11-1-2020

Disciplinary Literacy and the 4Es: Rigorous and Substantive Responses to Interdisciplinary Standards

H. Emily Hayden
Iowa State University, haydenemily4@gmail.com

Michelle Eades-Baird
SUNY Empire State College

Disciplinary Literacy and the 4Es: Rigorous and Substantive Responses to Interdisciplinary Standards

Abstract

The Common Core State Standards (CCSS) and the Next Generation Science Standards (NGSS) have described discipline-specific literacy skills needed to successfully engage with science concepts, and science assessments ask students to use language in many and varied forms to mediate their science thought and actions and prove mastery of content. Yet many science teachers have not been prepared with skills that help them recognize the ways literacy is integral to the discipline of science, much less integrate it. This research explored the experiences of three classroom science teachers as they worked to enact overlapping English Language Arts and science standards inherent in CCSS and NGSS through inquiry-based instruction. The 4Es' heuristic framed analysis of classroom observations of instruction, teacher interviews, and surveys. Ways the teachers utilized inquiry-based instruction to *E*ngage their students, *E*licit/Engineer their literacies, and *E*xamine and *E*valuate discipline-specific language practices are analyzed, with recommendations for specific, interdisciplinary, and ongoing support teachers will need in order to realize the disciplinary literacy goals of the CCSS and NGSS.

Keywords

disciplinary literacy, science literacy, interdisciplinary standards, 4Es, research collaborations

Disciplines

Language and Literacy Education

Comments

This is a manuscript of an article published as Hayden, H. Emily, and Michelle Eades-Baird. "Disciplinary Literacy and the 4Es: Rigorous and Substantive Responses to Interdisciplinary Standards." *Literacy Research: Theory, Method, and Practice* 69, no. 1 (2020): 339-357. DOI: 10.1177%2F2381336920937258. Reprinted by permission of SAGE Publications.

ACCEPTED

LITERACY RESEARCH: THEORY, METHOD, AND PRACTICE 2020

Disciplinary Literacy and the 4Es:

Rigorous and Substantive Responses to Interdisciplinary Standards

H. Emily Hayden & Michelle Eades-Baird

H. Emily Hayden, Assistant Professor
School of Education, Iowa State University
Emily Hayden is an Assistant Professor in the School of Education at Iowa State University. Her research focuses on improvement of literacy teaching and learning across disciplines, with special emphasis on disciplinary literacy for science.

Michelle Eades-Baird, Assistant Professor
School for Graduate Studies, SUNY Empire State College
Michelle Eades-Baird is an Assistant Professor in the School for Graduate Studies' Master of Arts in Teaching (MAT) Program at SUNY Empire State College. Her research explores science education and the critical roles that academic language and disciplinary literacy play in science inquiry.

Abstract

The CCSS and the Next Generation Science Standards have described discipline-specific literacy skills needed to successfully engage with science concepts, and science assessments ask students to use language in many and varied forms to mediate their science thought and actions and prove mastery of content. Yet many science teachers have not been prepared with skills that help them recognize the ways literacy is integral to the discipline of science, much less integrate it. This research explored the experiences of three classroom science teachers as they worked to enact overlapping ELA and science standards inherent in CCSS and NGSS through inquiry-based instruction. The 4Es heuristic framed analysis of classroom observations of instruction, teacher interviews, and surveys. Ways the teachers utilized inquiry-based instruction to **E**ngage their students, **E**licit/Engineer their literacies, and **E**xamine and **E**valuate discipline-specific language practices are analyzed, with recommendations for specific, interdisciplinary, and ongoing support teachers will need in order to realize the disciplinary literacy goals of the CCSS and NGSS.

Keywords: disciplinary literacy, science literacy, interdisciplinary standards, 4Es, research collaborations

Two major U.S. curricular reforms, the Common Core State Standards (CCSS) (NGACBP & CCSSO, 2010) and Next Generation Science Standards (NGSS) (Achieve Inc., 2013) describe discipline-specific literacy skills needed to successfully engage with science concepts. These literacy skills are integral outcomes on science assessments. The 2019 Trends in International Mathematics and Science Study (TIMSS) includes specific objectives for each science domain and every grade level that ask students to describe, identify, compare, contrast, explain, classify, conclude, predict, and interpret (Mullis & Martin, 2017). Thus, students must use language in many and varied forms to mediate their science thought and actions and prove mastery of concepts.

This complex, vital connection is reflected in the NGSS, which place significant focus on expressing scientific understanding through the use of language and literacy skills, and provide explicit links to CCSS for English Language Arts (ELA). CCSS and NGSS emphasize authentic literacy uses in science as effective ways to "advance the goals of both text comprehension instruction and science instruction” (Magnusson & Palincsar, 2004, p. 316). However, most secondary science teachers have no formal training in literacy teaching, and disciplinary literacy is fundamentally different from content area reading skills many encountered in their teacher training (Shanahan & Shanahan, 2008; 2012).

In response to these reforms, and in recognition that literacy skills and strategies for disciplines differ from those for content area reading, Moje (2015) described a heuristic to help students "navigate the multiple literacy contexts in which they live, learn, and work" (p. 254). The 4Es heuristic encourages teaching that guides students to **E**ngage, **E**licit/Engineer, **E**xamine, and **E**valuate disciplinary texts through inquiry. We used the 4Es to analyze three science teachers' implementation of literacy standards during inquiry-based science instruction, asking:

1. How do these science teachers address overlapping NGSS and CCSS-ELA during inquiry-based science instruction?
2. What can 4E disciplinary literacy look like within inquiry-based science instruction?

Perspectives

Interdisciplinary Views of Standards

From an early age, science achievement is significantly linked to reading and math achievement, so reforms focused on only one of these areas may fall short in improving science achievement (Morgan et al., 2016). National Assessments of Educational Progress (NAEP) results in both science and reading have found that only about one-third of students assessed are at or above Proficient achievement levels (National Center for Education Statistics, 2017). These findings, compounded by a leveling-off of interest in science around age 11 (Osbourne et al., 2003), open opportunities for rich, rigorous, interdisciplinary research to inform teaching practice and impact student achievement. Lee (2017) and Lee et al., (2013) analyzed interconnections of NGSS and CCSS-ELA and the overlap of ELA, science, and math standards, providing support for an interdisciplinary approach. To visualize these possibilities, Stage et al., (2013) designed a triple-Venn diagram showing the ways ELA, science, and math standards come together to support and inform knowledge growth. This visual helps situate the interdisciplinary teaching practices of our focus teachers.

