# Metacognitive Support for Reading in Science Classrooms

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**Abstract:** Students struggle to read science texts. This is especially problematic for designers of inquiry-based learning environments that make ambitious demands on readers. We report on our efforts to provide targeted strategic supports for struggling adolescent readers in science classrooms. Environmental science and biology high school students learned to use tools designed to foster three specific metacognitive skills: recognizing text structure, reflecting on content, and representing the gist of a text in a summary. During one school year, students had regular opportunities to use these strategies in class. Participants completed one tool use assessment at the end of the school year in which they used the tools during reading of a science text. Students then answered science comprehension questions about the text. Tool proficiency was correlated with both reading and science achievement. Tool proficiency also predicted science achievement when controlling for on-entry reading ability. The implications for science instruction are discussed.

## Introduction

Reading proficiency remains a key roadblock to successful implementation of ambitious science instruction for too many students in America. Science instruction that stresses inquiry requires students to read texts to learn new content in order to successfully engage in the kinds of practices valued by the science education community. These practices include reasoning from evidence, communicating with others about science, conducting complex investigations, analyzing and representing data, engaging in cost-benefit analyses, etc. (National Research Council, 1996). Too often, students, particularly in traditionally under-served educational settings, do not have the opportunity to develop science text reading proficiency that would allow them access to important science content. Teachers, too, are often under-prepared to support reading in science in ways that would deepen students' understanding of key science content (Gomez, Herman, & Gomez, 2007). Because of a limited repertoire of pedagogical strategies, teachers often skip readings, assign readings for homework, or didactically lecture about the content in the readings. Therefore, texts, a critical learning resource, are often ignored or underutilized in science instruction in too many high schools.

Designers of inquiry learning environments have focused on a myriad of challenges to successful inquiry in classrooms, including issues related to learning progressions, use of real-world data, the role of tools in investigations, and how to assess learning in inquiry settings — to name just a few. However, too little attention has been focused on reading in inquiry settings. Contemporary science classrooms are characterized by complicated texts and more diverse kinds of texts than in prior decades. Instead of just textbooks, science learners read from the Internet, trade books, science journals, newspapers, etc.

The following figures give some idea of the extent to which students are struggling to read in America:

- Only 31% of America's eighth-grade students — and roughly the same percentage of twelfth graders — meet the National Assessment of Educational Progress standard of reading "proficiency" for their grade level (NCES, 2005, 2003).
- Among low-income eighth graders, just 15% read at a proficient level (NCES, 2005).
- In a typical high-poverty urban school, approximately half of incoming ninth-grade students read at a sixth- or seventh-grade level (Balfanz et al, 2002).
- A mere 3% of all eighth graders read at an advanced level (NCES, 2005).

## The science reading gap

There is a large gap between what many students can read independently, with little or no teacher support, and what they are regularly expected to read in science class. To better understand reading proficiency in science classrooms, we administered the Degrees of Reading Power (TASA, 1999), which measures reading comprehension and can provide a measure of reading complexity for any reading passage, to all ninth-grade students at the Chicago high school that participated in this project. The mean DRP score for ninth graders was about 39. The left side of Figure 1 gives an example of text that students can read independently when they have a DRP score of 39. The right side is a sample of text (DRP=66) from the *Investigations in Environmental*

*Science* curriculum, a National Science Foundation-funded curriculum in use at the school.

| Passage with a DRP score of 39 (mean score for ninth graders in our sample):<br><br>*A bird's wings are well shaped for flight. The wing is curved. It cuts the air. This helps lift the bird. The feathers are light. But they are strong. They help make birds the best fliers. A bird can move them in many directions. Birds move their wings forward and down. Then they move them up and back. This is how they fly.* | Text those same ninth graders are expected to read, from the environmental science curriculum they are using (DRP=66):<br>*Beginning about 75 years ago, hundreds of small dams began to be "decommissioned." In the last decade, 177 dams were removed nationwide, with 26 of these in 1999 alone. Salmon conservation was not the sole reason for decommissioning these dams. Many were in poor condition, dilapidated from lack of maintenance and they posed a flood risk for areas downstream.* |
|---|---|

Figure 1. Text students can read independently and text excerpted from their science curriculum.

