Domain-specificity in the practices of explanation, modeling, and argument in the sciences

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To appear in F. Fischer, K. Engelmann, J. Osborne, C. Chinn (Eds.) *Interplay of Domain-Specific and Domain-General Aspects of Scientific Reasoning and Argumentation Skills*. NY, NY: Taylor Francis.

Acknowledgments

Project READI was the context for the work discussed in, and preparation of, this paper. Project READI was funded by the U.S. Department of Education Institute for Education Sciences *Reading for Understanding* initiative Grant R305F100007 to the University of Illinois at Chicago. Partnering institutions were Inquirium LLC, Northern Illinois University, Northwestern University, and WestEd. Project READI (www.projectreadi.org) activities involved well over 100 individuals employed by these organizations plus countless teachers who participated in professional development networks and/or allowed us into their classrooms. Overall, approximately 9000 students were involved in READI activities over the 6 year course of the project. We are indebted to the additional colleagues with whom we collaborated throughout the project, listed in alphabetical order here: M. Anne Britt, Michael Bolz, Stephen Briner, Candice Burkett, Jessica Chambers, Irisa Charney-Sirott, Rick Coppola, Gayle Cribb, Angela Fortune, MariAnne George, Thomas Griffin, Gina Hale, Allison Hall, Jodi Hoard, Johanna Heppler, Katie James, Kimberly Lawless, Sarah Levine, Cindy Litman, Joe Magliano, Michael Manderino, Stacy Marple, Kathryn McCarthy, Courtney Milligan, James Pellegrino, Jacquelynn Popp, Diane Puklin, Josh Radinsky, Ursula Sexton, Cynthia Shanahan, Teresa Sosa, Tanya Solomon, Jennifer Wiley, and Mariya Yukhymenko.

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Introduction

In approaching the theme of this book and this paper, our perspective on argument reflects the pragmatic context of a major research project for which the overall goal was improving reading for understanding among adolescents (ages 12 – 18) in three disciplinary domains: science, history, and literature/literary reading. Our project, Project READI (Reading, Evidence, Argumentation in Disciplinary Instruction) conceptualized reading for understanding as the capacity to engage in *evidence-based argumentation (EBA)* from multiple information sources, including the multiple modes and forms of information representations ubiquitous in the 21st century. EBA refers to a general structural form for argument: Claims supported by evidence that has principled connections to the claim through reasoning principles. Our use of information sources includes traditional printed text plus the plethora of multimedia in which modern day information is available, including online and offline sources, spoken and written, verbal and visual (graphs, diagrams, schematics, video), static and dynamic (Kress, 1989; Kress & Van Leeuwen, 2001; New London Group, 1996; Unsworth, 2002). We proposed work in three disciplines precisely because prior research and conceptual analyses suggested that there are important differences among disciplines in reading, inquiry, reasoning, and argument practices that emanate from differences among disciplines in their essential questions and concerns, in the kinds of entities and phenomena they attempt to describe and explain. That is, disciplines differ with respect to the kinds of claims put forth, the content and representational forms of the information from which evidence is derived, and the reasoning and inquiry processes invoked to derive evidence and warrant its support for a claim (e.g., Goldman, 2012;

Lee & Spratley, 2010; Moje, 2008; Shanahan, Shanahan, & Misischia, 2011; Stevens, Wineburg, Herrenkohl, & Bell, 2005). These disciplinary differences necessitate domain-specific instructional strategies. Students need to learn to situate "generic" processes of reading (e.g., word recognition questioning, inferring) and argument (e.g., making claims based on evidence, making counter claims) in the specifics of the discipline – in the texts, the questions, and the established principles of the discipline.

At the same time as we adopted a discipline-specific approach to our instructional interventions, we also sought to explore commonalities and potential synergies across disciplines. We asked what might "travel" from one discipline to another, at least at a heuristic level, for teachers as well as students. Could disciplinary comparisons serve as contrasting cases as it were, making more salient that which truly differentiated historical from scientific or literary argument? Thus, we sought where possible to establish parallels, noting apparent similarities but pushing against them to test their limits. The juxtaposition of the general with the specific in the context of teacher-researcher collaborative design work ultimately generated two important realizations among the teachers.

First, teaching "generic" argument structures would not be sufficient to support students engaging in disciplinary argumentation; nor would teaching generic reading strategies. Rather argumentation instruction needed to reflect each discipline's specific epistemic aims, values, and purposes (Chinn, Buckland, & Samarapungavan, 2011). Further, teachers reading texts within their own discipline constructed meanings and interpretations from them that teachers in other disciplines simply did not "see." This made more visible to teachers the reading demands of texts within their own disciplines. Second, through cross-talk with teachers in the other disciplines, teachers became more aware of the differences between the aims, values, and purposes of the three disciplines. This led to the realization that the reading comprehension, reasoning, and writing practices that constituted argumentation in their own discipline could not be taught by teachers in other disciplines. As well, as the design work evolved differences within each discipline emerged across topics or sub-disciplines and these had implications not only for what students were reading but what they needed to closely attend to. What kinds of entities and patterns were meaningful in, for example, economic data versus geographic data, or in the earth sciences versus the biological sciences?

