Challenges of Adaptations in Randomized Controlled Trials of a Reading for Understanding Intervention

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Random assignment originated in psychology laboratories and the logic of RCTs was later applied to agricultural and medical research. But educational settings are complex and dynamic systems quite different from contexts associated with other applications of RCTs. For example, good teaching requires adaptive expertise because the circumstances in which teachers do their work are not constant (Hatano & Inagaki, 1986; Bransford, et al., 2005). Teachers' expert knowledge and skills need to be relevant to solving not only the "routine" problems of teaching and learning but the novel problems that arise "in the moment" and for which new solutions must be constructed. Thus, researchers and developers must expect that interventions will be adapted. This raises two challenges for conducting RCTs on educational interventions, especially those that seek fundamental changes in teachers' practices.

Challenge 1: Specifying interventions and "fidelity of implementation" indicators that allow for the to-be-expected adaptations

Challenge 2: Providing time and space for teacher professional development so that teachers develop sufficient depth of understanding that adaptations are consistent with the design principles of the intervention.

In this paper, we discuss one way in which we have been addressing each of these challenges. With respect to the first challenge, we focus on the observation protocol we developed for use in assessing "fidelity" of implementation. We illustrate the "band width" of enactments that reflect different levels of "faithful" implementation of the READI instructional framework and principles. With respect to challenge 2 we discuss the design of the teacher professional development we have been enacting. Although we have been working in three disciplinary areas, we focus on the discipline in which we are conducting the RCT, science. To understand our approach to the fidelity challenge it is necessary to understand a bit more about the intervention and the nature of the professional development.

Project READI Intervention

The challenges of adaptation and the need for ongoing professional development are especially foregrounded when instructional interventions move away from traditional, lecture-oriented classrooms that are based on transmission models of instruction and learning. Inquiry-oriented classroom instruction emphasizes more active engagement on the part of students; greater agency in defining problems, in finding and making sense of information to address those problems; and in participation in dialogic discourse that critiques, questions and builds knowledge. This is the kind of complex instruction that is called for in the Common Core Standards in English Language Arts, History, and Science (National Governors' Association, 2010); in the Next Generation Science Standards, (Next Generation Science Standards Lead States, 2013); in calls for a greater emphasis on disciplinary literacies (e.g., Moje, 2008; Lee & Sprately, 2010); and in national and international assessments of student progress (e.g., NCES, 2013; NAEP, 2009; NRC, 2012; OECD, 2010, 2013a, b). Furthermore, it is the kind of education that is needed if students are going to be prepared to take their place as productive citizens in 21st Century society (cf. Goldman, 2012).

Reading for understanding plays a central role in these types of inquiry-oriented classrooms and not just in English Language Arts and History classrooms. In the context of the Institute for Education Sciences'(IES) initiative on Reading for Understanding, we have had the opportunity – and challenges - of developing and testing an instructional approach to inquiry-oriented instruction in three disciplinary areas – literature, history, and science – across the adolescent grade span. We dubbed it Project READI (Reading, Evidence, and Argument in Disciplinary Instruction) and defined reading for understanding as *engaging evidence based argumentation from multiple sources of information* (Goldman, et al., 2009; submitted). In this conception of reading for understanding, students are active constructors of knowledge through text-based disciplinary inquiry, with expected differences in reading and inquiry strategies that reflect epistemological differences among the disciplines (Goldman et al., submitted). A fundamental assumption and the basis of our theory of change is that opportunities for students to learn the knowledge, skills, and practices involved in text-based disciplinary inquiry are mediated by teachers (Coburn, 2003). However, many teachers themselves have never experienced these kinds of learning environments and thus have limited visions of what to teach, how to teach it, or how to assess learning. We anticipated, based on research on effective professional development (e.g., Darling-Hammond, et al., 2009; Desimone, 2009; Goldman, 2005; Greenleaf, et al., 2011) that teachers would need to be engaged in sustained, collaborative inquiry into instructional content and student learning if they were going to develop the pedagogical knowledge, skills, and practices needed to create effective learning environments for the sorts of text-based inquiry and evidence-based argumentation we envisioned.

