Science and Literacy in Teacher Education: What do Preservice Teachers Need to Know and Be Able to Do?

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Introduction

Expectations for students and teachers in this country are increasing, as standards are being put in place that expects more sophisticated work. One area in which new expectations are being put in place is in the intersections and synergies between science and literacy. A basic argument of this paper is that engaging in science-and-literacy practices can support the development of richer science learning *and* literacy learning. For example, by engaging high school students with authentic science texts (e.g. a *Scientific American* article, a scientist's blog post, a passage from a science textbook), science teachers can work on a key scientific practice related to obtaining, evaluating, and communicating information, as it relates to students' investigative work. Such engagement will also promote these students' literacy knowledge, practices, and capacity, more generally. At the same time, those same high school students can be engaged by their English Language Arts teacher in reading informational science text (e.g., a passage from a science news article). Here, the goal might be oriented more squarely on literacy goals such as distinguishing between fact and opinion or making connections between representations in words and diagrams. Similarly, an elementary teacher—responsible for teaching both language arts *and* science—can capitalize on children's literacy practices in science (e.g., by asking the children to write claims supported by evidence) toward the goals of promoting both important science learning and reinforcing literacy knowledge, practices, and capacities.

In this paper, we address two key questions:

1. What do we know about the skills that teachers need to learn in order to support literacy for science in both English Language Arts (ELA) and science classrooms? In short, *what do preservice teachers need to know and be able to do for literacy learning for science?*
2. What does research tell us about how teacher education (and professional development) opportunities should be structured to help teachers learn how to implement the science literacy practices in the Framework for K-12 Science Education and the Next Generation Science Standards and to implement the science literacy aspects of Common Core State Standards in ELA? We will focus on teacher education. Thus, in short, question two is, *what can teacher education do to support the development of the knowledge and practice identified in question one?*

In answering question one, we explore the Next Generation Science Standards (NGSS; Lead States, 2013) and the Common Core State Standards in ELA (NGAC and CCSSO, 2010). In answering question two, we draw briefly on examples from the University of Michigan teacher education program as illustrations of how working on literacy learning in science can look in teacher education, grounding these examples in the literature, and then close with a discussion of implications for teacher education.

What do preservice teachers need to know and be able to do?

The Framework for K-12 Science Education (NRC, 2012) and the Next Generation Science Standards (NGSS Lead States, 2013) set ambitious new standards for K-12 students in science. At the same time, the Common Core State Standards (NGAC and CCSSO, CCSSO, 2010), which include standards specific to science and other technical subjects, do the same in ELA. In this section, we briefly review these new standards documents, and describe their implications for what preservice teachers need to know and be able to do, with a particular focus on the work of supporting literacy for science learning.

Implications of the Framework for K-12 Science Education and the Next Generation Science Standards

The Framework for K-12 Science Education and the Next Generation Science Standards interweave three strands: disciplinary core ideas, scientific practices, and crosscutting concepts. Performance expectations in the Standards are written to integrate these three strands; thus, rather than learning content separate from "process skills", the new Standards expect students to be able to use scientific practices to develop conceptual knowledge, and to use conceptual knowledge as they engage meaningfully in scientific practices.

The disciplinary core ideas in the Next Generation Science Standards are organized in four disciplines: physical sciences, life sciences, earth and space sciences, and engineering, technology, and applications of science. Crosscutting concepts are ideas such as patterns, cause and effect, and stability and change. The Standards name eight practices (see the following for elaboration on some of these practices: Berland & McNeill, 2010; Bricker et al., in press; Schwarz et al., 2009; Windschitl & Thompson, 2006). These include:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Thus, a teacher of science (at the elementary, middle school, or high school level) must have rich disciplinary understandings of science ideas and concepts. The teacher must also understand and be able to engage meaningfully in scientific practices such as planning and carrying out investigations or analyzing and interpreting data. But deep understandings, such as a scientist would have, are insufficient for being an effective *teacher* of science. In addition to deeply understanding disciplinary core ideas and practices, teachers need content knowledge for teaching (CKT; Ball, Thames, & Phelps, 2008): the rich amalgam of disciplinary understandings with special knowledge such as knowledge of content and students, and knowledge of content and curriculum. Teachers will need this CKT not just related to disciplinary core ideas (i.e., what is traditionally thought of as "the content"), but also related to the disciplinary practices (i.e., they also need what Davis & Krajcik, 2005, referred to as pedagogical content knowledge for disciplinary practices).