Literacy Through Disciplinary Lenses

Despite these intersections, an unhappy history of literacy educators and specialists attempting to infuse specific narrative and rhetorical strategies into content area classes has resulted in pushback from disciplinary educators and specialists. This is well deserved, since strategies for ELA do not translate wholesale to other disciplines. The “academic and pedagogical hubris” (Hinchman & O’Brien, 2019, p. 527) behind such assumptions can stem from a belief that literacy specialists are best positioned to prescribe all literacy work, when in fact, disciplinary specialists are far better suited to understanding and teaching literacies used in their area (Shanahan, Shanahan, & Misichia, 2011). Recent research has promoted partnerships between disciplinary and literacy specialists, emphasizing the ways literacy specialists should privilege disciplinary teachers’ expertise while supporting infusion of literacy in ways that honor the discipline and the classroom context (Hayden et al., 2019; Snow, 2015). This emphasis is integral to our research.

A Theoretical Framework for Disciplinary Literacy and Socially Just Teaching

Research on disciplinary literacy has evolved from describing differences between content area literacy and disciplinary literacy (Shanahan & Shanahan, 2008; 2012), to exploring collaboration across disciplines (Fang & Coatoam, 2013; Hayden et al., 2019) and providing theoretical grounding for disciplinary literacy pedagogies (Carney & Indrisano, 2013; Moje, 2007, 2015; Shulman, 2005). Carney and Indrisano (2013) illuminated connections between disciplinary literacy and pedagogical content knowledge (PCK) (Shulman, 1986), the professional knowledge for teaching that combines content knowledge and pedagogy in ways that honor needs and abilities of the learners at hand. Shulman (2005) provided specification of PCK for practice by describing “signature pedagogies” (p. 52) that include “surface structure” teaching behaviors for a discipline, “deep structure” best practices, and “implicit structure” (p. 54-55). Implicit structure includes moral dimensions: beliefs, attitudes, values, and dispositions that members of the discipline hold; and it is here that Moje’s (2007) theories on “[fusing] the moral and intellectual in a way that produces socially just subject-matter instruction” (p. 1) can frame research on instruction.

Moje (2007) proposed that by honoring discourses, texts, and traditions of a discipline concurrently with what students bring to learning, teachers provide students with equitable opportunities to gain access and develop expertise in the discipline. With that access, students gain tools needed to question and critique accepted knowledge in ways that can expand knowledge and produce social justice. Providing students with these disciplinary tools empowers them to engage in discourse that pushes individual and collective knowledge forward. In this potential to move collective knowledge forward, disciplinary literacy may transcend the boundaries of a construct and move into the realm of theory. Unrau and Alvermann (2013) defined theory as a “propositional [network] commonly used to help … researchers and practitioners understand, explain, and make predictions about key concepts and processes in a particular field” (p. 49). Enacting Moje’s (2007) propositions by honoring discourses, texts, and traditions along with the skills students bring to learning can lead to instruction that provides all students with the tools necessary to access literacy across disciplines, and can frame socially just ways of teaching, learning, and knowing that can be observed and better understood.

Moje (2015) grounded this theory in inquiry with the 4Es heuristic, rendering disciplinary literacy performative and observable. During inquiry, students **E**ngage in hands-on minds-on work of a discipline, and the knowledge and skills **E**licited by the learning task can be leveraged by teachers to Engineer students' engagement with the disciplinary knowledge needed. While engaged in such work teachers can prompt students to **E**xamine the language, symbols, and other codes of the discipline, navigating discourse practices and learning how to question, read, write, and talk in ways that fit the discipline. Examination is further developed as students **E**valuate language practices for a discipline: a kind of code-switching, meta-language activity when students practice different uses of new and known language within the lexicon of the discipline.

Moje and Ellison (2016) as well as Hinchman and O'Brien (2019) promoted hybrid approaches to teaching and research, with interdisciplinary teams. Hybrid approaches that include literacy specialists with expertise in reading and writing, and disciplinary specialists with expertise in resources for sense-making in the discipline, could result in equitable and lasting disciplinary literacy methods. The overlapping NGSS and CCSS-ELA present rich opportunities for exploring hybrid disciplinary literacy practices in science, and our interdisciplinary authorial partnership for this paper brings attributes from both literacy and science to the analysis. We focus on experiences of three classroom science teachers implementing both NGSS and CCSS.

Methods

We collected interviews, classroom observations, and surveys from three classroom science teachers who were part of a multi-year professional development focused on supporting teachers as they implemented NGSS. The 4Es (**E**ngage, **E**licit/Engineer, **E**xamine, **E**valuate) grounded our analysis of these three teachers' implementation of inquiry and infusion of disciplinary literacy. The triple-Venn diagram developed by Stage and colleagues (2013) was used to document specific science and ELA standards observed in teachers' instruction, providing a roadmap for ways the teachers enacted standards that spanned disciplinary boundaries.

Context

The three teacher cases described here emerged from a sample of 72 classroom science teachers in an urban, public school district, who participated in the first three years of a 5-year professional development initiative, the Interdisciplinary Science and Engineering Partnership (ISEP). The district had 31,000 students and a 53% graduation rate (below the state average), and had not met Annual Yearly Progress goals in multiple areas at elementary and secondary levels for several years prior to ISEP.

ISEP included educational and community partners: the school district, a research university, a local four-year college, and private industrial, research, and manufacturing firms in engineering and scientific fields. To help participating teachers develop science inquiry skills, the initiative provided a range of summer research experiences. Teachers were able to choose a different summer experience every year of their participation from four options: scientific research with a university or private research partner, engineering design projects with local industry and manufacturing partners, university coursework focused on supporting elementary teachers to develop classroom inquiry projects, or curriculum writing with fellow science educators.