Accordingly, Project READI took on intervention at two levels – teachers and students. We focused efforts on developing and researching evidence-based argumentation instructional modules as student interventions but that would also serve as educative curricula (Davis & Krajcik, 2005) for teachers. That is, during professional development teachers would experience the kind of instruction envisioned for students, working through materials they would subsequently use with their students, and then reflecting on and anticipating what might be difficult for their students, how they would enact the modules in their classes, how they would have to adapt them, and so forth.

Student - level. The READI instructional approach for science integrates 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 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.

Texts in the READI interventions 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, employing scientific literacy practices with texts, actually sets of texts, as information resources that are quite different from science textbooks typical of many middle and secondary science classes. READI text-based investigations 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). The text-based investigations conform to an overarching set of design principles and learning objectives that reflect the epistemology, inquiry practices, enduring ideas and frameworks, and types of disciplinary texts and discourse forms of the science community. (See Table 1.)

Teacher-level. Pedagogically, the READI intervention repositions the role of the teacher just as it repositions roles of students and for texts. 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). Briefly, 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. 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. Further, when students discuss science phenomena in the classroom, their current conceptions become apparent; requiring teachers to organize instruction responsively to deepen these conceptions.

Elsewhere we have discussed the many reasons repositioning the role of teachers is difficult (Greenleaf, Brown, Goldman, & Ko, 2014). The READI professional development was designed to support teacher repositioning to support text-based investigations by students.

READI approach to Challenge 2: Professional Development

We have used three modes of professional development over the life of the project: collaborative teacher-researcher design teams, teacher inquiry networks, and structured professional development in preparation for participation in an RCT. The design team and inquiry network informed the development of the READI instructional approach to text-based inquiry in science and were critical to the way in which we structured the professional development activities that were intended to prepare teachers to participate in the RCT we conducted in 9th grade biology classes.

Collaborative teacher-researcher design teams. We have involved collaborating classroom teachers in a design – based research process for purposes of developing EBA instructional modules. The teachers have implemented these in their classrooms and we have been participant observers in these enactments, and closely documented this work. The documentation and reflection on the enactments have led to cycles of revision based on our growing understandings of what supports and instructional routines need to be in place to achieve the learning objectives listed in Table 1.

The modules begin with a driving inquiry question based in everyday experience that is designed to pique student interest and curiousity in a targeted science phenomenon. For example, a module focused on Methicillin-Resistant Staphylococcus Aureus (MRSA) begins with a video about a nurse infected with MRSA and another about 'superbugs' affecting athletes in high numbers. MRSA was chosen as a topic for text-based inquiry in part because it is a contemporary example of how the theory of evolution is used by scientists today to investigate critical problems that affect people in their everyday lives. As such, the module is relevant to content teachers need to address in biology and life science courses. From this opening, students generate initial inquiry questions that they investigate through close reading of a series of texts, including line and bar graphs, visual models, diagrams and expositions, that have been carefully and intentionally selected and sequenced so that students can cumulatively build explanatory models of the spread of MRSA including rapid increases in bacteria that are resistant to antibiotics. Close reading is accompanied by scaffolds/worksheets (e.g., evidence-interpretation charts, argument templates, graphic organizers) that guide students in the process of identifying relevant information and how it relates to their inquiry question, and attending to the vocabulary, core ideas, cross-cutting concepts, and practices of science. As well, metacognitive reflection routines that are incorporated into used individual, small group, and whole class discussions make explicit comprehension and reasoning processes, including how students ideas may have changed as a result of their inquiry. The sequenced texts and array of instructional resources support students in synthesizing across texts to develop and evaluate causal explanations and models for the phenomena (Chin & Osborne, 2010; Passmore & Svoboda, 2012). They also foster a culture of collaboration and discussion to support knowledge building and evidence-based argumentation. Iterative cycles of design have provided data on teachers and students experiences and adaptations to initial designs that have been made "in the moment." Thus, there has been successive evolution and refinement of the processes and criteria for text selection, the specific form(s) of the supports, and examples/descriptions of ways in which teachers orchestrate the instruction so that students are doing the intellectual work. in response to teachers and students experiences and the adaptations made.