Given this gap, what are the options for schools that want to ensure that students achieve in science? One choice is to choose different curricular materials in which readings are closer to the complexity level on the left in Figure 1. That would entail using upper-elementary or early middle school science curricula with these high school students. Another option is to change the existing texts to remove those elements (vocabulary, complex clauses, inferences, etc.) that increase complexity. A third option, which we mentioned earlier and which we believe to be common in high schools, is for teachers to essentially ignore the texts in instructional activity. Or, if they use the texts at all, they might didactically lecture about key content. All of these options do a disservice to students — texts should not be ignored. We choose a fourth option: to provide reading comprehension supports to scaffold reading and learning from texts like those on the right side of Figure 1.

## The Adolescent Literacy Support Project (ALSP)

We report on our efforts to develop, implement, and evaluate a program of science reading supports for students and teachers in one Chicago high school who implemented two yearlong, inquiry-focused science curricula: *Investigations in Environmental Science* in ninth grade and *BSCS Biology: A Human Approach* in tenth grade. ALSP provides pen-and-paper and electronic reading support tools to students and professional development for teachers on the use, purpose, and affordances of the tools, as well as ways to closely couple reading activity to science learning goals. The explicit goal of the ALSP project has been to increase students' science and reading achievement through student use of tools that encapsulate effective science reading strategies and to research the connection between reading achievement and science achievement. An influential report (National Reading Panel, 2000) that summarized evidence-based approaches to supporting struggling readers noted that reading achievement increased dramatically when students were able to learn and use specific strategies to monitor and deepen their understanding of texts. In the following sections, we describe the tools that instantiate the strategies we support. Next, we describe the setting for our work. Then, we present initial findings about how proficiency with the tools is related to science learning and reading comprehension. Last, we discuss the implications of this work.

### Reading strategies: structure, reflection and gist

Science readers should have a corpus of strategies they can use prior to, during, and after reading to learn from text. Students benefit when they are taught to apply comprehension strategies when they read (Anderson, 1992; Collins, 1991). Through repeated transactions with texts and by collaborative analysis and discussion with peers, students can better internalize and ultimately take ownership of the strategies (Pressley, El-Dinary, et al, 1992; Biancarosa & Snow, 2006). When internalized and used frequently, strategy use can lead to large positive effects on text comprehension (Anderson, 1992). Strategies can help students identify the structure of text in general; as well as its critical elements such as main and supporting ideas, arguments and evidence, etc., and signposts such as transitions, comparisons, and contrasts (Gomez, Herman, & Gomez, 2007). In addition, students should know how to reflect about, deconstruct, organize, and analyze text so that elements of the text can be examined and critiqued for understanding and communication (Gomez, Gomez, & Herman, 2008). They should also know how to summarize a text to integrate new and prior knowledge about a topic into one holistic representation of their understanding. Summarization helps students communicate their understanding of the gist of what they have read (Kintsch, 1998).

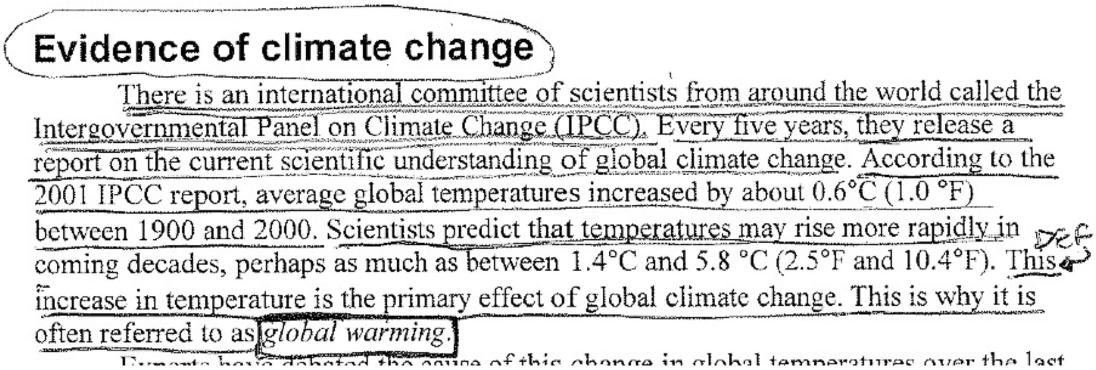
Each tool is designed to encapsulate an effective reading strategy for science texts. They are designed to help develop metacognitive reading skills to increase active cognitive processing of text. Such active processing should increase reading comprehension and science achievement. Though there are many conceptualizations of metacognition in the literature, we focus on developing students' conscious control of reading including planning, selecting, and using appropriate strategies; monitoring reading comprehension; analyzing the effectiveness of reading strategies; and changing reading behaviors when necessary (Ridly, Shutz, Glanz, & Weinstein, 1992). We conjecture that increases in metacognitive reading skills will allow students to comprehend more challenging text. Over time, as teacher support fades and reading strategies are internalized, students will be able to read more challenging texts more independently. Next we describe each tool in detail.