To support integration of these summer experiences into classroom instruction, monthly professional development meetings led by university science educators focused on implementing NGSS using inquiry and overlapping CCSS-ELA standards. Topics included defining the interdisciplinary science inquiry framework (Liu, et al., 2013), school-wide implementation and engineering design within the framework, and CCSS-ELA. Culminating projects included student science summits and teacher poster sessions. Both focused on classroom application of learning and were hosted by private research partners.

Case Selection for this Research

Ten focus teachers were initially selected to explore enactment of NGSS and CCSS-ELA standards within inquiry-based instruction. These 10 were representative of the entire cohort in terms of attendance at monthly meetings and participation in at least one summer research experience. They represented the range in grade levels and science subjects taught.

Preliminary research (Eades-Baird, 2015) revealed that these 10 teachers' enactment of ELA standards during science sorted into five profiles based on knowledge, values, and observed practices: ELA-Centered, Exam-Focused, In-the-Middle, Engineering Design, and Reform-Based. Half the 10 teachers represented an Exam-Focused profile, where preparation for mandated standardized tests drove instruction. This focus led to a preponderance of direct instruction across grade levels, with science inquiry only occurring in highly structured and confirmatory ways, and literacy occurring primarily as notetaking. The argument for and against an Exam-Focused orientation is not one we can address adequately here, but the stance was not surprising given the context, where district graduation rates were low and progress targets unmet. Although Exam-Focused instruction had not yet resulted in student improvement on these global indicators, it is probable that teachers were strongly encouraged to maintain the stance in order to improve test scores.

We explored profiles of teachers who did not take this Exam-Focused approach, teachers who worked to incorporate literacy aspects of both NGSS and CCSS-ELA into science instruction using inquiry. We refined our sample further by selecting three teachers, each representing one of three profiles most distinct from one another but giving a flavor for the entire spectrum of standards enactment. Danielle (ELA-Centered), Simon (In-the-Middle) and Bryce (Reform-Based) were contrasting cases, developed individually and then examined in cross-case analysis to explore how they implemented NGSS and CCSS reforms. All three teachers reported minimal knowledge of literacy standards supporting NGSS and only general knowledge of disciplinary literacy for science.

Data

Teaching observations, interviews, and surveys were completed. Observations were first conducted during the summer research experience prior to Year 1 school-year implementation. Observations continued through each year, and during the final year of data collection the three teachers were observed for five to seven consecutive instructional days. A pre-observation written interview was utilized in addition to a field observation form and a post-observation rating form that organized standards implemented during the observation (Stage et al., 2013).

Semi-structured interviews were conducted yearly with each teacher, with follow-up to clarify responses. The protocol included background information, questions about summer research experiences, goals and approaches to science teaching, understanding and use of inquiry, factors influencing implementation, understanding and valuing of literacy standards and skills for science, and self-efficacy for implementing literacy. A 15-item Likert-type survey was implemented in Year 3 exploring knowledge and valuing of literacy within science, and literacy integration.

Analysis

A panel of five university science educators analyzed interviews and classroom observations using in vivo and open coding (Saldaña, 2009). Interviews were first coded holistically for general themes. Second cycle coding utilized a combination of in vivo and open coding (Table 1). Surveys were analyzed for descriptive statistics. Data from observations was plotted on the triple-Venn diagram (Stage et al., 2013) illustrating implementation of science and

ELA standards. The triple-Venn analysis tool provided a way to triangulate teachers' observed implementation of science and literacy standards with their stated beliefs from interviews and

General Themes	Second-Cycle Codes
Approach	Exam preparation Hands-on "Inquiry" mentioned by teacher Basic skills before inquiry Student-driven
Goals/purposes	Build science understanding "Real world" understanding Exam preparation Discovery of scientific phenomena
Expectations	Exam readiness Application to "real world" Skills: collaboration, measurement, research, critical thinking
Understanding of inquiry	Higher order thinking Interdisciplinary Student-centered Problem-based
Perceived goals/expectations for CCSS-ELA	Non-traditional literacies: graphing, data tables Reading and writing Essays, projects, summaries, lab write-ups
Challenges to implementation	Curriculum and assessment Lack of materials Student skills, behavior, work ethic

surveys.

Table 1.

Selected General Themes for Science Teaching and Learning and Second-cycle Codes

Results

We first briefly describe all three teacher cases. We then focus on the Reform-Based teacher, Bryce, who enacted methods that most exemplified the 4Es, in order to unpack what 4E disciplinary literacy can look like in a secondary science classroom.

ELA-Centered: Danielle

As a sixth-grade classroom teacher, Danielle taught all content areas. Her first summer research experience was the university course to develop inquiry skills (Year 1). She moved on to conducting medical science research with university researchers, compiling cross-sections of a mouse brain affected by methamphetamines (Year 2) and studying factors that influenced plant growth (Year 3). Danielle had 14 years of experience, and her multi-faceted role certainly influenced her enactment of inquiry, NGSS, and CCSS-ELA.

The NGSS in particular require integrative science inquiry practices that several researchers have found elementary teachers were not prepared with during their pre-service training (McNeill et al., 2016; Osbourne et al., 2019). These researchers have called for ongoing professional development to support elementary teachers with integrating science inquiry practices into classroom instruction. Danielle seemed to struggle with implementation of both sets of standards. Some lessons were primed for inquiry but lacked student involvement, such as the water demonstration described below. Others focused on fundamental literacy activities, such as constructing vocabulary foldables.

During interviews, Danielle described her science teaching as “interactive,” “hands-on” and “problem-based.” Her purpose was to “allow students to explore, learn, and create new knowledge.” She expected students “to observe, measure, analyze, make hypotheses, [and] interpret data.” She connected these expectations to her summer research, which “required me to think outside the box … using higher order thinking skills and a lot of times my team had to sit down and understand all the vocabulary associated with our project.” Danielle’s expectations, combined with the standards she enacted could have **E**ngaged her students in disciplinary literacy by involving them in “inquiry that allows [them] to gain insight into how questions are asked and examined and how conclusions are drawn, supported, communicated, contested, and defended” (Moje, 2015, p. 257). However, teaching observations revealed mismatches between Danielle’s purposes and enactment of inquiry.

