READI for Science:

Promoting Scientific Literacy Practices through Text-Based Investigations for Middle and High School Science Teachers and Students

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Reading and writing are part and parcel of engaging in science inquiry. No scientist works without situating his or her work in prior research and the explorations of other scientists. Scientists learn about the work of others largely through reading (Yager, 2004). They read publications in their field looking for what's new, often expecting that their understanding may change as a result of compelling new evidence (e.g., Bazerman, 1985; Roth, 1991; Sinatra & Broughton, 2011). But they read with a critical stance, evaluating the reliability and reasonableness of new findings and explanatory models against existing accounts. Most scientists also write regularly to keep track of their inquiries and to share their work with others using agreed upon forms of discourse (e.g., bench notes, research reports, and research reviews) (Goldman & Bisanz, 2002). The inquiry process engages scientists in building models and explanations of the phenomena they study, using multiple semiotic forms (e.g., verbal, visual) to represent their ideas. Scientists understand that it is through this recursive literacy practice of writing and revising models and explanations based on evidence and counter evidence that robust scientific knowledge accumulates. Thus, inherent in the epistemology of science is its tentativeness: extant theories, models, and explanations reflect the best accounts given the results of inquiries to date. But these are expected to change with new inquiries.

This characterization of science inquiry and the accumulation of knowledge implies that learning science is to learn not only a body of scientific knowledge but the practices that produce it. This requires shifting students from learning *about* science ideas to figuring out *how* and *why* a phenomenon happens, and the evidence that supports these claims. In this vision, as learners participate in scientific practices such as exploration, modeling, reasoning, reading what others have found, and writing what they themselves find, they gradually gain access to the language, norms, and habits of mind of the scientific community (Lave & Wenger, 1991; Latour & Woolgar, 1986). They acquire an understanding of the epistemological status of evidence and claims and the process of knowledge building in science (Berland & Reiser, 2009; Chin & Osborne, 2010; Kuhn, 2010). They learn to rely on various kinds of sophisticated literacy skills - the ability to make sense of scientific terminology; to interpret arrays of data; to comprehend scientific texts, including traditional "verbal" expositions as well as graphs, tables, visual models, and diagrams; to use and interpret models and illustrations, and to read and write scientific explanations (Lemke, 1990; Osborne, 2002).

The Next Generation Science Standards (Achieve, 2013) and the Common Core State Standards for Literacy in Science and Technical subjects (Council of Chief State School Officers, 2010) embody this vision, emphasizing exactly the literacy and inquiry practices that position learners as actively engaged in doing science--as producers rather than consumers of science. The Next Generation Science Standards (NGSS) are intended to focus on deeper understanding of content as well as its application and to reflect the interconnected nature of science as it is practiced and experienced in the real world. To this end, the NGSS envisions a set of crosscutting concepts as well as practices of science and engineering to advance over the grade levels and topic areas in science and engineering education. All of the practices of science and engineering in the NGSS rely on language and literacy processes and explicitly include reading and writing in the multiple forms of text that are useful in representing, reasoning about, and communicating explanations of science phenomena. Likewise, the Common Core State Standards (CCSS) for science and technical subjects call for students to be able to read and comprehend increasingly complex and multiple forms of science texts. Students are expected to attend to text features and language structures typical of multiple forms of representations of science information, analyze the intricacies of embedded arguments, and themselves engage in argumentation as a demonstration of learning from texts (CCSSO, 2010). Similarly, the NGSS underscores argumentation as a central feature of science learning – an emphasis on articulating claims, entertaining alternative explanations and providing evidentiary support. The NGSS and the CCSS are thus well-aligned in calling for engaging students in authentic science practice, both in the context of first-hand investigations as well as in the context of working with and producing texts in science classrooms.

Scientific argumentation encompasses the ability to generate plausible claims, provide evidence for or against the candidates, providing lines of reasoning and convincing others through use of evidentiary support to account for phenomenon (Berland & Reiser, 2009; Ford & Wargo, 2011; Ryu & Sandoval, 2012). Science concepts themselves are represented in a variety of textual forms, from graphs, data charts, to explanatory models – all of which must be read, discussed and understood in order for students to ~~engage in~~ generate their own representations of science knowledge (Cromley, Snyder-Hogan & Luciw-Dubas, 2010; Goldman & Bisanz, 2002). Both primary data resulting from students' investigations and data collection activities, as well as secondary data derived from texts such as graphs, data tables, and scientific models are valued epistemic tools for generating scientific knowledge. Explaining, justifying, evaluating and challenging one another's ideas are central to both literacy and scientific practice (Chin & Osborne, 2010). Helping students learn to argue scientifically will mean engaging students in abundant opportunities to practice the talking, reading, and writing reflective of science--valuing evidence, constructing explanations, critiquing reasoning, and contesting alternative explanations. Thus, science literacy is not merely about communicating science; it is integral to all of the practices of science.

The CCSS and NGSS set high academic achievement bars in the face of persistent evidence of low literacy achievement and lack of engagement in science among students in the United States. On the 2009 National Assessment of Educational Progress (NAEP) in science, only 34 percent of fourth-graders, 30 percent of eighth-graders, and 21 percent of twelfth-graders performed at or above the proficient level (NCES, 2011). Similarly, the most recent national assessment shows that three-fourths of 8^{th} grade students score below the proficient level in reading, with very few students reaching advanced levels of reading proficiency, even by 12^{th} grade (Aud et. al., 2012). As students move up the grade levels, the literacy tasks and texts they encounter in school become more complex and specialized (Lee & Spratley, 2010). As youth get older they also report significantly less interest and self-confidence in their science ability. Elementary aged children report a high level of interest and confidence in their science abilities, but starting in the middle grades, interest and self-confidence in science drops off precipitously (NCES, 2011). Yet, interest in science careers among eighth-graders can be a better predictor than test performance in determining which students will pursue careers in science (Maltese & Tai, 2011), pointing to the need to build students' interest and success in science in middle and high school.