## Annotation

Text annotation is a strategy to make the author's message more explicit to the reader. Students are taught how to identify and mark important information, and disregard irrelevant information. Students typically annotate (by marking on the text) one or more of the following items:

- Difficult vocabulary words and in-text definitions
- Main ideas/arguments and related supporting ideas/evidence
- Headings, transitional words, and other signposts
- Other difficult words (non-science vocabulary) and sentence construction
- Inferences
- Conclusions

The structure of text and the connection between content elements becomes clearer as students, for example, search for supporting ideas for a main idea they have already identified. Teachers can model this annotation process to scaffold readings for their students, building to the place where students are independently annotating text. Below is an example of an annotation from an article on global warming.

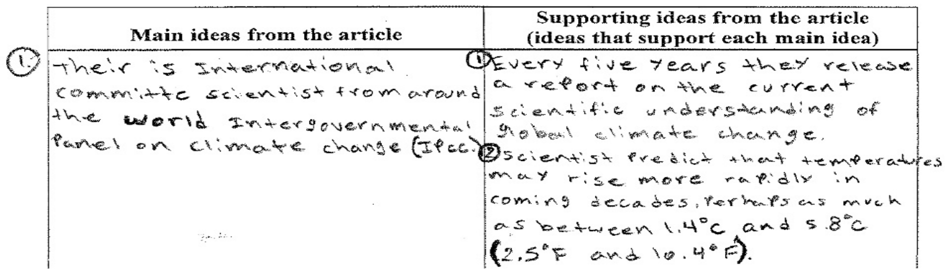

**Evidence of climate change**

There is an international committee of scientists from around the world called the Intergovernmental Panel on Climate Change (IPCC). Every five years, they release a report on the current scientific understanding of global climate change. According to the 2001 IPCC report, average global temperatures increased by about 0.6°C (1.0 °F) between 1900 and 2000. Scientists predict that temperatures may rise more rapidly in coming decades, perhaps as much as between 1.4°C and 5.8 °C (2.5°F and 10.4°F). This increase in temperature is the primary effect of global climate change. This is why it is often referred to as *global warming.* Def

Figure 2. Example of a student's annotation.

## Double-Entry Journals

A double-entry journal (DEJ) is a reader-response log that provides a structure for students to monitor and document their understanding of science texts. Completing a DEJ provides students with the opportunity to actively read and reflect on what they have read. The variety of DEJ structures allows teachers to focus student reading on an important idea or skill unique to a text (vocabulary, main ideas with supporting ideas, relating information in the text to prior knowledge, etc.).



| Main ideas from the article | Supporting ideas from the article (ideas that support each main idea) |
|---|---|
| 1. Their is International committe scientist from around the world Intergovernmental Panel on climate change (IPCC) | 1. Every five years they release a report on the current scientific understanding of global climate change. 2. scientist predict that temperatures may rise more rapidly in coming decades, perhaps as much as between 1.4°C and 5.8°C (2.5°F and 10.4°F). |

Figure 3. Example of a double-entry journal.

## Summarization

Summary writing is a critical scientific skill. It requires the reader to effectively digest new information and communicate it in writing in a way that makes sense to him as well as an external audience. Summarization is a particularly difficult task when students are reading texts far above their reading level. In summarizing, students must comprehend the text, identify main ideas, differentiate secondary ideas, integrate new knowledge with prior knowledge, and condense the information in a succinct and logical way.

Students had opportunities to summarize using both pen and paper and Summary Street, a web-based program that gives students immediate, machine-generated feedback on their summary writing. Summary Street allows students multiple opportunities to revise their summaries until they reach a specified standard. Summary Street supports student summarization by giving feedback on content, spelling, redundancies, irrelevancies, and plagiarism. The program allows students to get instant and private feedback on their work. Because the tool provides high levels of student interactivity, the teacher's class time is freed to have one-on-one conversations with students about their summaries and their understanding of the text (Kintsch et al, 2000).