As an example, we use Ball and colleagues' (2008) notion of CKT to analyze what a teacher will need to know to teach an elementary science lesson on the phenomenon of condensation (the change of state from water vapor to liquid water). A teacher would need to understand the mechanism of the process of condensation (that when water vapor in the surrounding air cools, its molecules lose energy and thus it forms liquid water on a cold surface). This would be an aspect of her common content knowledge – the content knowledge most adults could be expected to have. She also would need to be able to anticipate and recognize typical alternative ideas students may have about condensation (such as thinking that water leaks through a can of ice water). This would be knowledge of content and students. She would need to be able to plan a set of experiences with the phenomenon that could help to address specific alternative ideas (such as putting food coloring in the water or showing condensation forming on a cold mirror). This would be her knowledge of content and teaching. She should be able to draw on existing lesson plans to help her devise these experiences; this would demonstrate her knowledge of content and curriculum. Because she might want to integrate the students' learning of this disciplinary core idea related to the nature of matter with the scientific practice of developing and using models, she also would need to have strong specialized content knowledge around the scientific practice of modeling. She would need knowledge of content and students, and content and teaching, and content and curriculum to support her in developing a lesson or series of lessons that would support her students in doing such integration. For example, she would need to know typical problems that her students are likely to have as they engage in scientific modeling, and techniques she can use to support them in developing and using models of this phenomenon.

Yet even this *knowledge base* is insufficient for effective teaching. Teachers need to be able to *use* their knowledge in their teaching practice. Thus, teachers must develop an effective repertoire of teaching practices. Particularly useful teaching practices can be termed "high-leverage teaching practices" (Ball & Forzani, 2009). High-leverage practices are teaching moves that are "essential for skillful beginning teachers to understand, take responsibility for, and be prepared to carry out" (Ball & Forzani, 2009, p. 504). The University of Michigan teacher education program is oriented around a set of high-leverage teaching practices, such as explaining core content, leading a whole class discussion, modifying curriculum materials, eliciting and interpreting students' ideas, and conducting a meeting with a parent. These high-leverage practices provide one curricular focus for the elementary teacher education program, and are elaborated as competencies in the U-M secondary teacher education program. A high-leverage practice is the result of decomposing the work of teaching (Ball & Forzani, 2009; Grossman et al., 2009). Our high-leverage practices are written without reference to specific subject areas. Most are taught and enacted, however, in subject-specific ways (Davis & Boerst, in review). It is impossible, for example, to explain core content in a subject-neutral way; this practice is inherently grounded in the relevant discipline.

We used two types of considerations as we made choices about what to include in our set of program-level high-leverage practices (Davis & Boerst, in review). First, we drew on considerations related to *high quality teaching*. These considerations include that the practice was likely to be useful in (a) advancing students' learning, (b) many contexts and content areas, and (c) confronting inequities in American schools and schooling. These considerations helped us identify practices that are crucial for preservice teachers to learn, among the myriad possibilities. Second, we drew on considerations related to *high quality teacher education*. These considerations include that the practice could (a) be learned by a beginner, (b) be assessed, and (c) usefully serve as a building block in learning to do the work of teaching. Other considerations in this set include that the practice (d) is unlikely to be learned well only through teaching experience in the classroom and (e) could be justified and made convincing to preservice teachers as both meaningful and useful (Ball, Sleep, Boerst, & Bass, 2009). Employing these considerations allowed us to narrow our focus to a set of the core practices of teaching (Grossman & McDonald, 2008) that were truly high-leverage for preservice teachers.

Thus, drawing on this framework, an effective teacher of science needs a rich knowledge base *and* a rich practice base to be able to engage in the kinds of ambitious science teaching implied by the Next Generation Science Standards. The teacher needs content knowledge for teaching the disciplinary core ideas, crosscutting concepts, and practices, and needs effective teaching practices for teaching these, as well. (Note that "practice" is used both to refer to scientific practices and teaching practices; see Lampert, 2010, for a discussion of some of the multiple meanings of "practice.")