In the remainder of this chapter, we elaborate on our domain – specificity position. We first discuss the limitations of general characterizations of reading and argument. We then compare and contrast our three focal disciplines using a disciplinary literacy framework from which we derived learning goals for EBA from multiple information sources specific to each discipline (Goldman, et al., 2016). In that context and consistent with the focus on science in this volume, we illustrate how the same framework can be used to specify commonalities and differences across sub-disciplines within the sciences.

Processes of Reading and Argument in Science, History and Literature

To be sure comprehension and argument can be described similarly at a general level. That is, in the most general form Evidence-Based Argument can be portrayed as: Claims supported by evidence that has principled connections to the claim through reasoning principles (e.g., Toulmin, 1958). This "CER" model has been widely used in instructional approaches to middle school science (McNeill & Krajcik, 2012). Similarly, we can describe reading comprehension at a general level. Readers are presumed to construct mental representations of the words/images on the page/screen through various decoding and word recognition processes (e.g., RAND, 2002; Rayner, Foorman, Perfetti, Pesetsky & Seidenberg, 2002). They figure out what the text/images say by accessing word meanings and put them together to build an understanding of what is being said - literally - on the page. As they reason and make inferences about the literal information, they connect to prior knowledge, across different parts of a text, and to other texts and sources (Goldman, 2004; Graesser & McNamara, 2010; Kintsch, 1998; McNamara & Magliano, 2009; Myers & O'Brien, 1998; Perfetti & Britt, 1995; van den Broek, 2010; van Dijk & Kintsch, 1983). These processes result in some mental representation of what the text means in some larger sense. In this manner, readers build a model of the situation that can be inferred from what is said. They make this representation visible in talk, writing, and other forms of external representations of their thinking (Goldman & Wiley, 2011). (See for elaboration Goldman, et al., 2016.)

From this perspective, complex reading comprehension from multiple sources appears to involve similar processes regardless of discipline. These processes include questioning, making inferences within and across texts, and evaluating consistency, relevance, and sufficiency of information to address the task and produce the desired outcome of the inquiry for which the reading was undertaken. However, purposeful reading of disciplinary texts to accomplish meaningful disciplinary tasks and purposes requires particularizing reading processes and strategies to the nature of the discipline, including its goals and aims as well as its content, and especially relevant to reading, the ways in which information is represented in the discipline.

To illustrate, consider each of the three disciplines in which READI work was conducted. First, skillful science reading may involve a cyclical and iterative process of reading, thinking, and talking about texts for such purposes as constructing or evaluating proposed explanations of science phenomena; examining and critiquing methods of investigation or interpretations of findings, establishing the existence of phenomena (e.g., ions, atoms, elements), explaining their occurrence, and describing their essential properties. Shaped by the aim of science to explore, examine, and explain the natural and designed worlds, close reading of texts containing science information affords processes such as extracting evidence and interpreting it against well established science principles, for example by using the laws of physics or chemical and biological principles to establish and justify claims about such phenomena as friction, the greenhouse effect, or the effects of drinking too much or too little water. Questioning, inferring, and evaluating information relevance, consistency, and sufficiency are particularized in the contexts of conventions of the science community regarding how arguments for existence and explanation of phenomena are established.

In contrast, historical inquiry is typically about developing plausible and probabilistic interpretive accounts of the past, based on the evidence selected and recognizing that important pieces of the puzzle may be missing from the historical record. In history close reading of multiple documents and artifacts from the historical record is particularized for purposes of extracting evidence to support claims about what happened in the past and offer explanations of why. A critical process in history is establishing the source and its perspective, in part for purposes of contextualizing it relative to what else was going on at that time including various philosophical, political, economic, geographic, social, etc. movements. Indeed, sourcing is where historical experts begin their close reading of documents within their specialization (Wineburg, 1991). Cross-document comparisons are important to corroborate events and chronologies and make inferences about the relevance of information, what data to include and what to exclude. (See for elaboration DeLaPaz and Felton (2010); Reisman (2012); Shanahan, et al. (2011); and Wineburg (1991).)

Finally, the purposes and tasks of literary reading differ from either history or science. In literary reading, the inquiry task is about interrogating problems, issues, conundrums, moral and ethical dilemmas of the human condition (Lee, Goldman, Levine, & Magliano, 2016). Skillful literary reading involves close attention to how authors' choices of particular words, plot structures, character types may have interpretive significance with respect to themes and messages about the human condition. Indeed, they look for patterns of repetition, juxtaposition, discrepancy as these may cue nonliteral interpretive tropes that have significance for authors' messages. Of course, readers of literature may agree or disagree with what they construct as author message, appealing to other texts for counterpoints, personal relevance, the context in which the author wrote, and so on. (See for elaboration Hillocks and Ludlow (1984), Hillocks (2016), Langer (2011), Lee and Sprately (2010), and Rabinowitz (1987).)