Our position is that students are capable of high level literacy and science performance, but that their opportunities to learn how to engage in these practices are limited. They are therefore profoundly inexperienced with the kinds of academic literacy and science reasoning practices envisioned in the new standards. Despite the synergistic overlap of CCSS and NGSS, neither set of standards provide an instructional roadmap for organizing instruction to provide learners with opportunities to learn the knowledge, skills, and competencies needed to achieve the outcomes specified by the standards.

To bring about the changes in how students approach and reason in science classrooms, both teachers and students will need abundant scaffolds to move beyond the existing approaches to reasoning and knowledge building in science. Students need to stretch their abilities with increasingly complex texts and to engage in discipline-specific interpretive practices, exploring ideas and developing understanding through discussion (ACT, 2005). Establishing a set of shared goals, talk tools and strategies for engaging in sense making in the science classroom is central to developing learning environments that promotes scientific inquiry. Pedagogical routines need to redirect students' use of texts from information acquisition to taking an inquiry-stance. Students need to grapple with substantial complexity to clarify text meaning, ask questions, identify and accumulate answers to inquiry questions, develop explanations and models, and critique how well their models hold up. In short, they need to engage in the text-based practices of science.

In this paper, we introduce an instructional approach we are taking to integrate reading and writing with science inquiry and in so doing provide adolescent learners with opportunities to engage in the literacy practices of science at developmentally appropriate levels. We are developing this work through Project READI (Reading, Evidence, and Argumentation in Disciplinary Instruction) as part of the Institute for Education Sciences' Reading for Understanding initiative*.* For the past three years, in concert with science teachers, we have been engaged in collaboratively designing and developing the pedagogical approaches needed to support what we are calling text-based investigations.

Repositioning Texts and Students

We have designed READI text-based investigations to engage students in authentic scientific literacy and inquiry practices in order to learn science content, to construct explanations and models of phenomena in the natural world, and to support these constructions through scientific argumentation, both oral and written. Beyond immersing students in science investigation through text, we aim to build students' literacy practices for science – to advance their ability to grapple with the language and features of complex science texts; to engage in deliberate sense-making with these texts; to participate in productive peer-to-peer science argumentation; and to present their own understandings in science-specific ways, by constructing and critiquing models and explanations. We see these text-based investigations as complementary to first-hand experimentation. Both types of investigations involve asking questions; gathering, analyzing, modeling and interpreting data; developing explanations; arguing from evidence; and obtaining, evaluating, and communicating information.

Text-based investigations reposition both texts and students. Texts become resources for inquiry rather than conveyors of the "facts." Students read to understand and explain science phenomena. Rather than reading to receive and memorize the "truth," students become constructors of knowledge, using texts as information resources and employing scientific literacy practices. Engaging in text-based investigation sharply contrasts with the "content delivery" approach typical of most science classrooms, that relies on lectures, demonstrations or textbooks to "tell" students science (Alozie, Moje & Krajcik, 2010; Cervetti & Barber, 2008; Chiappetta & Fillman, 2007; McNeill, 2009).

To invite authentic inquiry and deep reading of science texts, the text-based investigation modules we are designing employ texts – actually sets of texts – that are quite different from science textbooks typical of many middle and secondary science classes. Typical science textbooks offer dense compendia of well-established science facts and theories. In conjunction with the way the goal of science instruction is often framed (as knowing correct answers to questions the teacher poses) textbooks socialize students to scan science texts for information rather than to engage intellectually with texts to construct deep understanding or to use texts as resources for inquiry (Berland & Hammer, 2012; Evagorou & Avraamidou, 2011).

In contrast, READI text-based investigations seek to create contexts for science learning that position science knowledge as tentative in nature and encourage students in questioning, sense making and knowledge building, an orientation to science and science learning that is largely absent from today's science classrooms (Pasley, Weiss, Shimkus, & Smith, 2004). Placing students at the center of text-based inquiry in science requires re-socializing students to actively construct meaning with science texts and to reposition science texts as resources for inquiry (Pearson, Moje, & Greenleaf, 2010). Pedagogically, this requires (1) careful consideration and use of a range of science texts – including line and bar graphs, visual models, diagrams and expositions (Fang & Schleppegrell, 2010; Goldman & Bisanz, 2002; Lee & Spratley, 2010; van den Broek, 2010), (2) building instructional supports around these texts to foster reading for inquiry purposes including conceptual change as well as academic language and literacy development; (3) supporting students in synthesizing across texts to develop and evaluate causal explanations and models for the phenomena (Chin & Osborne, 2010; Passmore & Svoboda, 2012); and (4) fostering a culture of collaboration and discussion to support knowledge building and evidence-based argumentation.

The text-based investigations that we collaboratively develop and test through design-based research methods conform to an overarching set of design principles and learning objectives.[1] The principles are realized in "evidence-based argument modules" that are comprised of tasks, text materials, and instructional supports (routines, tools) for task completion and the achievement of learning objectives. The learning objectives reflect the epistemology, inquiry practices, enduring ideas and frameworks, and types of disciplinary texts and discourse forms of the science community. (See Table 1.) These text-based investigations emphasize close reading attuned to the vocabulary, core ideas, cross-cutting concepts, and practices of science and metacognitive conversations about learning processes. Tasks are designed to be meaningful to the discipline and to students and to draw attention to things that are puzzling. Text materials and accompanying scaffolds and worksheets (e.g., graphic organizers, argument templates) support the construction of causal models and explanations. Texts are sequenced to build students' process skills and knowledge over the course of the module. Instructional supports for engaging in text-based inquiry include a variety of close-reading and metacognitive reflection routines that are modeled and scaffolded by teachers; individual, pair, and whole-class discussion processes;

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[1] Project READI is working on similar goals to those discussed here for science, in history and literature. The design principles are the same across the three disciplines but are particularized to reflect the practices of reasoning and argumentation in each discipline.

and activities that make explicit the relevant reasoning processes students employ in out-of-school contexts. These out-of-school reasoning processes make visible the knowledge and forms of expressing that knowledge that students bring to the science learning situation. Instruction begins with these student understandings and forms of expression and builds on them to broaden students' repertoires and tools.