What does all of this mean specifically when we consider what teachers need to know and be able to do in order to engage in effectively supporting students in literacy for science and the literacy-related practices in both science and ELA classrooms? While all the scientific practices have implications for literacy and depend upon rich literacy practice and capacity, the particular focus in this paper are the scientific practices most centrally associated with literacy, namely constructing explanations, engaging in argument from evidence, and obtaining, evaluating, and communicating information. We term these science-and-literacy practices, as a shorthand. Thus, teachers—in elementary classrooms where a single teacher typically teaches both ELA and science, and in middle and high school classrooms where one teacher is likely to teach ELA and another science—need to have deep understandings of these scientific practices and their connections to literacy. While these NGSS expectations, at the secondary level, most centrally implicate science teachers, ELA teachers, too, must be positioned to support the development of these science-and-literacy practices.

Implications of the Common Core State Standards for English Language Arts

At the same time, the Common Core State Standards for English Language Arts describe equally important ambitious goals for students' literacy knowledge, practice, and skill. Students need to develop knowledge, practice, and capacity in literacy, in strands related to reading, writing, speaking, listening, and language. The standards expect students to read and make use of increasingly sophisticated text, to write a variety of genres of text, to communicate flexibly, and to use language effectively and in keeping with the conventions of English.

The Common Core State Standards move the goals forward in expecting this knowledge, practice, and capacity to be developed not just in ELA classrooms, but also in the classrooms supporting learning in other academic content areas, including science classrooms. Indeed, at the sixth through twelfth grade level, besides the standards focused on ELA-focused reading, writing, speaking, listening, and language, the CCSS-ELA also has two additional sets of standards, one aimed at teachers of history and social studies, and the other aimed at teachers of science and technical subjects. These are intended to provide grade-specific standards aimed at developing the literacy requirements of particular disciplines, such as science. These focus on reading and writing in these disciplines. This focus on disciplinary literacy (e.g., Moje, 2008) and the use of literacy practices across content areas is one unique feature of the CCSS-ELA in comparison to earlier standards documents. Thus, to effectively meet the expectations of the CCSS-ELA, teachers—in science and ELA—need to have rich content knowledge for teaching literacy knowledge and practice, and need to have a rich teaching practice base for doing so, as well, as described above.

What does this mean for literacy learning for science? Specifically, teachers need to be able to support students in developing literacy knowledge, practices, and capacities in the context of science. These include work such as *distinguishing among fact, judgment, and speculation*; *integrating information expressed in words with information expressed visually* (e.g., in a data table); and *valuing evidence* (as described in the Common Core State Standards for ELA). For example, imagine that a high school biology teacher wants to engage her students in a rich genetics unit. One component of the unit could be to communicate with genetics experts, through posting questions in an online forum and sending drafts of their research design plans. In this case, the experts play two important roles: as an authentic audience for the students' communication, and as a source of information (see Bricker et al., in press). An ELA teacher working with the biology teacher could complement this work, supporting students in reading informational genetics-related text through the application of key disciplinary literacy strategies.

It is important to remember that the nature of scientific text is challenging. These texts often employ technical, unfamiliar language; the language is often dense and structured in less-than-accessible ways; and the texts include not just words, but also diagrams, graphs, charts, equations, and symbols (Bricker et al., in press; Gee, 2008; Lemke, 1998; Palincsar, 2013). Thus, supporting K-12 students in making sense of these texts—during language arts *and* science instructional time—is critical. As Palincsar (2013) notes, "the designers of the CCSS were quite concerned that students be supported to learn how to engage in constructing meaning with challenging text" (p. 11). Teachers, then, must demonstrate the capacity to support children in engaging in this close, attentive reading of text.

Summary: What do preservice teachers need to know and be able to do?

In sum, to be well-positioned to be able to support students' literacy learning for science, teachers need a complex integration of disciplinary knowledge and practices, content knowledge for teaching for supporting students in developing that knowledge and practice, and a rich array of teaching practices for supporting students in doing so. The science teacher needs depth in disciplinary core ideas and practices and the ELA teacher needs depth in literacy; the elementary teacher needs both. A secondary science teacher, secondary ELA teacher, *and* an elementary teacher all need to understand how to integrate science-and-literacy practices in support of student learning. In other words, teachers need to understand how the two subject areas (science and ELA) can be synergistic. This is a tall order! Because, due to these synergies, these expectations for teachers of different subject areas and at different grade levels are complex, Table 1 summarizes, at a gross level, the expectations.