Teacher Inquiry Networks. Professional development networks are a second way in which we have gained insights into the knowledge, beliefs, and pedagogical repertoires involved in repositioning the role of teachers. Network meetings have occurred 4 times over the course of an academic year and have operated for 3 to 4 years of Project READI. These networks are organized around the teachers engaging in text-based science inquiry with complex texts. 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. They are encouraged to try out a targeted set of these activities with their students. They bring their experiences back to the group for discussion among their colleagues. These discussions typically lead to new insights and understanding emerging. As well, they provide us with useful lenses into how and in many cases why teachers adapt and adopt the inquiry process in their classrooms.

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?

Our analyses of the discourse and artifacts generated during network meetings, as well as teachers' reflections on their learning and network experiences indicate that they begin to see that reading complex science text is neither automatic nor straightforward. We have seen how presenting teachers with 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 these 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. Their comments reflect that they have gained new eyes for the challenges their students face with science texts, as well as a deeper appreciation of their own capabilities as science readers, capabilities they can turn into instructional assets through modeling. Furthermore, their conceptions of argument have broadened from seeing argument only as an outcome of an inquiry process to understanding argument as a process, i.e., as a way to learn as well as an outcome of learning (cf. Osborne & Patterson, 2011). The following sample of comments from several science teachers reflects the insights and learning that teachers in the network have reported.

> "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."

> "I see the role that reading plays in Scientific Inquiry and understand how reading itself can be an activity in Scientific Inquiry. I used to think of how students would do a lab, gather data and then read/write to explain the phenomena. Now, I see how students can gather data and explore a concept through readings (of various styles, lengths of text)."

> "I like the current conceptual definition we have of argumentation in science. Argumentation in science is deeply rooted in evidence. Developing a scientific argument requires scientific reasoning that substantiates a claim through evidence. Thinking about my instruction in this way has helped me to be more intentional about the data I provide students and the ways I support student discourse. Often
> times, great learning occurs through class discussion and I have developed in my abilities to support that discourse and capture "A Ha!" moments in our classroom."

> "My summative assessments have dramatically changed since working on the definition of argumentation across the grade bands. I used to have a final project or test that would "cover" the lessons taught. Now, I see a summative assessment could be the argument itself, provided that students root their claims with evidence and sound reasoning. This provides insight not only to the extent to which the students understands the science content, but whether or not they are practicing evaluation of evidence and considering properly controlled variables and other items that dictate sound scientific design."

These and other comments made by the teachers indicate that they began to recognize differences between authentic reading and writing about science and the way in which science is portrayed in science textbooks (Schoenbach & Greenleaf, 2009). They also have gained new insights into 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.

Professional development for the RCT in 9th grade biology. The IES grant required that interventions be subjected to RCT efficacy studies. Project READI conducted a semester-long implementation of the READI science approach in Fall 2014 and extending through February, 2015 as it turned out. By definition, the RCT required that we describe the "it" of the intervention and that teachers were randomly assigned to intervention or comparison/control condition. This meant that we needed to recruit teachers who would be brand new to Project READI for the RCT. These requirements of the RCT design were in tension with what we had learned from the work with teachers on the design team and in the inquiry network.

Specifically, the experiences with the inquiry network and design team teachers confirmed a number of hypotheses based on our past work (e.g., Cognition and Technology Group at Vanderbilt, 1997; Goldman, 2005; Greenleaf, et al., 2011) that sought to change teachers knowledge, beliefs, and pedagogical practices. The two that were most problematic for designing and conducting the RCT are the following.

1. Repositioning the role of the teacher as envisioned in Project READI was a gradual process that took several iterations of implementation and reflection before teachers adaptations to suggested READI protocols and materials reflected the deep structure of the approach. Typically, the first time teachers tried many of the instructional processes they were tentative and

unsure of their success. Many initial adaptations retained the form but not the substance of the principles. Debriefing with colleagues in the design teams and networks was a crucial opportunity for feedback and subsequent tuning of additional implementation efforts.

2. Teachers took up the READI approach in different ways, over different time frames, and to different degrees. However, we saw evidence of change toward the envisioned target in approximately 90% of the almost 100 teachers with whom we had worked over the first 4 years of the project. This posed challenges for us in preparing them to implement the READI approach as well as

3. The READI approach asks teachers to make significant shifts in their current instructional practices. Although some pedagogical shifts are amenable to highly structured, scripted materials and practices, the READI approach is not. Given a limited time frame for preparing them to do so, we implemented an abbreviated version of the inquiry network experience, using EBA instructional modules as educative curriculum with them during the professional development.