An Example of a READI Text-Based Investigation Module

An example of a module focused on Methicillin-Resistant Staphylococcus Aureus (MRSA), developed with the input and collaboration of science teachers, serves to illustrate the general architecture of a READI text-based investigation module. MRSA was chosen as a topic for text-based inquiry for several reasons. It is a contemporary example of how the theory of evolution is used by scientists today to investigate and solve critical problems that impact everyday people in typical communities around the country. The topic of MRSA fits well with secondary life science courses, overlapping with processes of infection and contagion, bacteria/human ecology, and natural selection as a mechanism driving evolution. The topic of evolution is a central organizing theory of biology and research (NRC, 2011). An important additional criterion for topic selection was the potential appeal of chosen topics for study by adolescent students. MRSA disproportionately affects teenage populations. Additionally, because both evolution and MRSA are extensively written about for both lay populations and professional scientists, extensive textual resources with a wide range of accessibility and challenge exist, making it possible to create text sets which provide plentiful opportunities for close reading of authoritative sources at various reading levels across multiple representations representative of the discipline of science (CCSS, Appendix A, 2010).

To understand and consider how to intervene in the public health challenge presented by MRSA, students must understand how MRSA infection occurs, how MRSA is transmitted and spreads, how the widespread use of antibiotics is related to MRSA, and how bacteria and humans co-exist ecologically. As a culminating task, students are asked to apply what they have learned about the causal mechanisms driving MRSA evolution and spread by developing a scientific recommendation to manage the public health challenge posed. Specifically, students work in teams to:

- Identify a problem in their community related to the MRSA epidemic,
- Determine a course of action for their community that addresses the problem,
- Make a compelling scientific recommendation for the course of action by preparing an explanation of how and why the course of action will be effective, and
- Present the recommendation to the class in a science seminar

The MRSA investigation includes source texts in the range of representations students will need to comprehend in science classes, including science news reporting to problematize this phenomenon of potential interest to adolescents, multiple expository texts, data graphs, diagrams, and the like. (See Table 2 for examples.) A goal for the MRSA module, as for all text-based investigation modules, is learning to grapple with the language and syntax of science as well as the multiple forms of representation typical of science writing, in order to build students' familiarity and stamina with such texts as well as more robust science reading and sense-making practices. To serve this goal, we selected trustworthy science sources that naturally present ambiguities and challenges for comprehension, such as sources from reliable internet portals such as government and university web sites, NSF-sponsored research sites, and the like. We ensured the text set included data graphs, diagrams, and other visual forms of science communication. We also chose science reports from newspapers and non-print media for a variety of compelling "cases" of MRSA infection and spread. Together, some 20 texts presented information and data on the science of MRSA infection, transmission, evolution, and ecology. All potential texts were analyzed for their reliability on the science concepts targeted in the investigation. To reduce overall complexity of these sources, we used excerpts of texts rather than altering or simplifying texts.

Over the course of the investigation, MRSA texts and combinations of texts are deliberately sequenced to accomplish multiple purposes, for example, to:

- Support development of scientific epistemology and inquiry dispositions by evoking students' interests and purposes for studying the topic
- Scaffold the literacy-learning and science-learning experience by positioning the most accessible, engaging texts during the initial days of the inquiry and then steadily increasing the demands and complexity of texts as time progresses
- Build schema about important scientific concepts, such as evolution, interaction and scale, as well as relevant core sub-topics such as selection and adaptation, host-parasite relationships and MRSA bacteria with high-quality, vetted informational sources
- Build text schema and relevant comprehension processes for a wide-range of science texts representative of the discipline, such as graphs, tables, current events articles, textbook exposition, public service announcements and research reports
- Develop fluency, language-learning strategies and scientific vocabulary by providing opportunities to encounter and re-encounter science-specific words and terms (including words with multiple meanings as well as qualifiers and quantifiers) the meaning of which can be derived from context
- Provide evidence in the form of information and data that students will need to explain (develop a causal model of) MRSA infection and spread, the emergence of MRSA, and effective ways to limit MRSA's public health impact

Instructional Supports for Text-Based Investigations

An Interactive Notebook for students and an instructional guide for teachers accompany the MRSA investigation module, as in all READI modules, offering social and material support for active sense-making and a focus on explanation/model building (Gotwals, Songer & Bullard, 2012; NRC, 2012; Pluta, Chinn & Duncan, 2011; Schwarz et al., 2011). Students' work with the Notebook is designed to mirror the work of scientists – as text-based inquiry. Pedagogical routines focus teachers on engaging students in the active intellectual work of inquiry. They invite students to pose inquiry questions and then engage in further investigation through reading, to identify and accumulate data to answer their inquiry questions, to develop explanations and models, and to critique how well their models hold up. Throughout the module, teachers model these processes and support their uptake on the part of students. Students share not only what sense they are making of the science texts, but how they are going about it, thereby making their reading and reasoning processes public. Metacognitive conversation routines such as teacher modeling, think aloud, and text annotation and sharing support teachers and students in making reading and reasoning public and more scientific and evidence-based over time.

In these ways, students are supported to engage in active and collaborative sense-making with these texts. They learn to approach all science texts with the goal of constructing their own understanding of them. By supporting students to negotiate text meaning with others, instructional routines intentionally foster interactive argumentation to clarify meaning with the texts students encounter (Chinn & Anderson, 1998), as well as to establish a culture of argumentation in the classroom (Driver, Newton & Osborne, 2000).