Table 1: Expectations of science and ELA teachers in elementary and secondary.

	Teaching science	*Teaching literacy / language arts*
K-5 teacher	Typically, a teacher in a self-contained elementary classroom teaches both science (all disciplines) *and* language arts. In teaching science, this teacher is expected to help students meet the expectations in the NGSS (the integration of disciplinary core ideas, scientific practices, and crosscutting concepts), including the science-and-literacy practices such as obtaining, evaluating, and communicating information; constructing explanations; and engaging in argumentation.	Typically, a teacher in a elementary self-contained classroom teaches both science (all disciplines) *and* language arts. In teaching language arts, this teacher is expected to help students meet the CCSS-ELA standards for reading, writing, speaking, listening, and language. Many of these standards have to do with the use of informational text (e.g., on science topics), writing informative texts, and constructing arguments.
6-12 teacher	Middle school and high school science teachers are expected to help students meet the expectations in the NGSS (the integration of disciplinary core ideas, scientific practices, and crosscutting concepts), including the science-and-literacy practices such as obtaining, evaluating, and communicating information; constructing explanations; and engaging in argumentation. Science teachers should be supporting their students in these practices, as they relate to specific disciplinary core ideas. Related, secondary science teachers are also expected to help students meet the expectations in the CCSS-ELA standards for literacy in science and technical subjects, including reading and writing in science.	Middle and high school ELA teachers are expected to help students meet the expectations in the CCSS-ELA standards for reading, writing, speaking, listening, and language. Many of these standards have to do with the use of informational text (e.g., on science topics), writing informative texts, and constructing arguments. These *support* the goals outlined in the CCSS-ELA standards for literacy in science and technical subjects. Therefore, ELA teachers can help support the literacy-related practices being used in secondary science classrooms.

In the next section, we describe how teacher education can approach the task of preparing preservice teachers so they begin to develop these capabilities.

What can teacher education do to support the development of that knowledge and practice?

Case Example: The University of Michigan

The University of Michigan has engaged for the last decade in research-based reform of our teacher education program. As such, we use an elaborated example from our elementary teacher education program and a brief description of our secondary teacher education program to begin to address the second question, about what teacher education can do to support the development of the knowledge and practice needed by teachers to support rich literacy for science.

Three pillars guide the design and curriculum of the program at U-M: high-leverage teaching practices, content knowledge for teaching, and ethical obligations of teaching. As noted above, by high-leverage practices, we mean practices that are highly useful for teachers across content areas and contexts, but are also learnable by novices and are unlikely to be learned well simply through experience teaching (Ball & Forzani, 2009; Davis & Boerst, in review). Examples of high-leverage practices that we focus on in our teacher education program include leading a whole class discussion, eliciting and interpreting students' ideas, and conducting a meeting with a parent. The second pillar of the program is content knowledge for teaching (Ball et al., 2008). By this we mean understanding the subject area deeply oneself, being able to anticipate students' ideas, and knowing strategies and representations to use to support student learning. The third pillar of the program is a set of ethical obligations of teaching (TEI Ethics Project Working Group, 2009). Examples include treating all students with respect, seeing all students as being able to learn, and teaching academic subjects with integrity to the discipline.

We turn next to a description of how the elementary teacher education program is organized—using those three pillars—and how that organization supports preservice teachers in learning to support children in literacy for science.

The University of Michigan Elementary Teacher Education Program

The course sequence in the four-semester undergraduate elementary teacher education program includes, in part, the following courses:

- Children as Sensemakers #1
- Literacy #1
- Facilitating Classroom Discussions
- Literacy #2
- Children as Sensemakers #2
- Science Methods
- Student Teaching

Disciplinary literacy is threaded throughout the program. For example, the Facilitating Classroom Discussions class works on leading whole class discussions (a high-leverage practice) in the context of social studies content (e.g., apartheid in South Africa); the focus is on the engagement in text-based discussions (Kucan & Palincsar, 2013).