Design of the READI Science RCT professional development. Given the constraints of the RCT, we built on the professional development approach that had been developed by the Strategic Literacy Initiative in the context of a prior RCT (Greenleaf, et al., 2011; Schoenbach, Greenleaf, & Murphy, 2012) and adapted it to reflect the Project READI learning objectives and emphasis on evidence-based argumentation. Furthermore, we planned it to occur over 11 days that were distributed over a 10 - month period of time, beginning in February, 2014: Four days over 4 months (February – May); 5 successive days during July; and 2 days during the Fall, 2014 implementation (6 weeks and 10 weeks into the semester). The distribution of the professional development sessions was intended to provide teachers with at least some opportunities to try out some of the pedagogical practices of the READI approach. The professional development model drew on the *Reading Apprenticeship* (RA) model (cf. Schoenbach, et al., 2012), integrating it with the READI learning objectives for text-based inquiry in science (see Table 1). Over the course of the Spring and Summer sessions, teachers read various sections of *Reading for Understanding* (Schoenbach, et al., 2012) and engaged in adapted forms of many of the activities typically used in RA professional development. For example, Day 1 focused on engaging the teachers with close reading of science texts; in particular, in participating in the routines that they would enact to lay the ground work for and foster student engagement in science reading and learning. Participants explored how literacy has shaped their engagement with text, how the social conditions of the learning environment affected them, how they read and how they thought as scientists. They were asked to try out these routines in their classrooms in preparation for Day 2. They brought artifacts from these efforts to Day 2, discussed them and engaged in inquiry focused on engaging students in reading to construct explanations of science phenomena. Again teachers were expected to try out these routines in their classrooms and debrief at the next meeting. Similarly, on Days 3 and 4, the emphasis was on pedagogical practices for supporting text-based inquiry in science.

The 5 days during the summer were devoted more specifically to organizing the work of the semester – long intervention. Teachers were provided with an overview of the intervention semester that mapped out a progression of READI science reading and learning goals, READI materials appropriate to those goals, and science topics (See Figure 1.) As indicated in the figure, three READI modules – *Reading Models, Homeostasis,* and *MRSA* - were to be implemented. Corresponding to the progression shown in Figure 1, over the 5 days, the professional development focus moved across Building Classroom routines to support science literacy and meaning making, to Building a Repertoire of Science literacy and discourse processes, including an emphasis on science models, to Deepening scientific literacy and discourse practices for sensemaking. Thus, over the 5 days of professional development, they reviewed the pedagogical practices that had been introduced during the Spring and worked through more "science-specific" inquiry activities, including a focus on the role of argumentation in science learning and the nature of scientific models. Consistent with our view of the modules serving a dual role as student materials and educative curricula for teachers, the teachers worked through and discussed the READI candidate texts (see Figure 1) as well as the *Reading Models* module. Deep examination of the other READI modules occurred when teachers returned for professional development 6 (*Homeostasis)* and 10 (*MRSA)* weeks into the Fall, 2014 semester.

During the 5 - day summer professional development, teachers were also provided time to plan for their implementations. In the course of doing so as well as throughout the 5 days , they freely raised questions about how they would implement particular pedagogical practices and obstacles they anticipated with "their students." These obstacles ranged from limited English language skills to motivational issues to differences in achievement levels. (Our teacher sample reflected schools with different demographic characteristics and different percentages of students who met or exceeded passing scores on the Prairie State Achievement Exam.) These discussions confirmed our expectations that we were likely to see a wide range of variability in what and how the intervention would be implemented. Given our theory of change - teachers mediate the intervention that students participate in – and given the expected adaptations and variations in implementation, ideally we would have liked to have been in every teachers classroom each day. With two dozen intervention teachers and about the same number of comparison teachers this was clearly not feasible. Accordingly, we employed a three-pronged approach to accessing teachers' practices and addressing the Fidelity of Implementation challenge.