Other instructional supports include Evidence/Interpretation notetakers. These are used throughout the module to support students in identifying and making sense of the evidence they will need to make and support their scientific arguments (McNeill & Krajcik, 2011). Students practice transforming information from one representation into another, from words to graphs and models and from graphs and models to words, simultaneously building their conceptual understanding and flexibility with textual forms in science.

Students are supported to metacognitively monitor their changing conceptions as they encounter key concepts repeatedly throughout the unit, accompanied by new evidence and information. This metacognitive focus on conceptual change is hypothesized to result in robust concept attainment as well as new epistemological stances and repertoires on the part of students. We aim for students, as science readers, to come to expect that their conceptions may be challenged by new evidence and to learn to deliberate the strength of evidence and what that evidence implies as they progressively refine their understandings of the phenomena (Sinatra & Broughton, 2011). At intervals during the investigation, students engage in peer review processes to construct and critique models and explanations – their own and those of their classmates. By engaging students in building their understandings from close reading of high quality science texts, we aim to engage students in examining and critiquing their own and others' models and explanations of the phenomena at play.

Through the course of text-based investigation modules such as MRSA, students thus engage in arguing to learn while at the same time learning to argue scientifically (Von Aufschnaiter, Erduran, Osborne & Simon, 2008), acquiring argumentation knowledge and strategies through participation in argumentative dialogue with teachers and classmates. By using the practices of science to inquire into real world topics of interest such as MRSA, we hypothesize that students will simultaneously learn science content as well as literacy and inquiry practices of science.

In summary, the READI approach requires that students build an understanding of science phenomena from evidence and ideas in source materials as well as from developing and justifying their explanatory accounts for these phenomena. Taking this approach requires students' engagement with texts in ways that mirror the work of scientists, i.e., as text-based inquiry. Importantly, we have designed text-based investigations not only as a means to learn science, but as a means to learn <u>how</u> to learn science and <u>how</u> to engage in science literacy and inquiry practices; in short, as a means to develop these practices to support their work and learning in science now and in the future.

Repositioning the Role of the Teacher

Repositioning texts and students as realized in the READI approach has clear implications for the role of teachers in orchestrating instructional activities and supports. When the goal of science instruction is framed as knowing correct answers to questions the teacher poses, and the textbook is the repository of the answers, students search text for key words that match words in the questions and classroom discourse becomes little more than teacher-controlled testing of students' acquisition of information, or I-R-E sequences (Cazden, 1988; Cazden & Beck, 2003; Mehan, 1979). For text-based investigations, pedagogical routines need to redirect students' from using texts to acquire information to interrogating them for relevance to explanations they are attempting to construct. The complexities of such teaching, responsive as it must be to the conceptions of students, requires nimble modification of instruction according to the prior knowledge and responses of students (Duschl, Schweingruber, & Shouse, 2007).

There are a number of reasons it is difficult for middle and high school science teachers to adopt pedagogical routines that support authentic text-based inquiry in science. First, at the secondary level, science teachers are themselves relatively skillful at reading science materials, and instructional texts meant for students hold no mysteries or challenges for them. The ease with which they are able to comprehend traditional science textbooks blinds them to the difficulties students may have, reminiscent of the "expert blind spot" typical of experts in many areas (c.f., Bransford, Brown, & Cocking, 2000; Chi, Feltovich, & Glaser, 1993). At the same time, science teachers often lack knowledge and experience with inquiry and are inexperienced in the pedagogies that are needed to support it (Anderson, 2002; Bybee, 1997).

Second, science teachers, as well as other "disciplinary" teachers, do not see themselves as literacy teachers. That is, strategies and skills for sense making from text are typically viewed as the job of the English Language Arts or reading teacher. However, the interpretive goals and purposes for which students engage with science as compared to literary texts are quite different and require different disciplinary practices and are grounded in different epistemologies, core ideas, genres, and discourse practices (Goldman, 2012; Heller & Greenleaf, 2007; Lee & Spratley, 2010). Guiding a dialogic sense-making process requires knowledge of what that process is – what it looks like, feels like, etc. Although English Language Arts teachers may be familiar with literary reasoning and sense-making, they do not have the content knowledge nor knowledge of literacy and inquiry practices of science necessary to coach and guide students in reading and writing science. Science teachers need to guide and support students to develop these literacy and inquiry practices of science. For their part, middle and high school science teachers rarely know how to support students to engage in close reading with science texts, or how to articulate their own sense-making practices with these texts.

Third, the culture of many classrooms – science as well as others, does not support peer interaction nor does it invest students with the time and dispositions needed to work hard toward understanding (CCSSO, 2010; Schoenbach & Greenleaf, 2008). In many middle and high school classrooms, a culture of procedural display, of going through the motions to gain information at a surface level, is pervasive (Bloome, et al., 1989; Jiménez-Aleixandre, Rodríguez, and Duschl, 2000). The new standards drive toward deeper learning for all students. Many studies have found that both cognitive and non-cognitive strategies are developed by engaging students in challenging work with ample instructional support, rather than in simplifying tasks or focusing solely on skill building exercises (Baumann & Duffy, 1997; Beck, McKeown, Hamilton, & Kucan, 1997; Guthrie et al., 1996; Kamil et al., 2008). Researchers have thus underscored the need for conceptually rich, discipline-based skills instruction that challenges students intellectually while helping them build high-level literacy skills (Conley, 2008; Paris, 2005; Schoenbach & Greenleaf, 2009; Umphrey, 2009).

Establishing norms in which the intellectual work is shouldered by the students requires teachers to move off the stage of content delivery and into the role of a coach who orchestrates a dialogic process of sense-making from texts *(*Atwood, Turnbull & Carpentale, 2010; McConachie, et al., 2006; Wolf, Crosson & Resnick, 2006). This requires skillful construction and use of discourse routines that engage all students in sense making talk, yet these routines are unfamiliar to many middle and high school science teachers. Further, when students discuss science phenomena in the classroom, their current conceptions become apparent; requiring teachers to organize instruction responsively to deepen these conceptions.