Danielle’s science instruction enacted standards that fell solely in the science domain: S4 analyzing and interpreting data, and S6 constructing explanations and designing solutions; and one standard that fell solely in the ELA domain: E1 demonstrating independence reading complex texts and writing and speaking about them. She also enacted overlapping standards: S8 obtaining, evaluating, and communicating information; E2 building a strong base of knowledge through content rich texts; and E3 obtaining, synthesizing, and reporting findings clearly and effectively (Figure 1).

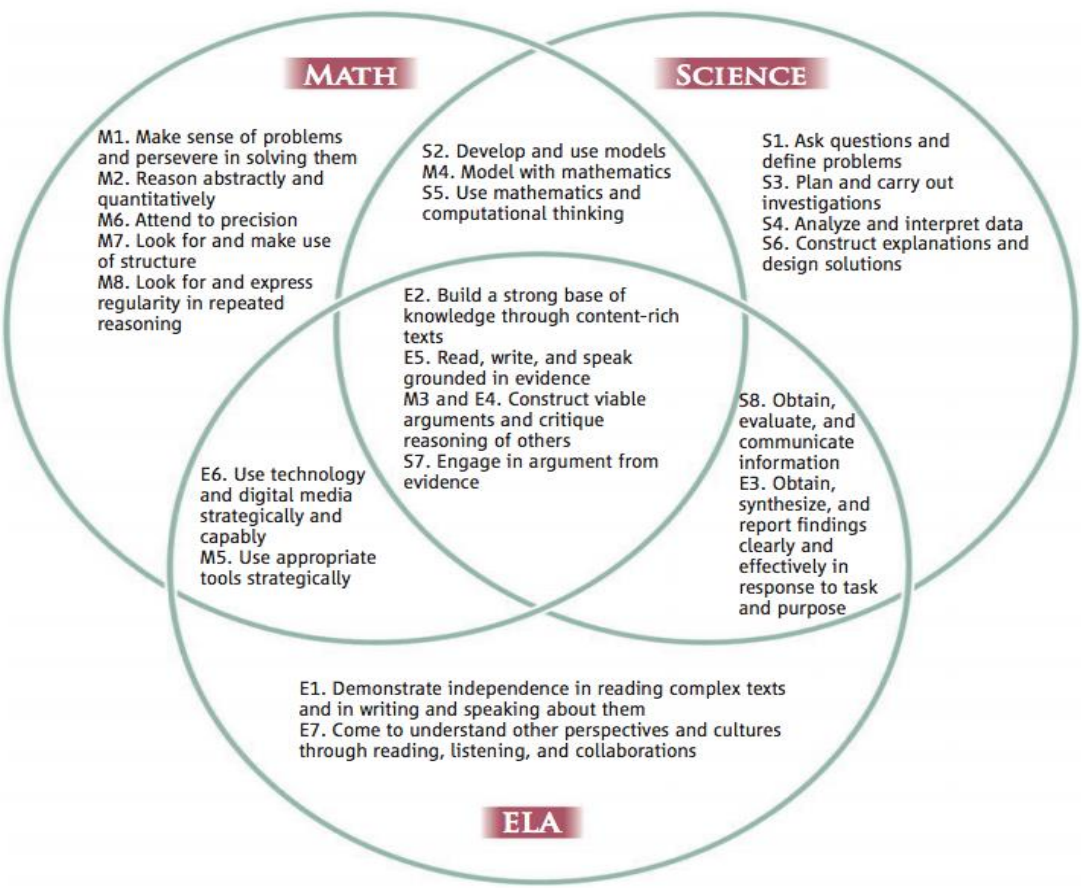

Figure 1.

Triple-Venn (Stage et al., 2013) used to document standards enacted in teachers' instruction

Observations of Danielle's teaching revealed increased frequency of science instruction and depth of inquiry. This growth mirrored her summer research experiences that moved from more structured learning experiences with the university course (Year 1), to laboratory techniques and conducting active research (Years 2, 3). Lessons observed in Years 2 and 3 were highly scaffolded and teacher-directed, but in Year 3 students were slightly more engaged in hands-on activity and fundamental literacy tasks.

In Year 2, Danielle demonstrated Earth's water availability in a lesson with no hands-on student engagement. After pouring out different amounts of water from a bottle to show proportions of fresh and salt water available, students completed a worksheet at their desks. In Year 3 a week of observations revealed that over half of science class time was spent on mastery of science vocabulary, constructing foldables for memorization. However, other lessons during the week demonstrated **E**ngaging practices: working with data from science journals and observations of plants with seed and soil variables, and producing a Venn diagram. Each student group presented their diagram to the class, communicating evidence from their experiments. These activities enacted overlapping science standards S8 and E3 (Figure 1), but one key disciplinary way scientists use literacy was notably absent from all observations and descriptions of science activity: argumentation from evidence. Danielle's students did not use data collected during inquiry to make claims with supportive evidence.

NGSS supports argumentation beginning in kindergarten, but ELA standards have traditionally focused on fact/opinion in primary grades, persuasion in middle grades and finally argumentation in late high school (Lee, 2017). Argumentation is essentially a newly highlighted expectation for ELA; and although there is a growing body of literacy research in this area

(Ghiso, 2015; Shi et al., 2019), experienced teachers like Danielle would benefit from professional development specifically focused on this genre. Danielle's incorporation of literacy for science leaned most heavily on ELA standards. Seatwork following demonstrations engaged students in close reading and interpretation of science text and extensive time learning vocabulary. This illustrated her attempts to bridge gaps between her students' below-level reading performance and engagement in literacy skills for science. Danielle noted that CCSS demanded more rigor and higher-order thinking, and while survey responses indicated that she placed high value on CCSS-ELA, she was not confident the standards would lead to improved student learning or were appropriate due to "high variability in background knowledge" and "below-level reading skills."