In summary, general level descriptions of complex reading comprehension processes that are invoked for constructing or evaluating disciplinary argumentation need to be specified in the discipline so that the process requires and reflects the display of disciplinary values on what is worth pursuing, perspectives, forms of evidence, and the concepts, phenomena, principles, and messages that disciplinary arguments target, the interpretive models as it were. The general processes involved in sense making (e.g., clarifying word meanings, paying attention to structure, questioning inconsistencies, inferring connections, comparing/contrasting) need to be specified to reflect the goals, aims, values, and conventions of the discipline. Disciplines differ in terms of the kinds of knowledge they are after, what they are making claims about, and the evidence and reasoning principles that constitute valid argumentation in that discipline. (See for elaboration Britt and Rouet (2012), Goldman, et al. (2016), and Rouet and Britt (2011).)

Differences in these interpretive models – in the outcomes of reading for understanding - reflect fundamental differences in the epistemology of each discipline; in the way disciplinary information is represented and read; and in what the discipline considers valid principles of reasoning and argumentation. We can think of differences between disciplines in much the same way that we think about differences between language communities. That is, members of a language community negotiate and agree on labels for objects and grammatical forms for sentences. Likewise, members of a disciplinary community have negotiated and agreed upon norms for generating and representing knowledge -- ideas, concepts, principles, and valid forms of argument that apply within that disciplinary community. (See discussions in Applebee, Langer, Nystrand, & Gamoran, 2003; Bricker & Bell, 2008; Driver, Newton, & Osborne, 2000; Gee, 1992; Goldman & Bisanz, 2002; Lee & Spratley, 2010; Moje, 2008, 2015; Norris & Phillips, 2003; Osborne, 2002; Wineburg, 2001). Thus, it is not just the “facts or principles” that differ from discipline to discipline but how the facts and principles come to be known – indeed even whether there are incontrovertible facts at all. For example, history is sometimes described as argument without end, attested to by the existence of over 40 volumes on the causes of the fall of the Roman Empire. In literary inquiry it is assumed that there are multiple meanings or interpretations of a literary work. The quality of the argument depends on reasoning about the language and structures in the text to support a particular interpretation (e.g., Hillocks & Ludlow, 1984; Rabinowitz, 1987). In science, criteria of quality include the weight of empirical evidence and the completeness and coherence of models and theories.

Thus, different disciplines may use the same or similar language and labels when referring to argumentation structure and processes but engaging in those practices is situated in the specific discipline. Situativity is a hallmark of learning sciences approaches and stands in contrast to efforts in other social and behavioral sciences to identify generalizable principles or "laws" of learning (Chinn & Sandoval, in press). We argue as well that reading and reasoning for purposes of disciplinary inquiry are equally situated in specific disciplines.

At the same time the specificity argument belies the realities of formal schooling for most adolescent learners. They are not immersed in a specific discipline for hours on end. Rather they typically switch hourly from one discipline to another and may be expected to read, reason, and argue in each of them. We grappled with how we might support appropriate balance of the general and the specific as adolescents moved from one discipline to another, and from one subdiscipline to another. With an awareness of this tension and of the need for a practical theory of evidence-based argumentation, we embarked upon the specification of what students needed to learn and how that learning might be supported.

Implications for Instruction and Student Learning in the READI Approach

Our starting point in our efforts to answer the question of what students needed to learn was to take a deep dive into each of the three disciplines with the goal of surfacing the kinds of knowledge that accomplished members of each of the three disciplinary communities might bring to bear when engaged in disciplinary inquiry and argumentation. What did they make claims about? What kinds of questions drove inquiry in each discipline? What did they read? What kind of evidence did they use? What kinds of information did they rely on? How did they represent that information? What kind of strategies and heuristics did they call on when reading and reasoning? How did they communicate with other members of their disciplinary community?

Noteworthy in this deep dive process is the diversity of perspectives that the READI team brought to this endeavor, resulting in a need to establish common ground among ourselves. Members of READI reflected multiple disciplinary backgrounds (e.g., assessment and evaluation; cognitive, discourse, and educational psychology; history and social studies education; linguistics; literary studies and English language arts; learning sciences; the biological, chemical, and physical sciences and science education) and were employed by a range of organizations, including 3 different universities, an LLC, and a service, evaluation, and professional development non-profit. Some were faculty members, others curriculum and professional development designers and facilitators. We partitioned ourselves into three disciplinary teams (Literature, History, Science) that reflected our heterogeneous expertise and with minimal overlap across teams to interrogate prior research regarding the kinds of knowledge needed for inquiry and argumentation within each discipline.

READI's Disciplinary Core Constructs

Within each group the analysis and interpretation of prior research involved a large amount of discussion and debate about form and function; about different kinds of argument, explanation, narrative, description, classification, and so forth. Likewise when we compared notes across disciplines. Eventually, we reached consensus on five categories of "core constructs" that enabled us to adequately classify the different kinds of knowledge that members of each discipline appeared to use when engaging in argument and inquiry practices. These core constructs do not refer to content knowledge in a discipline but rather what members of a disciplinary community know about how to engage in the practices of their discipline that generate the content knowledge base of the discipline.