## The Intervention

Over the last three years, the project has developed, implemented, and evaluated a suite of paper and electronic tools to support reading in ninth- and tenth-grade science classrooms at a large public high school in Chicago, which we will call "Lopez." We provided ongoing, practice-based summer and school-year professional development for teachers that stresses ways to integrate literacy activities with their science learning goals. We co-developed literacy and science activity pacing guides, scoring rubrics and other curricular implementation supports with the teachers. Though our work with teachers is a critical element of this intervention, it is not the focus of this paper. (For more details about our approach to professional development, see Sherer, et al, in press). Two research assistants were located at the school throughout the year. They provided materials and expertise on site. We collected substantial amounts of data, including student performance indicators, demographics, and student artifacts.

All students had used all three kinds of tools throughout the school year, but based on our ongoing observations of classrooms, opportunity to use the tools varied greatly by teacher. Some teachers made tool use a routine part of instruction. Others used the literacy supports less frequently. Some teachers preferred one kind of tool and less frequently used the others.

During the 2006-2007 school year, we supported eight ninth- and tenth-grade teachers and their students in 31 classrooms. Lopez serves 2,100 students. Approximately 90% of the student body is considered low-income based on eligibility for free or reduced lunch. The students are 68% Hispanic, 28% African-American, and 2% white. Nine percent are designated Limited English Proficient. For the 2004-2005 school year, only 21% of the students at Lopez met or exceeded standards in reading based on a statewide, standardized test of reading proficiency. Only 10% of students in science met or exceeded standards on the same test.

In 2006-2007, we administered the Degrees of Reading Power (DRP) test twice to all ninth graders in October and May. At the beginning of their freshman year, the 9$^{th}$ grade students' performance on the DRP indicated that of the 450 ninth graders tested, more than 300 had independent reading comprehension levels that were two or more years below grade level. Obviously, the students at Lopez are struggling readers and are not atypical of many readers in underserved schools.

## Methods

In May of 2007, 442 ninth- and tenth-grade participants from Lopez who were part of the ALSP intervention completed a two-day tool use assessment. Students were first randomly assigned to conditions in which they were instructed to use one of the three tools (annotation, DEJ, or summary) during and after reading a text from the environmental science curriculum that was unfamiliar to them. Then, after using one of the three tools, students were instructed to answer a series of short constructed-response items designed by the researchers to measure science achievement (see Figure 4).

1. What is global warming?
2. List the four consequences of global warming below. Explain how each consequence of global warming that you listed could affect the environment and life on earth.
3. What kinds of weather event changes are predicted as a result of global climate change?
4. What is the main cause of global warming, according to most scientists?
5. Why are some animals more likely to become extinct than other types of animals if the current rate of global warming continues?
6. What is some evidence that snow and ice are decreasing?

Figure 4. Sample of science achievement items from the tool use assessment

We designed this assessment so that we could collect data that was fairly well standardized across classrooms. The assessment was given over the same two days for all teachers. Students had two full class periods to read the text, use the tools, and then answer questions about the reading. Researchers were involved in and tracked administration of the assessment and noted problems such as absences for one or both days of the administration. After collecting the assessments, we began to score tool use and science achievement. Teachers were not involved in the scoring of their own students.

Two researchers and two teachers who had implemented the environmental science curriculum worked collaboratively to develop scoring rubrics for the science achievement items, and for tool use for each of the three tool conditions. To develop a rubric to score the science questions, we worked to determine what evidence from the reading could be used to construct the best answer to each question. For example, for the first question, "What is global warming?" we determined that a correct definition should include two notions that were made explicit in the text: Global warming involves an increase in temperature and has a worldwide effect. We wanted to ensure that a high score was possible for each student who carefully read the text and that it was not necessary to know a lot about the topic beforehand to receive a high score.

Next, we worked to develop rubrics for scoring student work with tools. As in the rubric for the science achievement items, we took an elemental approach. So, a student's annotation score represents a total of their scores across 26 individual elements. We only scored elements of the annotation work that we believed were most clearly related to receiving a high score on elements of the science achievement questions. For the global warming definition question mentioned above, we determined that for annotation, boxing (indicating a word is an important science vocabulary word) and noting where the embedded definition is in the paragraph might be related to receiving a correct score on that science item. After deconstructing answers into elements like these, we looked at each literacy tool to determine how literacy work might help a student in identifying and comprehending each science element.

Once initial rubrics were developed, scoring ensued. Teachers and researchers scored a sample of 40 of the same student question sets to work towards a reliable rubric that allowed for high inter-rater reliability estimates. Scorers needed to be in agreement on this sample before they could move on to scoring all tests. Initial agreement was high. Whenever agreement fell below 85%, critical discussions took place that led to clarification and redesign of the rubrics. When the scorers achieved the reliability standard for all questions, the teachers divided the exams in half and scored independently. They met regularly to ask questions they had flagged and did an additional trial of 10 exams in the middle of scoring as a final reliability check. A similar process was used for scoring elements of tool proficiency. Tool proficiency was scored by one teacher and one researcher with additional scorers involved during inter-rater reliability checks.