To illustrate ways in which elementary teacher education can work on both literacy and science, to help to prepare preservice teachers to be able to do this work effectively with students, we elaborate on examples from the program. The Children as Sensemakers #1 class was developed by Annemarie Palincsar to support preservice teachers early in the program in developing an orientation, and knowledge and skills related to the idea, that children are constantly engaged in making sense of the world, and that teachers mediate that sensemaking (Palincsar & Shaughnessy, 2012). This class takes place during the very first month of the program, when the preservice teachers are juniors. The main high-leverage practices of focus are *eliciting and interpreting students' ideas* and *implementing an instructional strategy in response to student thinking.* The class focuses on science content knowledge for teaching around the day-night phenomenon (i.e., what causes day and night).

Field-based assignments for this class include conducting a series of interviews and interactions with one child in first or second grade. In the first interaction, the preservice teacher elicits the child's initial ideas about what causes day and night. In the second interaction, the preservice teacher engages in an interactive reading (elaborated below). In the third interaction, the preservice teacher interviews the child to elicit their (potentially new) understanding of the phenomenon. All three of these field-based experiences are heavily scaffolded by the teacher educator. For example, interview protocols are provided, and the book and other materials for the interactive reading are provided along with a plan for conducting the interactive reading.

A preservice teacher, pseudonym Eliza, doing this work with a first- or second-grade child, can serve as an example. Like her colleagues, she engaged in an interactive read-aloud with the intent of promoting the child's sensemaking, using both a written text called "What makes day and night" and a simple physical model (involving a Play-Doh "earth", a flashlight "sun", and a toothpick intended to represent where a person is standing on earth). In reviewing a video record of how Eliza conducted this interactive read-aloud, we see that she launches the reading and then begins using text-based discussion strategies such as "What is the author comparing the earth to?" Here, we see connections to Common Core standards that expect students to "ask and answer questions about key details in a text" (CCSS.ELA-Literacy.RI.1.1) and "ask and answer questions to help determine or clarify the meaning of words and phrases in a text" (CCSS.ELA-Literacy.RI.1.4). We also see clear evidence of the preservice teacher supporting the child in the Next Generation Science Standards' practice of "obtaining, evaluating, and communicating information."

Later in the interactive reading, Eliza introduces the physical model. While her discourse strategies are still developing (e.g., "So, that's how it works!"), we also see her asking the child to make sense of the illustration in the book in conjunction with the words (engaging the child in "us[ing] the illustrations and details in a text to describe its key ideas"; CCSS.ELA-Literacy.RI.1.7) and then to make sense across two "texts", here the book and the physical model (engaging the child in "identify[ing] basic similarities in and differences between two texts on the same topic (e.g., in illustrations, descriptions, or procedures)"; CCSS.ELA-Literacy.RI.1.9). Eliza uses the physical model in conjunction with the written text to help the child make sense of the day/night phenomenon. We see the preservice teacher supporting the child in the scientific practices of "obtaining, evaluating, and communicating information" as well as "developing and using models", and we see Eliza building toward engaging the child in the scientific practice of "constructing explanations."

During this first month of the program preservice teachers are not expected to reach full mastery of their teaching practice, of course. The program loops back to a central focus on science, with emphasis on the scientific practices including the literacy-related scientific practices, in the science methods course that takes place one year later, in the preservice teachers' third semester of the program. The focus of this course is to develop preservice teachers' ability to enact science lessons and develop the knowledge and practices related to science lesson enactment. In the science methods course, preservice teachers work on high-leverage practices such as *explaining core content*, *eliciting and interpreting students' ideas*, and *using curriculum materials*. Preservice teachers develop a range of science CKT, because the lessons preservice teachers teach are keyed to their field placement classrooms. The field-based assignments for the class include teaching two science lessons.

How does Eliza teach an investigation-based science lesson one year later, after a year in the program? We see that she continues to incorporate science-and-literacy practices in her teaching—here with more sophistication. Her lesson in her fourth-grade pre-student teaching classroom was focused on decomposers and their role in ecosystems. We see Eliza moving seamlessly between supporting students in making first-hand observations of their decomposition cups (i.e., small containers filled with cucumbers, perlite, and, in one condition, earthworms) and using text to support their sensemaking about what their observations might mean. Specifically, while the children tell her about what they observe in their decomposition cups with and without worms (the decomposers), she draws their attention back to text they constructed previously in the unit (specifically, a set of graphics intended to depict the process of how a tree and a bison decompose in the natural environment, along with an explanation in words of how that process works). In this lesson, we see connection to the Common Core standard that states that children should "integrate information from two texts on the same topic in order to write or speak about the subject knowledgeably" (CCSS.ELA-Literacy.RI.4.9); here, one text is the graphics and print, and the other "text" is the observations of the decomposition cups themselves. Eliza supports the children in bridging these two texts. We see her supporting students in numerous scientific practices in her lesson, as well: planning and carrying out investigations (with particular focus on making and recording observations); obtaining, evaluating, and communicating information (through the use of the previously-generated text about bison's and trees' decomposition); and analyzing and interpreting data. Again, we see Eliza moving toward supporting students in constructing explanations, as well.