Goldman, et al. (2016) provide discussion of the literature examined and the instantiation of the core constructs in each discipline. In the context of the present chapter, we provide a brief overview of the generic labels for each of the core constructs and highlight the discipline specificity within each category (see Table 1). As shown in the first column, the five categories of core constructs refer to the nature of knowledge and knowing (epistemology), methods of inquiry, big ideas and principles that provide the basis and justify why particular information qualifies ~~warrant specific data serving~~ as evidence for particular claims, forms in which information is represented, and discourse and language structures of communication (i.e. oral and written discourse registers used among members of the disciplinary community. Note the value of the generic as a schema with which to approach the analysis of other disciplines as well as using them to capture variations within a discipline, i.e., specificity of sub-disciplines. In large measure because READI funding was to improve reading with understanding, our work focused on providing ways for teachers and their adolescent students to understand and manage the domain specificity of argumentation and inquiry practices. Unlike other chapters in this volume, we chose to engage students in science investigations through representations of science information, not generation of information through experimentation or observation practices.

As we worked on the design of instruction, we came to see epistemology as central, providing purpose and motivation to the ways in which inquiry is conducted, the reasoning principles that are invoked, and the forms in which information is represented, expressed, examined, critiqued, and negotiated in and through oral and written discourse. Earlier we indicated that while one could use the same labels for the processes of reading literature, history, or science information, the purposes of the reading and hence the products of the reading inquiry process differed. As well, the instantiation of similarly labeled reading processes is specific to the representations and discourse and language structures of the discipline. Thus we do not read "the same way" when we read literary works as compared to historical documents such as *The Declaration of Independence* or *The Treaty of* 1812 or either of these as compared to articles in *Science* that report new findings or dispute existing classification systems or explanations. These differences in purpose are captured in the epistemology core construct. For example, and as indicated in Table 1, literature aims to interrogate the human experience; history makes claims about the past; and the sciences describe, classify/categorize, and explain phenomena of the natural world.

Different representational and discourse/language forms serve the different epistemic purposes and thus portray disciplinary specificity. Literary authors choose among prototypical genres (e.g., novels, short stories, poems), plot structures and themes (e.g., coming of age, magical realism) and protagonists (e.g., hero/antihero; unreliable narrator) depending on the message they wish to convey. They manipulate language through choice of language structures, including particular images, symbols, narrators, patterns of word and phrase repetition, to invite the reader to go beyond the literal to interpretive meaning (e.g., Lee, et al., 2016). Historians bring their perspectives to bear on primary sources, creating secondary (e.g., historical narratives, biographies) and tertiary sources (e.g., textbooks) that may include multiple representational forms (e.g., photographs, cartoons, maps) to convey their accounts of the past. Furthermore, their argument may be couched in different language forms (e.g. descriptive, explanatory, narrative). Science employs a variety of representational forms to convey information, including diagrams, tables, flowcharts, graphs and figures. Scientists employ a variety of written genres that range from the more informal and personal (e.g., bench notes) to the more formal (e.g., refereed journal articles). Language in science writing reflects structures that tend to appear only in written form (e.g., passive voice, nominalization) and are lexically dense (Lee & Sprately, 2010). As well, commonplace words (e.g., causes, effects, correlates with) take on specific and technical meanings with which naïve readers may not be familiar.

Similarly, the inquiry methods reflect the differences in epistemology as well as the discipline – specific characteristics of the information representations and discourse/language forms. For example, in history the perspective of the source, the historical context, and whether artifacts in the historical record converge or are discrepant are crucial processes in evaluating the information and constructing an argument. In science, perspective of the source is less critical but coherence across different information sources is important (e.g., Lemke, 1998, 2004). As well, working across representations and correlating patterns in multiple data streams is an important process in establishing the existence of particular entities and in arguing for particular classification systems or causal mechanisms. Patterns are also important in literary interpretation but the patterns are extracted from detailed analyses of word, character, and plot choices made by the author. Finally, the third core construct, overarching themes, is perhaps the one that most closely reflects the content of the discipline and as such bridges between the content knowledge in the discipline and the argumentation and inquiry processes. For example, in history arguments employ relationships among events (e.g., chronology, causality, patterns of change over time) as well as principles drawn from societal frameworks (e.g., economic, political, geographic), themes of human and social system dynamics (e.g., migratory processes, industrialization, inter- and intra-group power relations). Although these are general relationships and principals they take on meaning differently depending on the specific time, place, and events to which they are applied. Likewise, in the sciences, explanatory mechanisms such as structure – function relations, scale, and cause and effect may be stated generally as cross-cutting concepts yet be expected to manifest differently within physics as compared to biological systems.

Generic versus Specific Tensions: The Case within Science

Our conclusions from developing the core constructs were that it was possible to describe all three disciplines similarly at a general level and that arguments in each discipline do take the form of Claim – Evidence – Reasoning (the CER framework used by McNeill & Krajcik, 2012). But equally clear was that the generic structural shell had to be particularized differently within each discipline. As well, disciplines are not monolithic. Comparisons across subdisciplines reveal variations in favored methods of inquiry, representations, and the reasoning principles that are best aligned with the questions and claims at the heart of the subdiscipline. Samarapungavan (this volume) argues that the very nature of evidence also varies widely across science subdisciplines. Sub-discipline specificity is as much the case in history and literature as in science. However, given the theme of this volume we elaborate on this point only within the science discipline.