Once scored, we conducted a series of correlational and regression analyses to determine whether proficiency with tools (based on rubric scores) was correlated with indicators of science achievement. Then, to further explore the connection between tool proficiency and science achievement, we conducted a series of regressions that included prior reading achievement as a covariate in predicting performance on the science questions in the tool assessment. These regressions can help us understand whether working with the tools improves science learning above and beyond a student's on-entry reading achievement.

## Results

Correlation results are presented in Table 1. As indicated, reading comprehension (DRP performance) is correlated with science achievement as measured both on the tool use assessment and by a unit science test administered in all classrooms earlier in the year. Reading comprehension also predicted tool proficiency. Tool proficiency for each tool is correlated with science achievement as measured on the tool assessment. DEJ proficiency is correlated with science achievement as measured on the unit science test but annotation and summary proficiency are not. The sample size for the unit test is much smaller than for the tool assessment. Summary scores and DEJ scores better predict science achievement then do annotation scores.

Regression results are presented in Table 2. We used the October standardized reading score as a covariate to determine whether tool proficiency increases the variance explained in science achievement once on-entry reading scores are controlled. Writing good summaries and detailed DEJs predicted science achievement above and beyond reading proficiency. Annotation scores did not predict science achievement when controlling for reading ability.

Table 1: Correlations for tool scores, reading achievement, and science achievement.

| | | Pre DRP (Reading achievement October | Post DRP (reading achievement May) | Unit science test | Science comprehension (score on answers to questions about reading) |
|---|---|---|---|---|---|
| Pre DRP (reading achievement October) | Correlation | 1 | | | |
| | N | 342 | | | |

| | | | | | |
|---|---|---|---|---|---|
| Post DRP (reading achievement May) | Correlation | .79* | 1 | | |
| | N | 285 | 348 | | |
| Unit science test | Correlation | .33* | .50* | 1 | |
| | N | 81 | 83 | 109 | |
| Science comprehension (score on answers to questions about reading) | Correlation | .57* | .51* | .34* | 1 |
| | N | 325 | 336 | 107 | 424 |
| DEJ tool score | Correlation | .48* | .49* | .56* | .42* |
| | N | 102 | 102 | 37 | 129 |
| Summary tool score | Correlation | .36* | .36* | .26 | .43* |
| | N | 94 | 101 | 30 | 118 |
| Annotation tool score | Correlation | .27* | .32* | .18 | .23* |
| | N | 119 | 120 | 36 | 144 |

* p<.05

Table 2: Regressions for 3 models: Predicting science achievement from tool proficiency and reading achievement.

| Models | F | Adjusted $R^2$ | B | SE B | $\beta$ | Significance |
|---|---|---|---|---|---|---|
| Model 1 | 23.8 | .29 | | | | |
| Reading (Pre DRP) | | | .21 | .03 | .52 | <.0001* |
| Annotation Score | | | .07 | .08 | .07 | .35 |
| | | | | | | |
| Model 2 | 31.6 | .41 | | | | |
| Reading (Pre DRP) | | | .20 | .03 | .52 | <.0001* |
| Summary Score | | | .48 | .17 | .25 | .005* |
| | | | | | | |
| Model 3 | 25.42 | .33 | | | | |
| Reading (Pre DRP) | | | .17 | .04 | .46 | <.0001* |
| DEJ Score | | | .26 | .11 | .21 | .02* |

*p<.05

## Discussion

The results indicate reading comprehension, as measured by the DRP test in October, strongly predicts science performance across the two measures of science achievement used in this study. This provides an important justification for our reading work in science classrooms. Science teachers and their students need to be convinced that the focus on making texts more prominent in science instruction is worth it, that such a focus can lead to increased science learning. The connection between reading comprehension and science achievement is clear from our data. Reading is a critical predictor of science learning.