Although Danielle missed opportunities to **E**licit/Engineer by infusing science vocabulary into inquiry-based activities (Moje, 2015) her focus on vocabulary was well founded. Difficulties with science language often keep students from mastering content (Hayden et al., 2020; Pearson, 2010), and in her summer research Danielle had experienced firsthand the challenges of science vocabulary. Moje (2015) noted that "learning [definitions] of the technical language of disciplinary subjects is not as useful … if students are not engaged in disciplinary inquiry, because they have no way to apply the language they are learning" (p. 255). But in Danielle's science classroom, and in Simon's, infusing disciplinary language by connecting it to conceptual understanding gained through inquiry did not occur.

In-the-Middle: Simon

With 13 years of experience, Simon taught 7th and 8th grade general science and advanced 8th grade Living Environments. His summer research experiences spanned a range of research and engineering; he shadowed a researcher at a cancer center (Year 1), worked along-side

Danielle at the university medical school compiling cross-sections of a mouse brain (Year 2), and worked with a private industrial engineering partner to create a teaching and demonstration model for cell membrane diffusion (Year 3). His goals for students evolved from an initial focus on exam preparation, to helping them “develop as positive individuals with awareness of real-world issues, equipped with tools to solve problems” that required science knowledge, and “develop[ing] base science content.”

Simon enacted the same number of ELA standards as Danielle and more science standards, but fewer overlapping standards. His teaching approach included both literacy and inquiry, but with no intersection. Like Danielle, Simon assigned literacy activities as seatwork separated from inquiry: “half the class doing literacy-based work, finding [answers], book work, and the other half [doing an] inquiry-based lab.” These literacy practices enacted standards related to reading complex texts (E1) and building a strong base of knowledge through content rich texts (E2). Science activities were focused on skill building with low inquiry, and Simon's instruction did not include argumentation.

Simon’s binary approach was reflected in standards enacted during teaching observations when time was split equally between direct instruction of facts and developing foundational science skills. ELA standards E1 and E2 were met through bookwork separate from inquiry activity. Science standards S1, S2, S3, S4, and S6 were observed during low-inquiry activities, such as building cell cake models with candies representing organelles, and during highly scaffolded skill activities for microscope use and pipetting. The only enacted standard that overlapped science and ELA was E2 when students spent time reading and answering questions with the textbook.

Simon reported evolving literacy practices in Year 2, when he included a focus on student writing, and in Year 3 to include presentation skills. He described ways he intersected literacy with science, including leading students in close reading of science text, pausing to help with vocabulary and comprehension, and incorporating student writing. These activities enacted ELA standards, but the only science element was the textbook. Classroom observations during writing activities revealed a focus on proofreading (using correct form of “their”) rather than writing from evidence and no student presentations were observed during seven consecutive lessons in Year 3.

During Year 3 observations, Simon led highly scaffolded literacy and low-inquiry activities that included completing teacher-constructed charts as well as close reads of a review book. In the first lesson, half of Simon’s seventh grade class conducted a close-read on parts and functions of the microscope while the other half completed a hands-on microscope activity. The close-read group developed comprehension questions that could be answered by the passage, and halfway through the class students switched tasks. This “literacy/inquiry” rotation continued in all lessons that week, and Simon continued to facilitate close-reads of science text and provide lists of cell vocabulary.

Simon transferred the science skills and model building from his summer research into his instruction, but not the scientific and engineering practices that they were embedded within. In Years 2 and 3 he placed increased attention on developing students’ pipetting and microscope skills, but these were divorced from any inquiry-based problem solving. Likewise, the focus on cell cake models in Year 3 was more about building a 3-dimensional visual representation of a biological structure than using it to explain scientific phenomena (Year 3). Had the cell cakes been used to explain phenomena they would have provided a strong example of **E**ngaging students through use of varied media to produce knowledge (Moje, 2015). The knowledge **E**licited could have been used to Engineer literacies specific to science. But all these skill and model building activities were kept separate from inquiry in Simon's classroom instruction.

Like Danielle, Simon's interviews and survey revealed contradictory views on CCSS-ELA, and he also seemed to feel tension between fundamental reading skills needed by his students and disciplinary literacies needed for science. Simon was unsure of his self-efficacy for teaching ELA skills, and this may explain his infusion of literacy focused on fundamentals: close reading, vocabulary lists, and proofreading. He had taken several literacy courses during pre-service training, but this background did not seem to help him recognize the skills for interpreting and acting on science text that he could impart as a science teacher. Science teachers have the expertise students need to **E**xamine texts in their field: to read and interpret science text, language, and visuals. However, like many secondary content area teachers, pre-service coursework may not have provided the training Simon needed to meet interdisciplinary standards.

Reform-Based: Bryce

Bryce had 10 years of experience teaching high school physics, as well as experience teaching reform-based science practices at a partner university. He worked with engineers in all three summer research experiences: building both a computer simulation to diagnose diseases for use in his Medical Physics course, and a Schlieren photography apparatus for use in his Conceptual Physics course. Bryce used these models to **E**ngage students directly with scientific phenomena, including providing first-hand discovery of how light reflects off different surfaces. Students' inquiry-based interactions with these models, particularly the Schlieren apparatus, **E**licited primary source data that provided the knowledge and skills needed for understanding disciplinary concepts, in this case, refractive light and how it could be used to visualize movement in fluids. Bryce leveraged this discipline-specific knowledge to Engineer students' development of an important discourse practice for science – argumentation -- when students were able to **E**xamine the ways evidence and data are used to make and support claims about phenomena.

Bryce was an exemplar among the 72 teachers participating in the professional development initiative. His practices demonstrated how disciplinary literacy could be infused with inquiry, merging NGSS and CCSS-ELA standards. Bryce described his teaching as student-driven, with teacher as facilitator of student learning. His goal was to help students develop 21st century skills, allowing them to learn by exploring, and he expected students to learn skills for lab activities, group work, critical thinking, and to know that science is a "fluid body of knowledge." Bryce expressed the highest level of understanding of inquiry among these three teachers, and placed inquiry first in his instruction, allowing students freedom to explore science materials and, as he describes:

> make mistakes and more importantly, realize their mistakes …. we're quick to say, "that's not going to work," whereas I love seeing a student going down the wrong roads, see that it's not working, [and] make their own plan for how to get back.