READI approach to Challenge 1: "Fidelity of Implementation" and Expected Adaptations

We used a three-pronged approach to assessing fidelity of implementation of the READI approach. We assessed teachers knowledge, beliefs and practices through a self-report survey that both intervention and comparison teachers completed prior to the beginning of READI professional development for the intervention teachers. Second, we developed a protocol for observing in intervention and comparison teachers' classrooms. Observations were conducted at two time points: approximately 4 to 6 weeks into the semester and then during the last week or two of implementing the READI learning progression (see Figure 1) as shown in Figure 2. Comparison teacher observations were "yoked" to the intervention teachers from their district and school demographic group. The third prong was employed only with the intervention teachers: They completed weekly logs of what they had done and their reflections about the week. We focus here on the observations and the observation protocol.

READI Observation Protocol. Over the course of a year, we developed an observation protocol specifically for the Project READI biology RCT. We began by closely examining existing observation instruments, including *Inside the Classroom: Observation and Analytic Protocol* (Horizon Research, 2003), *Low Inference Discourse Observation* (O'Connor & Michaels, nd), and *IES Biology Classroom Observation Protocol* (Strategic Literacy Initiative, 2009). We piloted these on videos of classroom enactments from the design team teachers and discussed what they did and did not capture with respect to the targeted instructional and learning processes we had identified as intended outcomes of the READI professional development and implementation with students. In the end, we drew heavily on the constructs and score point descriptions from the *IES Science Interview Protocol* (Strategic Literacy Initiative, 2009) to develop the READI Science Observation Protocol. These were well-aligned with the foundational science literacy practices at the core of Project READI's design. We adapted this protocol to be suitable for observations and incorporated dimensions and descriptors for the score points to capture the explanation, modeling, and argumentation learning progressions and objectives. We also added an additional construct relevant to the observations, Student Engagement and Participation, to capture on-task behavior of students.

The resulting observation protocol contained 7 constructs with 3 or 4 dimensions within each construct, as shown in Table 2. During an observation, raters took continuous field notes and based on these determined a rating on each dimension. Relevant segments of field notes were used as evidence for the ratings. In terms of reliability among raters, we had one rater who had not been part of the READI intervention team (external) and six who had worked more closely in developing the intervention. The average Intraclass Correlation among the external rater with each of the "internal" was .83, $p < .01$.

The descriptions of the four score points do not require that observers see exactly the same thing from classroom to classroom to assign a particular rating. The four score point descriptions are shown in Table 3 for Construct 1 and in Tables 4 and 5 for Construct 2 and 6 respectively. We look at observations of three teachers for Constructs 2 Teacher Support for Comprehension of Science Content from Text) and 6 (Collaboration) to illustrate the band width around each score point. For each, we focus on ratings for two dimensions: teacher support and student practice. The excerpts are drawn from the field notes and provide the support for the score point on the construct dimensions. The contexts of the observed lessons and excerpts for each teacher are the following.

T1 JT is implementing the MRSA module. Students have read the first three texts and are making an explanatory model of how MRSA is spread using evidence from the texts. JT is following the designed intervention (texts, tasks, instructional approaches) closely and best illustrates a traditional definition of a high fidelity implementation.

T2 DG is implementing with adaptations. In this particular class, there are a high number of struggling readers (2^{nd} -8^{th} grade). DG is often given the struggling readers as she has a reputation for caring about her students and helping them stay in school. DG is just starting the MRSA module. Students are reading the first text about a young teen getting MRSA after piercing his lip while home sick with bronchitis.

T3 SK is in the midst of the Homeostasis module implementation but needs to stop to prepare for a district wide assessment on "Organization and Homeostasis". She has structured the review by setting up stations for students to rotate through in small collaborative groups. The stations include three "models" (SK's term) of homeostasis from the nervous, endocrine and reproductive systems.

Construct 2. For this construct, all three teachers were rated at score point 4 on the dimension Nature of Teacher Support and a 3 on Student Practice. The excerpts from the field notes of the observations indicate that T1 was implementing the intervention "as designed," and that T2 and T3 had adapted the design. However, these adaptations reflected significant threads of the READI approach within their pedagogy and instructional approach. These included:

- the emphasis on the reading and comprehending of text – for T2, the MRSA lip piercing text and the added model of the bronchi and esophagus; for T3, the station texts about organization and homeostatis (3 models), the student READI Homeostasis models
- the teacher moves - both teachers used language and question stems practiced during the Science PD sessions to engage students in doing the intellectual work. T1 "Highlight your Golden Line. Nothing else for right now". T1 knew that most of her students still needed the scaffold of "nothing else for right now" so they would be very selective in what they were highlighting. T2's questions were open ended "So what's happening right now? What's step 5?"
- student practice – students are engaged in the sense-making of the texts. They have to read and draw information from the text to help with their inquiry.