The pedagogical routines needed to support the repositioning of texts and students for inquiry include close reading of a variety of science texts and representations for the purpose of developing and refining explanatory models of science phenomena, discourse practices to support explanation and argumentation, and classroom cultures that hold students accountable for doing the intellectual work while providing support for them to grapple with complexity.

Finally, as with any challenge, support and practice are key for developing students' self-efficacy. Science teachers need to build students' identities as resilient learners and their dispositions to engage in academic tasks by creating relevant learning opportunities in a safe environment where risk taking is rewarded (Yeager & Dweck, 2012). Research documents the effectiveness of interventions aimed at shifting students' explanation of setbacks from stable internal causes—"I'm no good at science"—to temporary, external causes—"This is really hard, and I need help to 'get' it" (Cohen, Steele, & Ross, 1999; Walton & Cohen, 2007, 2011; Wilson & Linville, 1985). These learning strategies involve metacognition, self-regulation, and cognitive strategies for reorganizing texts and content—processes that contribute to deeper understanding, improved academic performance, and feelings of self-efficacy (Farrington et al., 2012; Pintrich & DeGroot, 1990). The work that we have been doing, as well as a long history of research (Cazden & Beck, 2003; Herrenkohl, Palincsar, DeWater, & Kawaski, 1999; O'Connor & Michaels, 1993; Roth, McGinn, Woszczyna, & Boutonné, 1999; Wells & Arauz, 2006) indicates that these practices are new to teachers, as well as to their students. Yet they need to be established as part and parcel of the classroom culture to support the inquiry and literacy practices of science.

Supporting Teacher Repositioning to Support Text-Based Investigations

To help science teachers navigate this sea change, as well as to build our understanding of what it entails, Project READI has engaged partnering science teachers in ongoing Teacher Networks and collaborative Science Design Teams to develop and implement modules like MRSA.

Teacher Networks for Engaging in Inquiry into Science Teaching Practices. One way we have worked to build the insights and pedagogical repertoire teachers will need to mentor their students in evidence-based argumentation from multiple science sources is by inquiring deeply into what teachers themselves do as readers and thinkers to derive meaning with complex science texts of varied kinds. These texts might include science explanation and exposition in scholarly journals as well as the diagrams, data arrays, mathematical expressions, and graphs that convey information. The teachers simultaneously experience classroom routines for engaging students in active inquiry and sense-making with such texts: routines for modeling and mentoring students in productive reasoning processes, fostering metacognitive awareness of comprehension problems and problem-solving processes, and for promoting collaborative discussions of science texts.

Central questions driving these professional inquiries for teachers include the following:

- For what purposes do scientists read and write?
- What counts as text in science?
- What do we know and do as relatively skillful readers and writers of scientific texts?
- How do we build knowledge across texts about science phenomena?
- How do we develop models and explanations based on science evidence?
- How do we know these models and explanations hold up?
- How can we make this knowledge and these processes apparent to our students?
- How can we provide students with opportunities to practice and the mentoring and guidance they need to acquire these vital science literacy and inquiry practices?

When teachers have an opportunity to dig into science writing that poses challenges for them, they begin to see that reading complex science text is neither automatic nor straightforward. Challenging texts and explanation tasks, for example, making sense of a new theory of enzyme regulation in cell metabolism from a *Science Magazine* review of research, requires otherwise knowledgeable and confident science readers to marshal many problem-solving strategies, to pull together stamina, and to maintain motivation and effort to in order to gain new understandings. Teachers gain new eyes for the challenges their students face with science texts from such inquiries, as well as a deeper appreciation of their own capabilities as science readers, capabilities they can turn into instructional assets through modeling. The following sample of comments from several science teachers reflects the insights and learning that teachers experienced after participating in this type of text-based inquiry activity with texts that were at *their* difficulty level.

> "Everything is/can be inquiry. Teaching students to ask the right questions will empower them to guide their own learning for the right purposes."

> "The last activity on 'metacognitive conversation' was an amazing reading strategy which I will certainly use in my classroom. I think having us interpret the same text made us realize the different perspectives we each bring-> see text from students perspective. Students are given multiple texts to interpret (eg. Maps, tables, charts, text) and they need numerous opportunities to explore how to make meaning of each. Teachers can model different strategies to aid in their understanding."

> "It was helpful to read the MRSA graphs and work with partners to help make sense of the texts and how that influenced our thinking and led us to develop questions and work on a model."

> "Important to let kids interact with and discover things in the text without giving it to them."

As these reflections illustrate, teachers begin to recognize how poorly many science textbooks represent authentic reading and writing about science (Schoenbach & Greenleaf, 2009) and how impossible it would be for English language arts teachers to mentor students in science reading, particularly the range of graphs, diagrams, models, numerical expressions, and exposition that constitutes real science text. A recent study affirms that these kinds of carefully designed learning opportunities for teachers can and do translate into increased achievement for students (Greenleaf, et al., 2011).

Collaborative Design of Evidence-Based Argument Modules. Another way we have engaged science teachers is through ongoing collaborative design and implementation of text-based investigations. By deliberately inviting teachers to co-design modules and pedagogies of text-based investigation with us, we have both drawn from and built teacher expertise. We have worked together with teachers to identify the appropriate driving questions and candidate texts for a number of text-based investigation modules. We have engaged together in deliberation over how to sequence texts in ways that simultaneously deepen students' reading strategies and metacognitive awareness and control of them and enables students to construct increasingly robust explanatory models for particular science phenomena. At the same time as these inquiries and co-design opportunities build on and make explicit science teachers' knowledge and capacity, they have opened windows for us into teachers' current conceptions of text, of literacy, of science, and of the teaching of science. The inquiries result in modules, sequences, tools and scaffolds we can use to approach similar kinds of tasks with students, using texts at appropriate levels of complexity. They also alert us to areas of difficulty for teachers. As teachers implement the modules, observers are in their classrooms taking field notes and A/V recordings and talking with teachers after class to document their thinking and instructional decision-making. This work has enabled us to identify both some of the challenges in doing this work and evidence of its promise.