Bryce was observed twice during Year 2 and on five consecutive days in Year 3. In Year 2 observations, students participated in low-scaffolded, guided inquiry activities that explored light-spectrum glass with a guiding question: "What causes the color of the Sun to change from yellow to red as it sets over the horizon?" Groups presented findings and arguments using evidence from the inquiry. In Year 3, students investigated light behavior using foil and flashlights over the course of five consecutive observations. Again, they presented findings, arguments, and conclusions on light behavior using data collected on angles of incidence and reflection as evidence.

Year 2 observations enacted standards S1, S2, S3, and S4. In Year 3 students generated and recorded findings (S6, S8, E3, E5) and standards E1 and E2 were met via laboratory write-ups connected to inquiry. In both years, Bryce was the only teacher in the cohort who incorporated S7, E4 and E5: overlapping standards focused on argumentation using evidence from inquiry (Figure 1).

Bryce's instructional approach merged NGSS and CCSS-ELA standards. Every lesson included seven NGSS practices, with only S5, overlapping science and math, not observed; and four ELA standards: E2, E3, E4, and E5. Bryce was the only teacher whose practice enacted S7, S8, E4, and E5 focusing on oral presentation and argumentation using inquiry evidence, and although he expressed the lowest self-efficacy of the three teachers for implementing ELA with science, his practice demonstrated the highest implementation. By contrast, Danielle and Simon reported higher self-efficacy for implementing ELA, but fewer standards were observed during their instruction. Bryce recognized connections across disciplines, and the value of inquiry, as shown in his interview:

> Very few, if any, of my students are going into careers that require specific knowledge covered during my courses. However, each of them will be required to think critically and make appropriate decisions in every aspect of their lives. I like to think I'm teaching the art of critical thinking through the context of physics.

Survey data revealed Bryce's evolving views of disciplinary literacy for science. In Year 2 he viewed literacy in science as the ability to "read science literature and digest it appropriately." By Year 3 he described a more disciplinary view: "increased focus on evidence-based conclusions … attending to various forms of literacy like diagrams, formulas, graphs, charts [and] students will need to be taught strategies for interpreting scientific writing.” He called these “non-traditional” literacies; but, in fact, they are unique and critical forms of disciplinary literacy for science. Bryce shared an example of his disciplinary uses of literacy:

> One [activity] talked about reflection off smooth and rough surfaces and it was apparent five minutes into the lesson that students thought paper was a smooth surface so we actually took out microscopes and looked at it under 10x magnification, 100x, 430x. It was nice to build in that level of detail and rather than tell them about it, we took a whole bunch of things, had them classify it as shiny or smooth, and then looked at how light reflected off each one. They were able to develop this general rule that when things are rough, light is evenly dispersed; when something is shiny it’s going to be scattered in a particular direction.

This instructional sequence illustrated Bryce's belief in “following students' discourse" during science teaching, which he shared in his Year 1 interview. He recognized students’ misconception that paper was a smooth surface. His willingness to follow their discourse while providing just the right amount of support (Hayden, 2019) led to discoveries that exemplified inquiry with integration of the 4Es (Moje, 2015).

Enacting the 4Es

Nearly all disciplinary practices Moje (2015) described as **E**ngaging were used in the light investigation described above. Bryce re-framed his inquiry lesson to focus on an essential question about light dispersion that emerged from students’ interactions with materials: smooth and rough surfaces provided during the inquiry. The question stimulated interest and sparked curiosity of his students, who worked with the data on hand, classifying numerous objects as shiny or smooth using varied media including a disciplinary tool: the microscope. Students collaboratively synthesized their findings, developing and communicating a claim about light dispersion supported by evidence from their inquiry. Tools to **E**licit/Engineer learning were bound up within this activity, when students were thinking and acting like scientists.

Elicit/Engineer is a time when learning tools "originally presented as content literacy strategies find a place in … disciplinary literacy" (Moje, 2015, p. 267). Pearson (2010) described explicit connections between the ways we practice inquiry in ELA and in science. In ELA inquiry, we set purposes for reading with content area tools like KWL charts (Ogle, 1986). In science we do the same, but we call purposes "research questions." In ELA, text is the material for our inquiry, and we make inferences from text evidence, confirming or rejecting after close reading and interaction. In science, the material for inquiry is encountered during investigations, and we organize and report evidence discovered.

In these ways, content area strategies and disciplinary strategies can synergize, and teachers can guide students to **E**xamine these synergies, focusing attention on the language and discourse practices of specific disciplines. The light dispersion inquiry provided a natural opportunity to use the microscope as a disciplinary tool, perfect for collecting data students needed for their essential question and for developing the "disciplined perception" (Moje, 2015, p. 268) used by scientists. Hands-on investigation of different surfaces also provided the opportunity to connect important concepts about light with the vocabulary labels for these concepts: reflection and dispersion. Teaching science language in such interactive ways is crucial to developing ownership of science concepts (Hayden et al., 2020; Pearson, 2010). "Drawing attention to the technical language" (Moje, 2015, p. 268) in this case, means recognizing subtle differences between knowing what a reflection in a mirror is, and understanding the principles of light reflection and dispersion learned in science. A connection is formed between a known word and a new definition, exemplifying the way Tier-2 words (Beck et al., 2002) are used within science.

Noticing these subtle differences in how language is used in science, e.g. what "reflection" means when talking about light on paper versus an image in a mirror, helps students **E**valuate findings by putting their feet in different worlds, navigating "across and between their own everyday habits of mind" (Moje, 2015, p. 268). Thinking like a scientist means thinking differently about everyday concepts. Moje provides the example of a chemistry teacher explaining how numbers are rounded in mathematics versus chemistry, and Bryce utilized this **E**valuation of language in science when talking about speed:

> When you look at distance covered and the time period it was measured over and understand how those relate to the motion of the object [that's] a much more effective way of introducing the [concept] of speed. It's a ratio and I have always been a fan of "a name is nothing more than a term that allows me to understand what you're saying and you to understand what I'm saying."