Tool proficiency, for all three kinds of tools, was related to reading comprehension and science achievement. This is also an important finding that helps provide a rationale for the approach we have taken. Reading work that is done in science classrooms must lead to changes in science achievement for such approaches to be taken up by participants. It also provides initial evidence that the tool work is being properly contextualized within science instruction by teachers and students. Adolescents need to become skillful in applying strategies while they are reading content-area texts so that the application of strategies is closely coupled to disciplinary activity (Heller & Greenleaf, 2007). Learning to apply strategies to disciplinary text connects the strategy use to the knowledge and reasoning process that are specific to the disciplines (Heller & Greenleaf). This is a key element of our approach: Strategies must be taught, customized and understood in relation to science texts that have their own structures, purposes, and roles in science learning. Too often, decontextualized strategies are taught in reading or language classes to give students some support across content domains. The evidence for the utility of domain-independent strategies is unconvincing. We conjecture that science-specific reading strategies, closely integrated into science instruction, are more likely to address the reading gap described above than more generic strategies that require teachers and students to engage in work that is removed from working toward their science learning goals. It is still an open question about how specific/generic reading strategies can apply across and within content domains. For example, though the work we have done to date has taken place in environmental science and biology classrooms, it is unclear whether reading in physics, chemistry, or geology would require fundamentally different strategies encapsulated in tools or whether there is more similarity than differences in science readings across disciplines.

Another important finding is that DEJ and summary proficiency, but not annotation proficiency, predicted science achievement on the tool assessment when controlling for on-entry reading levels. These findings suggest that teaching students these relatively targeted ways to read and learn from texts can increase understanding of texts, and that understanding does translate into higher science achievement. This provides us with some evidence that the tools are helping students develop metacognitive skills such as improved comprehension monitoring and strategy application.

It is interesting that annotation proficiency did not predict science achievement when controlling for on-entry reading level but that DEJ and summary proficiency did. This may impact how we redesign materials and supports for tools in future work. It may be that marking a text during annotation is somehow less supportive of metacognitive skill growth and comprehension because it is potentially a less active process than DEJ and summary work, which require more active transformation of understanding because students have to construct new (physical, written) representations of the text in the DEJ and summary work. That is an interesting speculation for future work. Also, it is possible that elements of the annotation do predict science achievement on particular items from the list in Figure 4 but do not predict the total score as well. Finally, it is possible that, because the scoring rubric included 26 different items that made up the annotation score, the connection between annotation proficiency and outcome is masked. We will study the relative utility of the tools more carefully in future research.

Because we made an effort to standardize administration of the tool use assessment, we were unable to examine some interesting questions about tool proficiency that we would like to explore in future work. For example, we considered allowing students to choose which tool they would use with the reading on the assessment, perhaps allowing them to demonstrate the metacognitive skill of strategy choice. But, to ensure that we had roughly equal numbers of students in each condition, we decided to randomly assign students. In follow-up work and in our ongoing analysis of existing data, we will try to determine whether particular tools work better with specific kinds of texts and learning assessments. Though the science achievement measure on the tool use assessment was designed in consultation with one teacher to reflect typical kinds of assessment of science learning in the curriculum, it is clear that we did not develop a measure of science achievement that is independent from students' reading comprehension. Students had to write responses after reading the passage to the questions. Thus, writing was also involved in producing evidence of science achievement. None of this is different than what typically occurs in the assessment of science learning, but it is worth noting how science assessment is often inextricably bound with reading comprehension skills whether that is acknowledged or not.

As inquiry approaches to teaching and learning become widespread in American schools, more and more students with varying reading strengths will be participating in these ambitious learning environments. For struggling readers and even for their more accomplished peers, *reading to learn* (Yore & Shymansky, 1992) remains a challenge. Yes, this skill — perhaps even more than others that have received more attention from the science education community — likely predicts a host of science-related outcomes including, ultimately, the likelihood that a student becomes a scientifically literate adult who reads about science through text to stay informed about the world. To develop accomplished science readers requires providing students and their teachers with tools and supports, including opportunities to learn about, practice, and customize the tools to reflect their deepening proficiency with the strategies that the tools encapsulate. Our work is an attempt to better understand the connection between reading achievement and science achievement and to take that connection seriously in the redesign of reading activity in inquiry classrooms to make text a more prominent learning resource in instruction.

We are particularly interested in understanding how science instruction changes when students have better understanding of and access to the content of science readings. Future extensions of this work include a careful mapping of science reading comprehension to instructional activity. For example, if students understand a text better, are there changes in the quality of classroom discussions around that text, including the participation of struggling readers who were too often marginalized by the challenge of discussing texts that they did not understand. There are many ways in which increased reading comprehension likely leads to increases in science achievement. Understanding those pathways may help us design more, and more effective, reading supports that closely couple reading activity to science learning activities.

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