Different science sub-disciplines address largely distinct phenomena; although they share the general level purpose to describe, categorize/classify, and explain, they target different entities and relationships. As well, what is contested or unknown is distinct to a particular sub-discipline. Thus the models, and theories are of different phenomena, and involve different entities and relational principles and mechanisms. The sub-disciplines draw on different bodies of theory for warrants/backing. That is, biology draws on evolution, chemistry on quantum mechanics, and physics on relativity and quantum mechanics. As well, the sub-disciplines have different "mid-level" theories and principles. Some of these have analogous principles: homeostasis in life science and equilibrium in chemical & physical systems. Homeostasis and equilibrium are similar in the sense of "balance" or "steady state" but they differ in terms of what is balanced and how (e.g., balanced forces, balanced concentrations of reactants and products, balanced chemical levels in organisms). Other mid-level theories may be more unique, having no analogues in other sub-disciplines (e.g., natural selection in biology). The rules for evidence validity are very specific, not just to the sub-discipline but to the kind of evidence.

It is interesting to note that interdisciplinary science arguments will draw on frameworks of multiple sub-disciplines. For example, arguments in bio-physical sciences may be backed by frameworks of evolution and quantum-mechanics. Furthermore, even within a sub-discipline the locus of arguments shifts, driven by available technology, gaining access to new data, data processing, or resolution/closure of previously contested questions. In other words, scientists argue about different explanations at different times as well as in different sub-disciplines.

With respect to overarching principles, there is a domain general level at which they can be named, as the NGSS has done with cross-cutting concepts. However the manifestation of these is specific to sub-disciplines of science in terms of the entities and mechanisms, as we indicated in the discussion of homeostasis and equilibrium. Another example is the idea of cause and effect, itself a general principle but what cause and what effect vary by phenomena and by sub-discipline (e.g., arguments for what caused a strain of bacteria to become antibiotic - resistant versus arguments for what caused (is the origin of) the Earth's hydrosphere). The rules, also, for determining what is or isn't a system vary by sub-discipline. A system in biology may be a cell but not half a cell, but from a physical thermodynamic perspective, “anything” can be a system.

With respect to representations, the nature and type of visuals varies by sub-discipline, with different entailments for reading and reasoning processes. Phylogenetic trees are common in biology but not in chemistry and physics. Force diagrams and circuit diagrams are ubiquitous in physics but far less frequent in biology. Different sub-disciplines are focused on different phenomena for which there are differences in what needs to be depicted and how. As well, when it comes to discourse and language structures the nature of the phenomena with which the subdiscipline is concerned dictates specialized vocabulary. Some words take different meanings in different sub-disciplines: nucleus and cell in biology versus in chemistry & physics. But even these are disambiguated (nucleus of an atom vs nucleus of a cell, galvanic cell vs living cell) when the full terms are used. Thus, each subdiscipline brings with it specific technical terms and definitions. However, throughout this discussion, it is important to keep in mind that it is useful that the general provides a schema for instantiation in the specific.

Science Learning Goals and Supports for Evidenced Based Argument from Multiple Text Sources

The core constructs captured “what” students needed to know about each of the disciplines to engage with argumentation. We then developed learning goals that reflected the integration of the core constructs with reading, reasoning, and argument practices in each discipline. The science learning goals (see Table 2) were specifically for text-based investigations as compared to investigations in which students generate their own data using, for example, experimental or observational techniques. (See Greenleaf, Brown, Goldman & Ko (2013) for discussion of our rationale for this focus.). The first goal, close reading of the representations used for conveying science information, involves reading traditional text as well as a variety of visual models of structures and processes. Sense making processes are identified in learning goals 2 – 5 in Table 2. Students ask a variety of questions as they closely read the materials in efforts to construct, justify, and critique explanations of science phenomena, including what and how specific information is relevant to the inquiry task, if at all; what does or does not make sense; how it fits together. Through this process, cross-cutting ideas become instantiated for the specific topic and domain concepts and core ideas germane to the specific subdiscipline and topic become refined to reflect their specific and technical meaning for that topic and phenomenon. That is, in doing this close reading, students may invoke ideas they bring from other sub disciplines of science and sometimes from other disciplines. The negotiation of meaning involves successive approximation to what matters for that specific topic. In other words, students begin to approach new content with schema derived from what they know. They successively instantiate and differentiate the new material they are learning and thereby specify the general in the specific domain and topic. This process is effortful and time consuming but manageable with appropriate facilitation, instructional supports, and a classroom culture that values and normalizes “effort after meaning” (Bartlett, 1932).

The design of these supports involved working in close collaboration with teachers to develop tasks, tools, text sets, and activity structures that would provide opportunities for students to engage in the practices identified in the learning goals. We strove to achieve the Goldilocks state, i.e., an appropriate balance between the familiar and the unfamiliar. Achieving a balance between general and specific that would enable students to make sufficient connections between what they knew and the new. More often than not it took successive iterations to get there. We illustrate this process in the context of a tool designed and developed to support students' in reading the various visual models prevalent in science texts.