Bryce facilitated student inquiry, but did not direct it. Instead, he used his role as a more knowledgeable other to support students' learning journey. In this environment, his students were able to practice the ways of thinking and knowing that scientists use.

Conclusions

All three teachers were able to address at least one overlapping NGSS and CCSS-ELA standard, but Bryce successfully enacted the most. His commitment to inquiry-focused, hands-on instruction included all 4Es, and his students enacted literacies in ways that fit the discipline of science. The story was very different for Danielle and Simon. Despite their participation in summer research experiences that could have served as models for classroom instruction, and despite describing their teaching as hands-on and inquiry focused, little to no enactment of the 4Es framework was observed in their practices.

The varied contexts these three teachers worked within certainly played a part, and this was particularly true for Danielle who was responsible for teaching all content areas to her 6th grade students and may have had the least science content preparation in her preservice program. Conversely, Bryce worked with older students and had provided professional development to in-service teachers on reform-based teaching. This gave him a level of expertise that served his high school students well. Simon, who enacted the fewest ELA standards, and more science standards than Danielle but fewer than Bryce, truly exemplified the middle ground where many science teachers may now find themselves. They know some content area literacy strategies from their teacher preparation, but not enough to recognize the ways those strategies can be transformed to enhance students' understanding of disciplinary texts within science.

Danielle and Simon may have needed more explicit guidance on connecting learning from the summer research experiences to classroom inquiry, and certainly could have benefitted from more instruction on framing disciplinary literacy in science using the 4Es. Danielle implemented **E**ngaging practices by having students compile data and observations to present to their classmates, but missed opportunities to leverage knowledge and skills gained from this activity to **E**licit/Engineer disciplinary literacy practices and connect vocabulary directly to hands-on inquiry. Although she recognized the challenges of science language, having experienced them herself in her summer research, vocabulary activities in her classroom were still separated from inquiry. Somewhere, a connection was missed.

Simon seemed to be caught on the hooks of outdated content area literacy practices. His book study/low-level inquiry rotations did not serve either group of students well, and his ELA practices were at the lowest level of all three teachers, focused on proofreading and text interactions separated from hands-on inquiry. The skills Simon transferred from his summer research experience were also low-level, focused on developing technical skills without connecting these to inquiry-driven activities, and on building models that were not leveraged to **E**ngage or **E**licit/Engineer disciplinary knowledge. If the cell cake models had somehow been used to advance knowledge of how organelles function in tandem or alone, knowledge could have been **E**licited that would have enhanced disciplinary understanding. Instead, the cakes served as 3-dimensional representations only, rather than as a tool for understanding why organelles exist and what they do.

Implications and Future Directions

Systemic changes in teaching practices are necessary to fully incorporate disciplinary literacy with inquiry as the authors of the NGSS intended. Enactment of these standards imposes obvious shifts in science instruction and requires significant changes for all parties interested in teaching science and preparing others to teach science. This includes school districts, departments of education, and agencies involved in ongoing training and development of teachers and enactment of science curricula.

In order to help in-service teachers make this paradigm shift, long-term implementation support inside and outside the classroom is needed. The 4Es can be the framework to help teachers conceptualize and enact disciplinary literacy for science. Specifically, the 4Es frame ways of thinking with language in science: questioning, problem-solving, data gathering, reading specific text features, and using claims and evidence for argumentation. Inquiry-driven instructional methods outlined in NGSS provide the perfect arena for developing disciplinary literacy, since opportunities to experience, describe, and label hands-on activities are fertile ground for language use and development.

Teacher preparation programs should make concerted efforts to prepare science teachers to incorporate disciplinary literacy, and to prepare literacy teachers to think about literacy in disciplinary ways. Although coursework in foundational and academic literacy are required for all future teachers, science teachers need targeted work in disciplinary literacy for science. In particular, by emphasizing the incorporation of argument from multimodal sources of evidence (texts, graphs, data tables, models, video, computer simulations, and inquiry-based science experiences) novice science teachers can practice ways to **E**xamine important science discourse practices, and **E**valuate the uses of new and known language within science (Moje, 2015). In doing so, they may be better prepared to enter their classrooms with the skills and confidence to enact the 4Es.

Moje (2015) contends that teaching disciplinary literacy is socially just, because it prepares all students to participate actively in construction and evaluation of scientific knowledge and claims. By using the 4Es as both theory and framing for lesson planning, for disciplinary literacy courses in teacher preparation, and for in-service science teacher professional development, future research might focus on how well this approach influences diverse students' participation in the science classroom and their interests in pursuing science careers.

Limitations

Because this research reports the practices of three science teachers, broad generalization is not possible. Additionally, all of these teachers chose to participate in a professional development experience focused on improving their implementation of NGSS and literacy standards. As such, they are all exemplars due to their interest and willingness to learn. While this openness to learning may have influenced the findings, it may also have presented a realistic view of the challenges science teachers face. Even highly motivated science teachers will face challenges in implementation of reform standards. They deserve the ongoing support of the research community.

References

Achieve, Inc. (2013). *Next Generation Science Standards*. Achieve, Inc. Retrieved from www.nextgenscience.org

Beck, I. L., McKeown, M. G., & Kucan, L., (2002). *Bringing words to life: Robust vocabulary instruction*. Guilford Press.

Carney, M., & Indrisano, R. (2013). Disciplinary literacy and pedagogical content knowledge. *Journal of Education, 193*(3), 39-49.

Eades-Baird, M. (2015). *Exploring urban science teachers' beliefs, perceptions and implementation of Common Core State Standards for ELA within the context of interdisciplinary science inquiry: A mixed methods study*. [Unpublished doctoral dissertation]. University at Buffalo, State University of New York.

Fang, Z. & Coatoam, S. (2013). Disciplinary literacy: What you want to know about it. *Journal of Adolescent and Adult Literacy, 56*(8), 627-32.

Ghiso, M. P. (2015). Arguing from experience: Young children's embodied knowledge and writing as inquiry. *Journal of Literacy Research*, *47*(2), 186-215.