Teacher Support *Rating: 4. Criteria:* Teacher MOVES promote student comprehension of science content from text (e.g. Teacher moves support students to engage in meaning-making -- elaborating, problem solving, evaluating)

T1 (JT)
T does a variety of moves with various Ss to help support the task of model building. The focus of these moves is to probe for causal mechanism).

T: What is helping MRSA spread? What is the reason? (pushing for elaboration)
(after 11:11) What does that have to do with the fact that they are resistant to antibiotics? Get it now? Give me some ideas.
S; I'll put….2007 and 1997….cuz there's going to be more infections in 2014.
T: Why?
S: It got worser
*T: Why worser***.** *You're fine. What's going on with antibiotics? (probing for causal mechanism)*

After 11:31
T: this is all good but WHY is it happening

T2 (DG)
Teacher was constantly assessing students' understanding also checking for background knowledge gaps
S1: He's sick with that bronchitis.
S2: I just had bronchitis and had a hard time breathing.

Class gets into a discussion of the bronchi and the esophagus (the teacher realizes from the questions and comments that many students don't understand that the bronchi and esophagus are separate body parts and have different functions.)
T: Here let me show you.
The teacher quickly draws a diagram of the bronchi and lungs, esophagus and stomach on the board and gives the Ss a quick lesson on the function of each.
T: Didn't you learn this last year in health? Most students shake their heads no.
S: Oh so that's why they say it went down your wrong pipe!! I never got that til now.

T3 (SK)

Teacher moves from station to station through most of the period, probing students to assess comprehension
T (to group of students): "What's happening in step 5?"
S: "It's going to respond."
T: "What's the response?"
S: "I am going to freak out (note--this is in response to what is happening in the picture of a person's hand over a flame)
S: "Oh the nervous system makes you pull back."
T: "Okay, and in this case, it's a reflex. So what happens in step 5?"
S: "It moves."
T: "Right...use the text...use the actual clues

Student Practice *Rating: 3. Criteria:* Students OFTEN did the work of reading and comprehending science content from text (e.g. made use of annotations, talking to the text, science talk stems, evidence/ interpretation charts, silent sustained reading)

T1 (JT)
Ss are using their Evidence/Interpretation charts and texts in order to finish constructing their models. As students finish, teacher gets them set up in reviewing and critiquing one another's models.

A pair of Ss have gotten together to engage in critique. Ss are struggling with depicting the role of antibiotics in this rise of MRSA. 1 S raises hand. T comes over and tells a 3rd student to explain his model to the others who are struggling with how to show that relationship. (T first had 3rs student re-read the antibiotic text R8, before pairing them together for support)

T2 (DG)
T: You have 5 minutes - you need to read through this article - highlight only your golden line - nothing more for right now
"Kansas City teen gets MRSA from lip piercing"
Students are quietly reading except for a couple of boys who are having a hard time getting started - teachers goes over to them and gets them going.
1:50 - all students are engaged in reading the text and trying to pick out golden lines. Classroom is completely quiet.
T: Okay looks like most of you are ready.
T: 3 volunteers to share a Golden Line and Why
About a dozen hands go up.

T3 (SK)
As students work through the stations review, they focus on reading of text to answer the questions

Student 1 looks at her own model of homeostasis in her binder (READI Homeostasis module activity) to respond to questions on the Stations Review worksheet.

Student 2 asks her about the picture at their station:
S2: "What is this?"
S1: "Use your notes (points to her model) to answer 1 and 5."
S2 takes out her model from her binder (READI Homeostasis module actity).
S2: "Oh yeah it's the response....effector equals response."
Students write down their ideas.

Construct 6. For this construct, Collaboration, the same three teachers were rated at score point 3 on both Teacher Support and Student Practice. Again in T2 and 3 we see significant indicators of the READI approach in pedagogy and instructional approach even with their adaptations.