Initially, we surveyed various ways that extant textbooks and inquiry-oriented curricula introduced models to students. One textbook presentation we found seemed promising in that it reflected the diversity of models in science and provided relatively accessible descriptions of of physical, conceptual, mathematical and numerical models. However the descriptions did little to help students develop criteria for evaluating models, or for deciding when and why one type of model might be preferable to another.

We then drew on prior research that had developed and tested a general description of the function of models: they help scientists explain, predict, and describe natural phenomena (Krajcik, Reiser, Southerland, & Fortus, 2011). This is a fairly typical way in which models are introduced in middle school science classrooms. Students subsequently built on this general definition by reading, comparing and contrasting alternative models for the same phenomenon across a variety of sub-disciplines of science. As they read them, students discussed which model was better, why, and later, which model best addressed specific inquiry questions. Specifically, Figure 1 provides a snapshot of the of the middle school module that was used in the context of investigating Earth Science processes. This was built on the work of Pluta, Chinn, and Duncan (2011) who had used these various models as part of an elicitation task for assessing students' ideas about models and criteria for models. We transformed their task into an inquiry task by creating a variety of model pairs. Students discussed and argued about which of these pairs (A and B, C and D) were good models and WHY. Teachers used shareouts of these small group discussions as instructional opportunities for creating criteria for models and exploring the strengths and limitations of various types of models for answering different questions and highlighting different aspects of Earth Sciences phenomena.

However, as we shared this model reading module with biology teachers, they quickly pointed out that learning to read these models was not going to be helpful for reading the kinds of models students would encounter in biology. Indeed these discussions contributed to revisions to the core constructs and a deepening understanding that situating (instantiating) evidence-based argument practices had to be done at the sub-discipline, specific topic level in science but also for the topics we were working with in history and in literature. In the sciences, as we noted earlier, various subdisciplines are focused on answering different types of questions about the natural world, employ different types of procedures to collect data, have specific criteria and reasoning processes for generating inferences and evidence for claims. These distinctions shape the argumentation process and outcomes, including the models and representations.

These reflections shaped the design of the next wave of curricular tools and assessments to reflect subdiscipline specificity that would more directly support students in engaging in the argumentation processes stated in the learning goals. Specifically, we worked with three 9th grade biology teachers who were participating in the California Teacher Inquiry Network, to develop a biology reading models module that used a task structure similar to the initial module that we had originally intended to be a more general models module. The teachers first identified developmentally appropriate models for specific sub-domains of biology and then one of them took the lead role in developing this second, biology specific module. She selected various models that reflected the kinds of phenomena, inquiry questions, and representations that manifest the disciplinary core ideas of High School Biology, as reflected in recent reform documents (NGSS Lead States, 2013). This module aimed to support students in reading various

Biology models and developing and refining their definitions of science models through sensemaking classroom discussions. (See Figure 2.) The module culminated by asking students to read and compare alternative models (e.g. models of photosynthesis and cell membrane structure) and evaluate which of these models best addressed a single inquiry question. Developing the norms, strategies, and criteria for reading and evaluating models laid the foundation for later work, wherein students drew on these routines and criteria to construct explanatory models by synthesizing and transforming textual information.

Summary

In our work on argumentation we have been attempting to identify a practical theory of argumentation for teachers and for their students (Cronen, 2001; Kettle & Sellars, 1996). Practical theories capture principles - knowledge, beliefs, values - born in lived experiences that can guide actions in new experiences; they are dynamic and responsive to new experiences (Handal & Lauvas, 1987). In our case, we seek a practical theory that has just the right mix of disciplinary specificity and generality to be useful and actionable for teachers working within their particular subject-matter domains. Collaborative exploration within and across disciplines about the nature of knowledge and argumentation helped expose levels at which similar descriptive language might apply as well as the discipline and subdiscipline – specific characteristics. Differences in the kinds of claims, evidence and reasoning that were valued and respected surfaced in these cross discipline (and subdiscipline) dialogic debates, and teachers came to realize the unique aspects of their own specializations. We argue that this would have been less likely had teachers been working only with those in their own specialization areas.

We would also like adolescents to have practical theories of argumentation that could serve a schematic function and facilitate their argumentation practices in the multiple disciplines they are asked to engage with in the course of a school day. Schematic guidance could assist them in anticipating general forms of argument but with the knowledge that these are realized quite specifically and differently depending on the epistemics of the discipline or subdiscipline. Learning to engage in disciplinary inquiry involves coming to understand differences among disciplines and subdisciplines in what kinds of claims are valued and informative, the reasoning practices and principles that transform data into evidence for (or against) claims, and the underlying epistemics that both lead to and from which all three derive.

Our analytic processes as we have engaged with the fundamental character of argumentation across just the three disciplines, in combination with our collaborative work with teachers, have led us to the realization that we have just scratched the surface regarding the kinds of knowledge, reading and reasoning practices involved in competent argumentation within any given discipline. We are still wading into the instructional waters of what competencies learners need to practice disciplinary argumentation, how to guide them in appropriate application of what they know and can do, and how to provide tools for learning and assessment that advance those competencies.