Challenges in Doing this Work

Over the course of our work to support teachers to implement modules like MRSA, it became apparent that the enabling pedagogies at the heart of text-based investigations – close reading of a variety of science texts and representations, developing and refining models of science phenomena, explanation, argumentation, discourse practices to support explanation and argumentation, and classroom cultures that held students accountable for doing the intellectual work while providing support for them to grapple with complexity – were new to both teachers and their students. We learned from documentation of initial attempts by collaborating teachers to conduct text-based investigations that we needed to foster a change in the learning ecology of the classroom to support this work. That is, classroom norms for intellectual work, close reading, and collaboration had to be established from the first day of class. Text-based investigations could not merely "drop in" to existing traditional instructional environments. To implement text-based investigations, teachers needed to learn new ways of working in the classroom. Ongoing professional development to make particular instructional approaches stronger and more salient was a clear necessity for teachers to support effective text-based investigations.

Likewise, documentation of initial efforts revealed that students needed to learn new ways of engaging with texts and science. Although we had conjectured that students would likely scan texts for correct answers to questions rather than engaging with text to build deep understanding or as sources for inquiry, our observations in science classrooms revealed that students did not readily utilize text-based information to generate evidence-based explanations. Often, they provided personal opinions or knowledge based on experience and not typically grounded in science or causal explanations of phenomena in the natural world. We did see evidence of change in that even with the initial implementation attempts, students successfully developed a range of reading strategies such as asking questions, developing conjectures, or noting new ideas within a given text. However, they struggled to identify the relevant textual information as evidence for the driving questions, to generate claims and inferences from textual evidence and to identify next steps for deepening their causal explanations. When the time came for students to construct explanations, they did not necessarily cite textual evidence to support their claims; rather they sometimes reverted to their prior understandings, attesting to the resistance-to-change of prior conceptions (Chinn & Samarapungavan, 2009; Driver & Easley, 1978; Harvard Smithsonian Center for Astrophics, 1987). In other words, investigations with texts were not initially treated as opportunities for deepening and expanding explanatory models for phenomena.

In addition, our documentation of the professional development work as well as initial attempts to implement text-based investigations indicated that both students and teachers struggled with how to read and make sense of science models in discipline-informed ways, a "reading" or sense-making process that involves noticing elements and causal relationships in the model and attending to how science phenomena might be accounted for using models (Pluta, Chinn & Duncan, 2011). Students initially treated model building as an opportunity to "get the right answer" and display it; their focus was on aesthetics instead of evidentiary support and completeness of ideas. Thus, the disciplinary practices of reading and constructing models were treated without attention to the elements and causal relationships, or evaluated based on evidentiary support.

We similarly discovered that the middle and high school science teachers held abundant competing schema about science models. Before engaging themselves in developing explanations and models from multiple science sources and their own hands-on investigations, many science teachers thought of models as surrogates for the real world. They used models in science instruction, they said, when phenomena were too big, too small, or too dangerous for students to encounter directly. They used pudding and candy models of the cell as an example of this idea of model as surrogate, or representation of the real. In contrast to this notion of model as surrogate, some science teachers thought of science models as something that only practicing scientists construct, based on deep knowledge of a phenomena. Why, they questioned, would it be worth class time to engage students in constructing their own, flawed models of the world, rather than giving them the "right" model to begin with? Our challenge was then to help teachers construct an understanding of the processes involved in modeling, rather than a fixed idea of models as "things", and come to value the processes of building knowledge for themselves across a set of texts and experiences, representing that knowledge as an explanatory model, and knowing it was an approximation to the real world. In short, to engage in the epistemological stances of science for themselves. When they did engage in inquiries into their own processes of investigation and model building, they began to both newly value and design similar experiences for their students.

These experiences with teachers and students caused us to redouble our co-design work with science teachers to focus on generating new instructional and material supports to address these needs. We developed a short Reading Models module, with the purpose of setting the stage for reading and evaluating science models and understanding the role of models in science. We introduced this "mini-module" as a precursor to other content-focused text-based investigation modules. The models investigation was designed to introduce the ways models were used in science and help students develop criteria for what counts as a good model. This mini-module also was designed to focus on getting routines set up early for close reading and sense-making discussions and evidence-based argument, to be built upon in subsequent modules. We drew on the elicitation tasks from Pluta, Chinn, & Duncan (2011), as well as readings from the IQWST curriculum (Krajcik & Reiser, 2004) and through embedded think aloud and discussion routines, introduced close reading with a variety of science models. In addition, the module was designed to engage students in class discussion about the epistemic role of models in building new knowledge in science, and how the merit of a model was reliant on evidentiary support. This mini-module also provided an opportunity for students to compare and evaluate models of the same phenomenon and discuss their relative ability to provide insight into underlying mechanisms, or how different models might be used to highlight different processes.

At the same time, we increased our support for teachers as they implemented the text-based investigations, helping them identify ways to strengthen their instantiation of close reading as active sense-making with a focus on explanatory model building. We continue to engage in co-design work with teachers, who have taken increasing responsibility for the intellectual work of generating driving questions; finding, modifying and sequencing texts; and adding in the necessary pedagogical supports and activities to develop modules that support text-based investigations.

We also know, from our collaborative design work, that Rome was not built in a day. Students need socialization to new expectations and routines, as well as time and experience to develop new practices. Teachers need to set new routines in place that enable them to deepen students' intellectual work over the course of a semester and year. To support this developmental progression, and based on observations from the iterative design and implementation process, we have drafted a set of instructionally appropriate learning trajectories for engaging students in text-based inquiries as a means to developing their ability to grapple with and make meaning of science texts, participate in productive argumentation discourse with peers, and construct and evaluate the adequacy of their explanatory accounts for science phenomena. The progression is meant to serve as a guide to teachers in advancing these learning goals over the course of a semester and year. We are engaging partnering science teachers in bringing the draft progression to life in their classrooms, helping us identify gaps in the proposed sequence, and in mapping their instruction onto the sequence. As they teach this year, we are documenting their work to harvest examples of promise as well as pitfalls to inform our ongoing design research.