The teacher education experiences were purposefully constructed to support novices in being able to do the work Eliza demonstrates. The Children as Sensemakers #1 class is most heavily directed and scaffolded in the engagement in science-and-literacy practices. However, the elementary science methods class, too, purposefully values these practices and supports preservice teachers in learning to engage in them. Throughout the elementary program, preservice teachers work on applying content-area literacy practices across the academic disciplines. The preservice teachers learn to use informational text with children, conduct text-based discussions, recognize the many kinds of "texts" students need to be able to interpret (e.g., graphs, diagrams, data tables), support students in learning to use academic language and to bridge this to their everyday language, and to use discourse moves that support children in engaging in argumentation.

The University of Michigan Secondary Teacher Education Program

The secondary program reflects different expectations and constraints, of course, because preservice teachers are training to be effective teachers in their major content area. The coherent course sequence in the secondary program includes a course called "Using Literacy to Teach and Learn Science Content in the Secondary Schools" (see Moje & Bain, 2012, for a description), a science methods course, and student teaching. In the secondary science programs (undergraduate and master's), throughout these integrated experiences, preservice science teachers focus on disciplinary literacy practices such as writing to communicate disciplinary knowledge and findings and close reading to obtain information and analyze the validity of claims. They learn to engage in differentiated instruction, particularly to support the range of students in secondary classrooms, and to use strategic scaffolding for learning experiences, using literacy strategies specifically related to science content. They use records of practice from science classrooms (e.g., video records of themselves teaching) to study high-leverage teaching practices (including teaching practices supporting science-and-literacy integration). Their experiences in their field placements each semester enable them to observe their mentor teachers engage in putting these ideas into practice. Thus, as in the elementary program, secondary science preservice teachers are learning to use high-leverage science teaching practices that reflect rich content knowledge for teaching science, and they are developing capacities around engaging students in a range of science-and-literacy practices such as obtaining, evaluating, and communicating information, and engaging in scientific argumentation.

The various courses in the secondary teacher education program focus on several key aspects related to the synergies between science and literacy learning. First, instructors in the program work to make a case to secondary science teachers that professional scientific work is infused with a variety of literacy practices, and therefore middle and high school students also need to engage these critical literacy practices in their science classrooms. For example, much of science hinges on the following: (a) developing explanations about the natural world (e.g., Braaten & Windschitl, 2011), (b) making a case to others that one's explanations have merit and are supported by evidence (e.g., Bell, 2004), (c) participating in a community of practice (i.e., conducting research in the disciplines), including ways of talking and writing, and (d) using a variety of symbol systems (e.g., words, equations, diagrams). The scientific practices foregrounded in the NGSS help make a case to teachers that students should have ample opportunities to engage in these types of activities in science classrooms. In addition, these literacy practices are learning and inquiry tools (see Pearson, Moje, & Greenleaf, 2010).

Second, teacher educators work to help secondary science teachers understand what counts as text in scientific disciplines and science classrooms. Scientific text is multi-modal and middle and high school students need to learn how to "read" various representations such as charts, graphs, diagrams, images, etc.

Third, teacher educators work to help the preservice science teachers better support middle and high school students navigate amongst their everyday languages, and then the science-related technical terminology that they are expected to use as part of their investigative work (see Brown & Spang, 2008, for example). Teacher educators also help the preservice teachers make scientific text accessible to students by using strategies such as text analysis, graphic organizers, and connecting text to students' interests (e.g., Armbruster, Anderson, & Meyer, 1992).

Thus, like in the elementary program, the preservice science teachers at the secondary level learn to engage in teaching practices that support their students in engaging in the science-and-literacy practices so important for learning – at a level of sophistication appropriate for their students in grades 6-12.