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Table 1. Core Constructs: General Definitions and Highlights of Instantiations for Literature, History, and Science[a]

Core Construct: General Definition	Literature/Literary Reading	History	Science: Text-based Inquiry
Epistemology: Beliefs about the nature of knowledge and the nature of knowing. What counts as knowledge? How do we know what we know?	Literature as a window into interrogating the human experience including the social, political economic, and cultural contexts of the world. Literary texts are open to dialogue among communities of readers within and across time. Literary critique values attention to both content and form, and investigates how decisions by authors regarding structure and language use influence meaning.	Claims about the past are based on a historical record that is inherently incomplete, conflicting, and obscure, and therefore provisional and contestable. Historians make interpretive arguments about the past based on the historical record but from their own perspectives.	Description, classification, and explanation of the natural and engineered worlds expressed as models and theories that are • approximations and have limitations • based on sound empirical data • socially constructed • meet criteria of parsimony, and logical cohesion • subject to revisions with successive empirical efforts that reflect changes in technology, theories and paradigms, and cultural norms.
Inquiry Practices, Reasoning Strategies: Ways in which claims and evidence are established, related, and validated	Infer from details within texts • plot sequence and causal links between events, actions • characters motivations and psychological states, and relationships among of characters • structural generalizations about	Historians investigate questions, interrogate the historical record, or analyze historical interpretations through • sourcing • contextualization • corroboration	Scientific knowledge is built by: • developing coherent, logical classification systems, explanations, models or arguments from evidence • advancing and challenging classification systems and

	how inferred meanings are achieved rhetorically. • generalizations the reader argues the author is making about the world beyond the text itself. Evaluate how rhetorical strategies are employed to help shape reader's response. To construct interpretations, draw on prior knowledge of • social milieu of the text • human intentionality • moral and philosophical precepts • other works by the author, related literary and non literary texts	• questioning inclusiveness (what perspectives, sources, data are included or omitted) • questioning coherence • avoiding logical and reasoning fallacies	explanations • converging/corroboration of evidence • comparing/integrating across sources and representations • evaluating sources and evidence in terms of scope, inferential probability, reliability, and extent to which it accounts for evidence.
Overarching concepts, themes, principles, frameworks: Foundational concepts, ideas, reasoning principles, and assumptions. These serve as a basis for warranting, justifying, legitimizing	Readers construct interpretations of literary texts using belief systems and principles that reflect • morality and philosophy • historical contexts • traditions of critical theory (e.g., Reader response, feminist, New Criticism, Post Structuralism) • intertextuality, including	Historians draw on a variety of interpretive frameworks: • societal systems (political, economic, technological, social, geographic) • relational (chronological, contingent, causal, coincidental, chance) • change over time • thematic (migratory processes,	Scientists connect evidence to claims using • cross-cutting concepts (patterns; cause and effect; scale, proportion and quantity; systems and system models; energy and matter in systems; structure and function; stability and change of systems). • disciplinary core ideas in the physical sciences, earth and space

connections between evidence and claims.	relations among literary texts, between literary texts as well across literary and historical, sociological, philosophical texts	industrialization, power relations) • complex systems	sciences; life sciences; and engineering, technology, and applications of science.
Forms of information representation/types of texts: Types of texts and media (e.g., traditional print, oral, video, digital) in which information is represented and expressed.	Prototypical genres and ways of structuring plots; kinds of prototypical protagonists. • generic genres (e.g. stories, poems, dramas) • specialized poetic genres (e.g. haiku, ballad, sonnet) • exemplar plot structures (e.g., coming of age, science fiction, fable, satirical works, myth, magical realism) • exemplar Protagonists (tragic hero, antihero, mythic hero, trickster,)	Texts types in history are • primary sources that include all texts from the period of study (e.g., autobiography, memoir, fiction, news story , editorial, political cartoon, art, graphic novel, video, legal documents). • secondary and tertiary sources (e.g., biography, historical fiction, data tables, textbook, editorial, polemic essay, political map). History texts appear in a range of media, including traditional print, radio, TV, video, and hypermedia.	Scientific texts may have different explanatory purposes (e.g., cause effect, correlation, comparison, process sequence, chronology, enumeration, description). Science texts convey meaning with multiple representations (e.g., verbal, diagrams, equations, graphs, tables, simulations, flowcharts, schematics, videos). Different types of sources (genres)are written for different au diences and purposes, with implications for their content and structure (e.g., bench notes, refereed journal articles, textbooks, websites, blogs).
Discourse and language structures: The oral and written language forms in which information is expressed.	How author's selection and sequence of action, dialogue and description create an imaginary world into which the reader is invited through the manipulation of language.	Structure of historical arguments can be • descriptive (*What was the case?)* • explanatory (*Why was it the case?*)	Science texts contain • distinctive grammatical structures (e.g., nominal-izations, passive voice). • technical and specialized expressions.

