced when teachers participate in *pedagogies of investigation and enactment*[4] (Lampert et al., 2013; McDonald, Kazemi & Kavanaugh, 2013; Grossman et al., 2009; Grossman & McDonald, 2008; etc.).

In pedagogies of investigation, teachers investigate, analyze, and otherwise learn about new pedagogical practices. For instance, teachers might read about and discuss new pedagogical practices, analyze videotaped examples of pedagogical practices (Lampert et al., 2013), and/or participate in work that is expected of students—at a level suitable to teachers, as is characteristic of high quality PD (Borko, 2004). In pedagogies of enactment, teachers participate in role-play and enactments of new pedagogical practices at levels of increasing authenticity and complexity (Grossman et al., 2009). For example, teachers may begin by role playing a particular pedagogical practice with a small group of teachers. After they have received feedback on their work in these relatively low-stakes enactments, teachers may co-teach with a more accomplished colleague before enacting the practice alone in a classroom. Importantly, after each cycle of enactment, teachers participate in new rounds of investigation, interpreting and analyzing students' thinking and classroom events in light of the enactment (Lampert et al., 2013). Findings that such a cycles supports teachers' learning have continued to be robust across a number of disciplines in which ambitious teaching is valued, such as science, mathematics, history, literature, and writing (i.e., Windschitl, Thompson & Braaten, 2011; Kazemi et al., 2016; Aldston, Danielson, Dutro & Cartun, 2018; Author, 2016; under review). They also dovetail well with other findings in the teacher learning literature, often particular to disciplinary literacy,

[4] For insightful critiques, see Zeichner (2012) and Philip et al. (2018). Note that these critiques are concerned, mostly, by how a "core" or "high leverage" teaching practice is defined, rather than with the design of these andragogies, which rest upon solid theorizing about concept development from the standpoint of social constructivism (Vygotsky, 1986; Smagorinsky, Cook & Johnson, 2003; Author, 2016; Author, under review).

which suggest that inquiry is key to teachers' learning (e.g., Dobbs, Ippolito & Charner-Laird, 2017).

Developing a Professional Vision of Disciplinary Concepts and Practices

Given that teachers often report a lack of self-efficacy—and, indeed, interest—in either disciplinary literacy or in disciplinary computational thinking, one might ask how teachers learn what disciplinary literacy or disciplinary computational thinking are. Since Shulman's (1986) landmark work on teachers' forms of knowledge—pedagogical knowledge, content knowledge, and pedagogical content knowledge—the field has reached consensus that, in order to teach well, teachers must have content knowledge. This work has been extended into subject specificity (e.g., Ball, Thames & Phelps, 2008) and also to better understand how teachers integrate technology into their pedagogical work (Koehler & Mishra, 2009). Thus, teachers' need for content knowledge has long been a settled question.

But content knowledge is not all that teachers need: Teachers also need to know how to transform content for pedagogical purposes, which Shulman (1986) called pedagogical content knowledge (PCK). Shulman's (1986) provides an invaluable framework for helping us to understand what teachers need to know and understand in order to be effective teachers. Yet it is based—largely—on a cognitive constructivist view of learning, unlike disciplinary literacy and disciplinary computational thinking. Thus, we must ask what it means for teachers to develop PCK from the standpoint of ambitious instruction. What do teachers need to know and be able to do to teach ambitiously?

Horn (2020) specifies what PCK is from a social constructivist view of learning: Pedagogical judgement, which includes the ability to make decisions about classroom practice in light of pedagogical action, which is what teachers do in the classroom; pedagogical responsibility, which is about what teachers view as their ethical, academic, and bureaucratic obligations; and pedagogical reasoning, which is teachers' interpretations and rationales for this work. In other words, it is not enough to know that expert readers visualize as they read, that computational thinking involves pattern recognition, or that differentiation is an important instructional technique. Teachers must learn to make use of this information—and much, much more—to make professional decisions about their work (Author, under review).

To support pedagogical judgement, teachers must develop a professional vision of ambitious instruction in disciplinary literacy and disciplinary computational thinking. For Windschitl (2002), as for others who have long studied teachers' learning (e.g., Lortie, 1975; Grossman, 1990), teachers rarely have a vision of ambitious instruction, as such practices were not commonplace when teachers were in school themselves (and, incidentally, they are still not commonplace; e.g., Snow-Renner & Lauer, 2005; Whitney et al., 2008; Smagorinsky, Cook & Johnson, 2003). This is likely to be particularly true in both disciplinary computational thinking and disciplinary literacy, as teachers report low self-efficacy in both (Angeli et al., 2016; Lent & Voigt, 2018).

Thus, teachers must have an image of ambitious teaching in order to enact it themselves. As Elmore and colleagues (1996) highlight teachers' practices are "unlikely to change without some exposure to what teaching actually looks like when it's being done differently and exposure to someone who could help them understand the difference between what they were doing and what they aspire to do" (p. 241 as qtd. in Windschitl, 2002, p. 161). Indeed, research on instructional change highlights the importance of teachers' ability to envision ambitious versions of instructional practice: Munter (2014) surveyed hundreds of teachers about their views of ambitious mathematics instruction, comparing teachers' descriptions of what ambitious classroom life looks like to observations of those same teachers' instruction over the course of four years. He found that teachers' instruction did not become more ambitious until teachers were able to articulate a vision of what ambitious math instruction looks like in the context of a classroom.