Implications for Teacher Education

How can teacher education support preservice teachers in being able to use literacy for learning science and to use science as a means for improving literacy? We highlight five recommendations.

First, teacher education should use innovative pedagogies of practice (Grossman et al., 2009). One such pedagogy is *representations of practice*. Secondary science teacher educators can use videos that show high school science teachers engaging students in using and making sense of authentic science texts (e.g., journal articles) as part of their investigations, for example—this can illustrate the ways teachers need to support students in unpacking the language and structure of such texts. Elementary science teacher educators can do the same, and/or build on print representations (such as classroom vignettes in the NRC report *Taking Science to School*; NRC, 2007; and its practitioner-oriented companion, *Ready Set Science!*; Michaels, Shouse, & Schweingruber, 2008). Such representations of practice can illustrate ways in which science explorations can incorporate meaningful engagement with literacy practices (such as "research conferences" in which students share their preliminary findings with scientists and community members, gain additional insight, and continue to refine their understandings through additional data gathering).

A second pedagogy of practice is *decompositions of practice.* Science teacher educators might choose to provide an instructional framework for science lessons that outlines the main elements of a science investigation lesson, with pointers to opportunities for engaging with a variety of forms of text (e.g., informational text, data tables, graphs, diagrammatic models). Science teacher educators might also provide preservice teachers a lesson plan template that they can use to help them attend to the key elements of lesson design. Such a template can provide reminders about the importance of meaningful discourse moves to promote the norms of discourse in the discipline (e.g., "Why do you think that?" to elicit evidence or reasoning and "What evidence helped you arrive at that claim?" to support argumentation).

Finally, *approximations of practice* can be used to help preservice teachers learn to do the work of teaching. An approximation of practice can be as small as a "turn-and-practice" where a preservice teacher turns to his colleague next to him and tries out a particular discourse move, or as large as a guided public rehearsal (Lampert, Beasley, Ghousseini, Kazemi, & Franke, 2010) of a science lesson. Such approximations of practice can serve as scaffolding for preservice teachers, both supporting their practice and problematizing it for more productive learning (Davis, in review).

Second, the curriculum of teacher education can be organized around a set of high-leverage teaching practices, content knowledge for teaching, and the ethical obligations that should guide preservice teachers' practice (Davis & Boerst, in review). This can support preservice teachers in becoming well-started beginners (Mikeska, Schwarz, & Anderson, 2009). In the context of the science-and-literacy practices, this means that preservice teachers need to be supported in, first, developing the rich disciplinary understandings of science so that they can see the value of such science-and-literacy practices as constructing explanations, engaging in argumentation, and obtaining, evaluating, and communicating information. Thus, the orientation toward content knowledge for teaching must be expansive, beyond disciplinary core ideas and inclusive of scientific and engineering practices (Schwarz, 2009; Windschitl et al., 2008; Zembal-Saul, 2009). In addition, the preservice teachers must be supported in learning to engage in the high-leverage teaching practices most centrally implied by these science-and-literacy practices. This might include leading whole class discussions, explaining core content, and developing norms for discourse that reflect the discipline. Finally, preservice teachers must be supported in engaging in this ambitious work with *all* the students in their classrooms. We say more about this last challenge below.

Third, teacher educators across both literacy and science coursework should support preservice teachers in learning a range of scaffolding strategies that can help K-12 students engage in these science-and-literacy practice. For example, science educators could provide preservice teachers with examples of scaffolding that they can use to support students' meaningful engagement with explanation and argumentation, such as the claim-evidence-reasoning framework (McNeill & Krajcik, 2009; Zembal-Saul, McNeill, & Hershberger, 2013). They could also learn ways to set up participation roles to help build toward the classroom discourse norms of scientific argumentation (Herrenkohl & Guerra, 1998). On the literacy side, they can learn to effectively use prediction guides, anticipation guides, and question guides (Martin, 2002), graphic organizers (Coburn, 2003), and strategies such as text annotation and text summaries (Gomez et al., 2010). These preservice teachers also need to be supported in selecting texts for students to use in the first place (Palincsar, 2013).