	Major ways of using language: • imagery: Language used to create a visual representation and invite emotional response (e.g., use of descriptions, metaphor, simile) • figuration: Language used to invite a figurative interpretation beyond the literal (e.g., symbolism, irony, satire) • problems of point of view: Who is speaking; reliability; authorial versus narrative audience; relation of narrator's point of view to the author (e.g., omniscient narrator, unreliable narrator, multiple narrators) • rhetorical strategies and patterns (e.g., parallelism, contrast, repetition, understatement, exaggeration, allusion, dialogue typography, privileged placement)	• narrative (both descriptive and explanatory structures). Linguistic features of history texts mark conventions of chronology, periodization, perspective, theme and topic. History texts include accurate and thorough documentation of sources, usually in the form of footnotes or notes. Conventions for claim and evidence presentation in oral and written forms include • one-sided, two-sided arguments, multi-sided • two-sided, multi-sided refutational arguments • implicit arguments (embedded in descriptive and narrative structure) • oral arguments (debates, discussions, conversations)	• signals to the degree of certainty, generalizability, and precision of statements. Argumentation is a scientific discourse practice in which evidence is used to support knowledge claims, and scientific principles and methods are used as warrants. Conventions for claim and evidence presentation in oral and written forms include • one-sided, two-sided arguments, multi-sided • two-sided, multi-sided refutational arguments • implicit arguments (embedded in descriptive and narrative structure) • oral arguments (debates, discussions, conversations)

[a]See Goldman, et al. (2016) for expansion and explanation of the core constructs in each of the disciplines. This table merely provides a summary for purposes of quick comparisons across disciplines.

Table 2. Learning Goals for Text-based Science Inquiry

1. Engage in close reading of science information to construct domain knowledge, including multiple representations characteristic of the discipline and language learning strategies. Close reading encompasses metacomprehension and self-regulation of the process.

2. Synthesize science information from multiple text sources.

3. Construct explanations of science phenomena (explanatory models) using science principles, frameworks, enduring understandings, cross-cutting concepts, and scientific evidence.

4. Justify explanations using science principles, frameworks and enduring understandings, cross-cutting concepts, and scientific evidence. (Includes evaluating the quality of the evidence.)

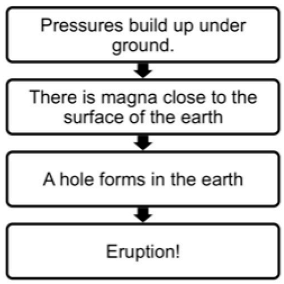
5. Critique explanations using science principles, frameworks and enduring understandings, cross-cutting concepts, and scientific evidence.

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.

Figure 1. Middle school Reading Models module task

Text A

How a Volcano Works



Text C

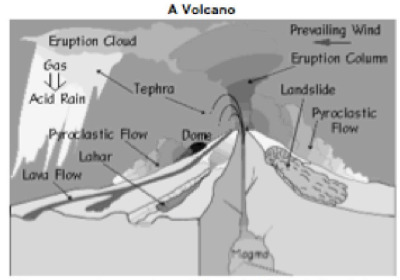
Volcano Making Kit

Text B

Erupting Volcano in Pool

Text D

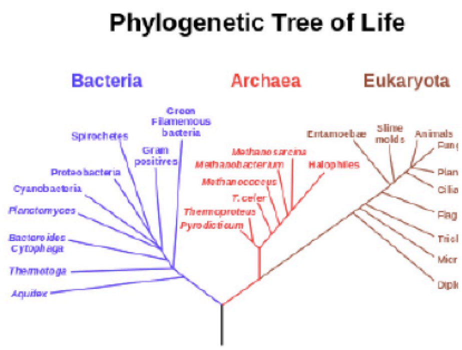
A Volcano



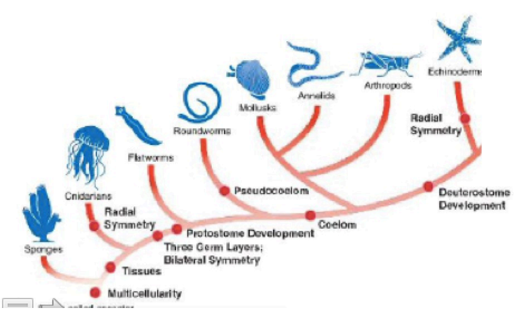
Here we see how a volcano is formed. Magna is found deep below the surface. It moves towards a hole in the ground. Finally, lava flows from the hole, as smoke also pours from the opening.

Figure 2. Models used in Biology Reading Models Module. Model A is in an image in the public domain (https://en.wikipedia.org/wiki/File:Phylogenetic_tree.svg). Model B was retrieved from http://kvhs.nbed.nb.ca/gallant/biology/biology.html, August 2013.

Model A: Relatedness of Life



Model B: Relatedness of Life



What Makes a Science Model Better?

Individual/Pairs Read

Read Model A and Model B. While reading, make your thinking visible using either Think-Aloud with partner note-making, Talk to the text, or *I read / I thought* double-entry notes. Your teacher will say which to use.

Pair Discussion

With a partner, go through Model A and Model B, discussing your reading *bit by bit*. Take turns sharing and listening. Help each other clarify roadblocks. Add good ideas from your discussion to your notes (i.e. your annotations or double-entry notes).

Individual Think-Write

Silently read the question below. Circle the best response and write your reasons for choosing it.

Which model is better, Model A or Model B? Why?

- Model A is better.
- Model B is better.
- Models A and B are equally good.
- It is impossible to say which is better.