Hayden, H. E. (2019). "See, you can make connections with the things you learned before!" Using the GRR to scaffold language and concept learning in science. In M. B. McVee, E. Ortlieb, J. Reichenberg, & P. D. Pearson (Eds.), *The gradual release of responsibility in literacy research and practice*, pp. 189-204. Emerald Publishing Limited.

Hayden, H. E., Eades-Baird, M., & Singh, A. (2020). Learning the words AND knowing the concepts: An in-depth study of one expert teacher's use of language as a cultural tool to support inquiry. *Literacy*, *54*(1), 18-28. doi: 10.1111/lit/12192

Hayden, H. E., Singh, A. & Eades-Baird, M. (2019). Gaining access to the language of science: A research partnership for disciplined, discursive ways to select and assess vocabulary knowledge. *Reading Horizons: A Journal of Literacy and Language Arts, 58*(2), 1-23.

Hinchman, K. A., & O'Brien, D. G. (2019). Disciplinary literacy: From infusion to hybridity. *Journal of Literacy Research, 51*(4), 525-36.

Lee, O. (2017). Common core state standards for ELA/Literacy and Next Generation Science Standards: Convergences and discrepancies using argument as an example. *Educational Researcher, 46*(2), 90-102.

Lee, O., Quinn, H., & Valdes, G. (2013). Science and language for English Language Learners in relation to Next Generation Science Standards and with implications for Common Core State Standards for English Language Arts and mathematics. *Educational Researcher, 42*(4), 223-33.

Liu, X., Gardella, J., & King, K. (2013, February 12). *Developing a conceptual framework for interdisciplinary science inquiry (ISI)* [Conference Proceeding]. The Math and Science Partnership Learning Network Conference, Washington, D. C. http://hub.mspnet.org/conferences/msp_lnc_2013/MSPLNC2013_TuesdaySessions.html

Magnusson, S. & Palincsar, A. (2004). Learning from text designed to model scientific thinking in inquiry-based instruction. In E. W. Saul (Ed.), *Crossing borders in literacy and science instruction: Perspectives on theory and practice.* International Reading Association, Inc.

McNeill, K. L., Gonzalez-Howard, M., Katsh-Singer, R., & Loper, S. (2016). Pedagogical content knowledge of argumentation: Using classroom contexts to assess high-quality

PCK rather than pseudoargumentation. *Journal of Research in Science Teaching, 53*, 261-290.

Moje, E. B. (2007). Developing socially just subject-matter instruction: A review of the literature on disciplinary literacy. In L. Parker (Ed.), *Review of Research in Education, 31*, pp. 1–44. American Educational Research Association.

Moje, E. B. (2015). Doing and teaching disciplinary literacy with adolescent learners: A social and cultural enterprise. *Harvard Educational Review, 85*(2), 254-78.

Moje, E. B. & Ellison, T. L. (2016). Extended and extending literacies. *Journal of Education, 196*(3), 27-34.

Morgan, P. L., Garkas, G., Hillemeier, M. M., & Maczuga, S. (2016). Science achievement gaps begin very early, persist, and are largely explained by modifiable factors. *Educational Researcher, 45*(1), 18-35.

Mullis, I. V. S., & Martin, M. O. (Eds.) (2017). *TIMSS 2019 Assessment Frameworks.* Retrieved from Boston College, TIMSS & PIRLS International Study Center website: http://timssandpirls.bc.edu/timss2019/frameworks/

National Center for Education Statistics. (2017). National Assessment of Educational Progress (NAEP): 1992-2017 reading assessments. Washington, DC: Institute of Education Sciences, U.S. Department of Education. Retrieved from https://www.nationsreportcard.gov/reading_2017/

National Governors Association Center for Best Practices, Council of Chief State School Officers (2010). *Common Core State Standards*. Washington, DC: National Governors Association Center for Best Practices, Council of Chief State School Officers, Washington, D.C.

Ogle, D. M. (1986). K-W-L: A teaching model that develops active reading of expository text. *The Reading Teacher, 39*, 564-570.

Osbourne, J. F., Borko, H., Fishman, E., Zaccarelli, F. G., Berson, E., Busch, K. C., Reigh, E., & Tseng, A. (2019). Impacts of a practice-based professional development program on elementary teachers' facilitation of and student engagement with scientific argumentation. *American Educational Research Journal, 56*(4), 1067-1112.

Osbourne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education, 25*(9), 1049-1079.

Pearson, P. D. (2010). Embedding literacy learning and instruction within inquiry-based science: Impact and synergies. Retrieved from http://www.nlnw.nsw.edu.au/videos10/7830_2010_pearson/7830/links/pearson.pdf

Saldaña, J. (2009). *The coding manual for educational researchers.* Sage.

Shanahan, C., Shanahan, T., & Misichia, C. (2011). Analysis of expert readers in three disciplines: History, mathematics, and chemistry. *Journal of Literacy Research, 3*, 393-419.

Shanahan, T. & Shanahan, C. (2012). What is disciplinary literacy and why does it matter? *Topics in Language Disorders, 32*(1), 7-18.

Shanahan, T. & Shanahan, C. (2008). Teaching disciplinary literacy to adolescents: Rethinking content-area literacy. *Harvard Educational Review, 78*(1), 40-59.

Shi, Y., Matos, F., & Kuhn, D. (2019). Dialog as a bridge to argumentative writing. *Journal of Writing Research, 11*(1), 107-129.

Shulman, L. S. (2005). Signature pedagogies in the professions. *Daedalus,* Summer, 52-59.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4-14.

Snow, C. (2015). Rigor and realism: Doing educational science in the real world. *Educational Researcher*, *44*(9) 460-66.

Stage, E. K., Asturias, H., Cheuk, T., Daro, P.A., & Hampton, S.B. (2013). Opportunities and challenges in next generation standards. *Science*, *340*(6130), 276-277.

Unrau, N. J. & Alvermann, D. E. (2013). Literacies and their investigation through theories and models. In D. E. Alvermann, N. J. Unrau, & R. B. Ruddell (Eds.) *Theoretical models and processes of reading* (6th ed., pp. 47-90). International Reading Association.