Fourth, science teacher educators should capitalize on commonalities across both elementary and secondary teacher education. These science teacher educators can set as a goal the identification of points of overlap, intersections, and leverage with respect to supporting teacher learning across the science-and-literacy practices (e.g., argumentation, explanation, use of information), and the high-leverage teaching practices of focus in their program. Then, after having done so, common instructional approaches can be developed and employed. For example, in our own work across our elementary and science methods classes, we are developing a set of representations of practice in the form of narrative vignettes (Kademian, 2013) to illustrate the ways in which a range of scientific practices, including the use of representations, can be used across elementary and secondary science.

Finally, teacher education programs should infuse disciplinary literacy as a focus throughout coursework and fieldwork (Bain & Moje, 2012; Moje & Bain, 2012). Preservice teachers should have the opportunity, for example, to see students (in the field and through representations of practice) examining literacy-related products such as research articles. They should see students engaging in a range of participation genres that are authentic to the work of scientists and engineers, such as conference talks and research group meetings, so they can begin to recognize that these are not just school-based tasks or, alternatively, only the realm of science – but are meaningful examples of work that both students and scientists can engage in (Bricker et al., in press). Preservice teachers should have the opportunity to work to develop classroom norms for the discourse of argumentation and evidence. They should be able to support students in considering their audience as they make presentations or write reports of findings (Bricker et al., in press). And finally, preservice teachers should be supported in recognizing that meaningful literacy work is infused into both first- and second-hand science investigations; it is not just a tag-on report-writing activity for enrichment or to capture a final-form lab report.

What are the threats to this work on science-and-literacy practices? What might go wrong? One threat is that an emphasis on disciplinary literacy could be interpreted as a move toward teaching science only by text. The Next Generation Science Standards make clear that the full range of practices should be engaged in science learning, and that all are valued; teachers will need support in reaching these expectations. Another possible threat is that texts would be created only by professionals or only selected by the teacher. Instead, teachers must learn to support students in creating texts themselves, as well. A third threat might be an under-estimation of the support students need in engaging in these science-and-literacy practices. Teachers need to anticipate the struggles students will have, and develop strategies to support the students in overcoming those challenges.

In sum, what are the implications for teacher education of the Next Generation Science Standards and the Common Core State Standards for ELA, specifically with regard to what we in this paper are referring to as the science-and-literacy practices? What do preservice teachers need to be able to do? Preservice teachers need to be able to hear and see the science in students' talk, artifacts, and writing. They need to be able to develop discourse norms that allow students to talk and write science and support students in talking science as a sensemaking activity (Lemke, 1990). They need to be able to develop and use scaffolding to support students in constructing evidence-based explanations and arguments (Berland & McNeill, 2010; McNeill & Krajcik, 2009); obtaining, evaluating, and communicating information (Bricker et al., in press); and more generally communicating science to a variety of audiences and using a variety of genres. Preservice teachers need to be able to use, find, interpret, and evaluate informational text effectively to support deep conceptual learning, and be able to support students in doing so. Relatedly, they need to be able to generate, use, and evaluate a *wide range* of texts, including representations of ideas and of data (e.g., tables, graphs, diagrammatic models, simulation data, records of observations, primary texts, informational texts, etc.), and be able to support students in understanding these. They need, then, to be able to engage in text-based discussions (Kucan & Palincsar, 2013) to support students in engaging with that wide range of texts in meaningful ways. Preservice teachers need to be able to support students in attending to audience. Finally, preservice teachers need to be able to do all these things to support *all of the students* in the classroom.

This last point brings us to a few cautions with which we will close. One concern is, how do preservice teachers learn to do this effectively in the range of classrooms across this country? In a time when many students are not reading and writing at grade level, how can teachers best support them? How can teachers learn to do this work with students whose first language is not English? Teacher education must attend in deep ways to these concerns, supporting preservice teachers not just in learning to engage in science-and-literacy practices with students who have had a plethora of opportunities both in and out of school to practice using academic-style discourses , and/or students whose first language is English, but also with students who have not had many opportunities or whose first language is not English. To do so, preservice teachers must learn to capitalize on the strengths these students bring to the classroom and build on those funds of knowledge (Calabrese Barton & Tan, 2009; González, Moll, & Amanti, 2005). Doing so is one strategy to engender rich discourses that bridges everyday discourse norms and science discourse norms (Brown, 2006). Positioning these new teachers to be able to engage in this work with all their students, as recommended by both the Next Generation Science Standards and the Common Core, has the potential for improving the science learning *and* literacy development for the full range of students across the United States.

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