Evidence of Promise in the READI Approach

Although we have uncovered multiple challenges in bringing text-based investigation to life in middle and high school science classrooms, we have also seen a great deal of progress in teachers' implementation of text-based investigations and evidence-based argument in science. A close analysis of instruction in one high school physiology class previous to and during the MRSA module implementation demonstrated a radical shift in pedagogy toward science inquiry as the focal point of instruction and away from absorption of science information and facts from lecture and powerpoints. Student learning about MRSA was mediated entirely by textual resources – both the interactive notebook and the MRSA texts – with text-based discussions and collaborative sense making of the science content gleaned therein guided and orchestrated by the teacher. This stood in stark contrast to what is typical in science instruction, and what was typical of this teacher's instruction up to this point.

Other teachers demonstrate similar gains in implementing more student-centered, inquiry-focused pedagogies. More instructional time is spent in collaborative group arrangements, either pair or small group. Teachers are offering modeling, guidance, and support, along with giving directions for tasks students are to complete in pairs or groups, to orchestrate collaborative sense-making with module materials and texts. With the varied texts being the main source of content, including the directions for student work embedded in the Interactive Notebooks, close reading is taking a much more central role in learning tasks. Close reading for scientific explanation is becoming a focus of instruction: how to read a particular text, what to read for, what kind of difficulties students expect to have with particular texts, what strategies they use while reading, what strategies the teacher demonstrates with Thinking Aloud to find evidence for a claim, and so forth. Teachers initially approached science reading with skepticism, knowing how deadly instructional uses of texts can be in science. But as one middle school teacher exclaimed, when texts are approached as objects of inquiry for authentic science puzzlement and explanation, students become deeply absorbed in the work:

> "Today was about reading as inquiry in science. This is very different from reading that traditionally happened in my science class. Now kids are being aware, their brains are on while they're reading. [Before] kids had bad experiences with reading, [such as] one kid is reading aloud, no one is really listening. But now we've been very intentional as a class about reading... I keep waiting for them to say that this [stuff] is boring. But they love it, they are so into it!"

We are seeing evidence of the promise of this approach in student learning, as well. The assessment tasks we have developed parallel the science reading-argumentation tasks while being reduced in scope and limited to individual work. They require close reading with annotation of a set of science texts presenting information about a scientific phenomena, development of an explanatory mental model for the science phenomena synthesized from information presented in the text set, and composition of a recommendation for potential courses of action drawing on their own mental model and grounded in evidence from the text set. In our analyses, we are seeing that students' annotations increase in quantity and quality with experience in text-based investigation, moving from no evidence of thinking on the page, to indicators of increasingly meaningful science inquiry processes. Their constructed models increasingly reflect the relevant aspects of a causal explanation, for example, linking three aspects of an explanatory model for malaria: elements of the system, interactions, and aggregate effects. Analysis of these data suggest that more time and experience with the close reading and modeling tasks is correlated with better performance on the assessment. We have some evidence, then, that experience with text-based investigation is helping both science teachers and their students develop literacy in science, knowledge about science concepts, and valued inquiry practices of science such as modeling and explaining phenomena.

Moving Forward

The theory of change on which we based Project READI stipulates that teachers mediate the opportunities that students have to learn. The history of efforts to re-form classroom instruction is replete with evidence that efforts to change educational practice through the introduction of new standards, assessments, materials, strategies, or anything else for that matter are ineffective and unsustainable without investing in building the capacity of classroom teachers by providing opportunities for them to learn how to support student learning. Likewise, it is clear that for the READI approach to be taken up effectively on a broad scale there has to be an investment in professional development that builds teacher capacity for responsive and adaptive teaching.

Ultimately, then, we envision the READI intervention as ongoing professional development accompanied by material supports and worked examples in multimedia formats that can be accessed, discussed by networks of teachers, and reflected on in the context of teachers' own ongoing efforts to implement text-based investigations in science. The text-based investigation modules that have been designed and iteratively implemented and revised through Project READI can serve as material resources for professional development inquiries, be implemented in teachers' science classrooms, and be models that guide teachers' own instructional decisions and designs for additional modules in topic areas. We are currently focused on building a progressive sequencing of text-based investigation modules that provide opportunities for the introduction and successive deepening of the literacy practices of science.

We see a promising synergy of the Common Core and Next Generation Science Standards' advancement of inquiry, literacy, and argumentation, yet these standards present the field with both opportunity and challenge. Science educators are being asked to simultaneously build students' conceptual understandings of science, to engage students in the practices of science, and to advance students' literacy practices in science. In this context of high challenge for students and teachers, it will be vital to develop teacher capacity for science teaching that can simultaneously address all of these goals, as well as ways to fundamentally shift student engagement and proficiency in science reading, writing, and learning. Engaging in science reading for inquiry, repositioning texts as sources for building explanations and models in an ongoing culture of science argumentation, is one promising way to help science teachers advance students' engagement and learning of science, while at the same time building their scientific and literacy practices.