Taken together, these studies highlight the need for teachers who are learning to teach disciplinary literacy and disciplinary computational thinking to develop a professional vision of what those look like in the classroom and how they can be supported. In the world of disciplinary computational thinking, for instance, it is not enough for teachers to know what decomposition is; they must also have examples of what it means to decompose a process in everyday life, what it means to decompose a process used to write a poem, and what it means to decompose a process so that it can be represented as an algorithm that a computer can use. In the same way, in disciplinary literacy, teachers must develop a vision of what it means to draw an inference from a scientific journal article and what it means to draw an inference from a piece of literary fiction (Lent & Voigt, 2018; Dobbs, Ippolito & Charner-Laird, 2017).

Yet, these examples only detail the disciplinary literacy and disciplinary computational thinking processes that learners (teachers and students) undertake. Teachers must also develop a professional vision of instructional practices they might use to support students' development of disciplinary literacies and disciplinary computational thinking, such as modeling or using inquiry-oriented collaborative workgroups. Work in this area is ongoing, but the professional learning structures noted above—collaborative teacher workgroups focused on problems of practice, as well as cycles of investigation and enactment—are showing great potential as supports for teachers' development of both pedagogical judgments and a professional vision of ambitious disciplinary literacy and computational thinking.

Discussion

Both literacy and computational thinking can be conceptualized as social practices that characterize the work of particular communities of practice; namely, academic disciplines. Although this may, to some, sound like an abstruse theoretical point, it has far-reaching implications for how literacy and computational thinking might be taught across the disciplines. As we have seen, teaching literacy and computational thinking as social practices—indeed teaching from a social constructivist stance on knowledge construction in any area—requires us to shift our epistemic stances on what knowledge is, focusing not on internal mental constructions, but instead on the means through which individuals in communities move toward more central participation in those communities (Lave & Wenger, 1998).

Scholars have begun to specify what it means to teach from a social constructivist stance, which they have called *ambitious instruction* (e.g., Windschitl, 2002; Grossman & McDonald, 2008; Grossman et al., 2009; Lampert et al., 2013; Dutro & Cartun, 2016; Kazemi et al., 2016; Ball & Cohen, 1999; Cohen, 2011). By recognizing that teaching both disciplinary literacy and disciplinary computational thinking will require an ambitious stance on instruction, we can draw upon insights from this body of work to inform the design of professional learning opportunities for teachers. Research across a number of content areas, including—significantly—disciplinary literacy, continues to better understand how supports for teachers' professional learning about ambitious instruction can be designed and implemented. It agrees that such supports must allow teachers to:

- have access to a coherent and ongoing system of job-embedded instructional supports
- participate in job-embedded collaborative inquiry
- investigate and enact particular teaching practices

- develop a professional vision of disciplinary concepts and practices

This research is particularly salient to both disciplinary literacy and to disciplinary computational thinking, because recent history highlights that, in the case of disciplinary literacy, teaching students a host of content-neutral reading comprehension strategies, without embedding those strategies in the context of the social practices that characterize particular disciplines, has led to modest gains in high school students' reading comprehension scores, but has not deeply influenced students' content area learning (e.g., Lent & Voigt, 2018; Jacobs, 2008).

The need to understand computational thinking as a social practice is as much a bureaucratic necessity as a theoretically sound decision: If computational thinking is expected to be taught exclusively by computer science teachers, we are currently in a position in which it will rarely be taught. Although an increasingly number of state departments of education are adopting or developing standards that address skills and concepts in computer science—in 2018, 22 states had such standards, and an additional 11 were in the process of developing them (2018 State of Computer Science Education, 2018)—only about one-third of US high schools offer courses in computer science. One reason may be that too few teachers have the background knowledge and skillset to teach courses in computer science: In the year 2016, institutes of higher education in 39 states and the District of Columbia combined to graduate exactly zero teachers qualified to teach computer science. The other 11 states graduated 37 teachers certified to teach computer science—total. There are a plethora of reasons for this, not least that many states do not have a certification in computer science which they could bestow on a qualified candidate (2018 State of Computer Science Education, 2018). Thus, we must ask: Who will be teaching the computer science standards that the near majority of states have now developed?

The answer is the existing teaching force. In many states, these standards are explicitly expected, at the K-8 level, to be integrated into teachers' existing content area or disciplinary teaching. Thus, it is incumbent upon us, in higher education, to work toward a better understanding of how we might support teachers to integrate computational thinking into their existing instruction. We can begin by building upon what we have learned from social constructivist theories of learning, which have led to the birth of both disciplinary literacy and to deepening understandings of ambitious instruction. Disciplinary views of literacy and computational thinking may feel new, but they most certainly are not. There is good evidence that building from here is a wise course of action.

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