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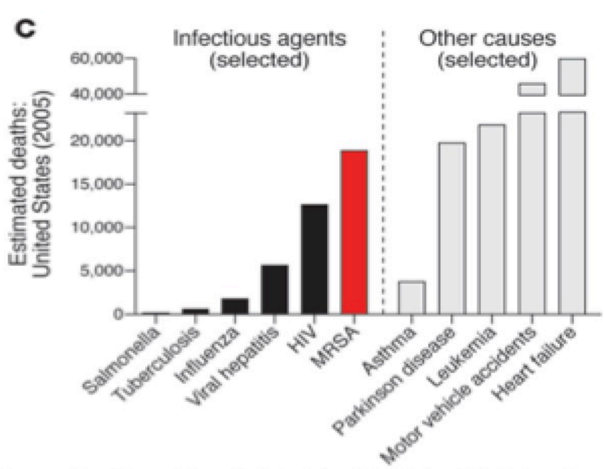
Table 1. READI Learning Objectives for Science

1. Engage in close reading of science information to construct domain knowledge (core ideas, cross-cutting concepts, principles), including multiple representations of information that are characteristic of the discipline. Close reading encompasses metacomprehension and self-regulation of the reading and reasoning processes as well as language learning strategies.
2. Synthesize science information from multiple text sources.
3. Construct explanations of science phenomena (explanatory models) using science principles, frameworks, and cross-cutting concepts and scientific evidence.
4. Justify explanations using science principles, frameworks and cross-cutting concepts and scientific evidence. (Includes evaluating the quality of the evidence.)
5. Critique explanations using science principles, frameworks, cross-cutting concepts and scientific evidence.
6. Demonstrate understanding of epistemology of science through inquiry dispositions and conceptual change awareness/orientation (intentionally building and refining key concepts through multiple encounters with text); seeing science as a means to solve problems and address authentic questions about scientific problems; tolerating ambiguity and seeking "best understandings given the evidence", considering significance, relevance, magnitude and feasibility of inquiry.

Table 2. Examples of texts that comprise the MRSA Text Set

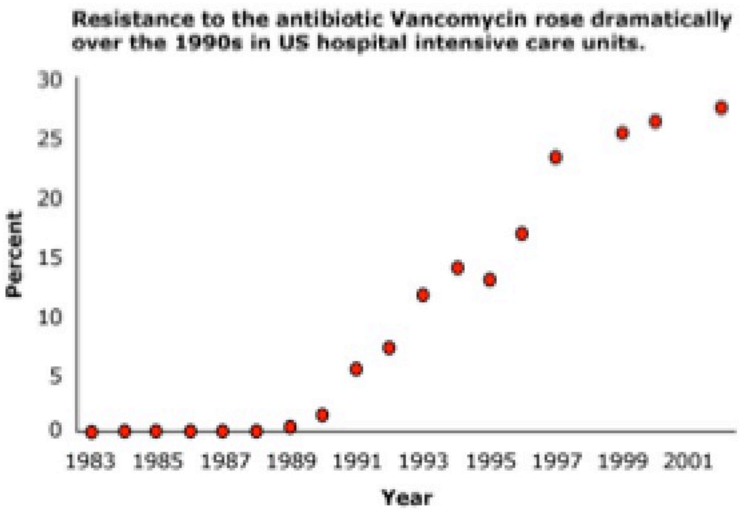
MRSA Text Set/Sequence

- Connie's Story: A Nurse's Personal Story with MRSA (video) http://webmm.ahrq.gov/perspective.aspx?perspectiveID=58
- 'Superbug' MRSA Worries Doctors, Athletes http://abcnews.go.com/Health/Primetime/story?id=410908&page=1&singlePage=tre
- Kansas City Teen Gets MRSA From Attempted Lip Piercing, Almost Dies http://www.foxnews.com/story/0,2933,354696,00.html#ixzz1m0Zzjt9b
- How long do microbes like bacteria and viruses live on surfaces in the home at normal room temperatures? edited by Bob Sillery http://www.popsci.com/scitech/article/2002-08/how-long-do-microbes-bacteria-and-viruses-live-surfaces-home-normal-room-tem
- Antibiotic / Antimicrobial Resistance http://www.cdc.gov/drugresistance/index.html
- Comparison of Estimated Death in U.S. in 2005 http://www.jci.org/articles/view/38226 Frank R. DeLeo, Henry F. Chambers, *J. Clin. Invest.* 2009; 119(9):2464
- MRSA History http://mrsa-research-center.bsd.uchicago.edu/timeline.html http://articles.latimes.com/2006/feb/26/science/sci-staph26/3
- *Contagion* movie trailer
- Superbug, Super-fast Evolution (excerpt) University of California Museum of Paleontology
- Resistance to Vancomycin graph (excerpted) Battling bacterial evolution: The work of Carl Bergstrom. University of California Museum of Paleontology
- Battling Bacterial Evolution: The Work of Carl Bergstrom
- Natural Selection and Antibiotic Resistance (excerpt) Battling bacterial evolution: The work of Carl Bergstrom
- Modification by Natural Selection (excerpt) MODERN BIOLOGY by Holt, page 287
- Growth and Reproduction http://www.biologyreference.com/Ar-Bi/Bacterial-Cell.html#ixzz1RG7ByBLw
- Wash Your Hands. http://www.health.harvard.edu/fhg/updates/update0806d.shtml
- The Success of Evolutionary Engineering Adapted from www.sciencemag.org SCIENCE VOL 293 7 SEPTEMBER 2001
- Microbes and You by David Oliver (excerpt) The Science Creative Quarterly, 8/2003, *Microbes and You,* http://www.scq.ubc.ca/microbes-and-you-normal-flora/



Source: http://www.jci.org/articles/view/38226, Frank R. DeLeo, Henry F. Chambers, *J. Clin. Invest.* 2009; **119**(9):2464

Table 2 continued



Antibiotic/Antimicrobial Resistance

Antibiotics and similar drugs, together called antimicrobial agents, have been used for the last 70 years to treat patients who have infectious diseases. Since the 1940s, these drugs have greatly reduced illness and death from infectious diseases. Antibiotic use has been beneficial and, when prescribed and taken correctly, their value in patient care is enormous. However, these drugs have been used so widely and for so long that the infectious organisms the antibiotics are designed to kill have adapted to them, making the drugs less effective. People infected with antimicrobial-resistant organisms are more likely to have longer, more expensive hospital stays, and may be more likely to die as a result of the infection.

Source: http://www.cdc.gov/drugresistance/index.html