- the teachers' focus on collaborative processes (i.e., participation structures, equity of voice, risk free climate, inquiry approach)
- teacher moves to facilitate discussion using open ended questions inviting multiple student responses (i.e., what else?, how are you doing?, someone else?)
- teacher modeling disciplinary discourse and thinking - (i.e. How did you know that?, where in the text?)
- student practice – build off of other's ideas, ask questions of others, offer an alternative explanation – students feel safe to challenge other's ideas
- student practice – students are respectful of other's ideas, input; equity of voice
- student practice – students use disciplinary knowledge from the text; are able to go back to text and substantiate their comment

Teacher Support: *Rating 3. Criteria:* Teacher OFTEN mentored, facilitated, and/or modeled collaborative processes and disciplinary reading, thinking and discourse routines.

T1 (JD)
Students were in small groups. Teacher circulated.
S: what does widely mean?
S2: percentage
T: what is helping MRSA spread? What is the reason?
Ss talking
T: why has MRSA gone up?
S: germs bacteria
S2: so it's the antibiotics
T: Are they working?
S2: No
T: Why aren't they working? Why not?
S: Your body gets used to it
S2: Adapt

T2 (DG)
Students were in whole class discussion but T is questioning to put the intellectual work on the students rather than giving them the answers or asking more leading questions.
T: So where did it come from?
S1: I think the bacteria from the needle cause it was dirty.
S2: I agree that MRSA was on the needle.
S3: Coccus means the bacteria is circular - I remember that from when we studied bacteria.

S: MRSA is not a virus; it is a bacteria.
T: What else?
S: It's drug resistant
T: How did you know that?
2 Ss together right away say "Where in the text?" looking at S1
T: Good that's what we need.
S: Paragraph 4 - S reads the text segment from paragraph 4
S2: He got MRSA from the lip piercing
S3: R5, line 8!

(S reads the sentence)

T3 (SK)

Students were moving from station to station in collaborative groups. T3 checks in with each group to make sure they are talking with one another and are focused on modeling.
T: Get on the same side [of the table] so you can figure it out together. This is a cooperative activity--talk about it and come to the best conclusion you can. Then write down what you talk about together.
8:03
T to Ss at 1st station: All right. How are we doing? Are we talking [to each other]?
To another station:
T How we doin'...? So at step 5 [or the model]...what step is this? We have a stimulus and that sends a message to the skin...and the muscle does what?
S It responds.
T Okay it responds, so what's the response? What is your response going to be? Figure it out together.

Student Practice *Rating: 3. Criteria:* In conversations, students OFTEN attended to evidence, built off of one another's ideas, asked probing questions, and offered alternative explanations.

T1 (JD)

A pair of Ss have gotten together to engage in critique. Ss are struggling with depicting the role of antibiotics in this rise of MRSA. 1 S raises hand. T comes over and tells a 3rd student to explain his model to the others who are struggling with how to show that relationship. (T first had 3rd student re-read the antibiotic text R8, before pairing them together for support)

T2 (DG)

S1: The first paragraph
"is recovering in from hospital from........... infection
T: Why is that a golden line?
S1: it tells us about the viral infection he got from the lip piercing
T: Is it a viral infection? What makes you think that?
S1 reads information from the 3rd paragraph
S2 No it's not the same infection they're talking about.
S3 I think they're talking about the same because the viral infection must have been there before the knee surgery.
(Additional students add to these ideas.)

T3 (SK)

Student looks at her model of homeostasis on the yellow sheet to respond to questions.
S1 to 2S about the picture at their station: What is this?
S2 Use your notes to answer 1 and 5.
S1 What?.
S2 Here, the flame.
T walks over.
T: Right. What's the stimulus that's causing the imbalance? Like in the hypernutremea article...the old woman had dementia...why?
S1 She wasn't drinking enough water
S2 ...dehydrated

We have not had time to discuss the range of variation that we have seen in the other constructs nor in the comparison classrooms. Suffice to say that there was also variation among the observations in other constructs and among the observations that received the same ratings in the comparison classrooms. We are also pleased to report that the ability of the Observation Protocol to accommodate the range within a score point rating is not obscuring differences among score points. Preliminary results indicate that at both observation points, intervention teachers were rated at significantly higher score points than comparison teachers on a number of dimensions. Note, however, that the self-report teacher surveys indicated no differences among the two groups of teachers prior to the intervention teachers beginning the professional development. The differences at observation 1 are consistent with the intervention teachers' professional development and the work they had done in their classrooms by that time. Table 6 shows where there were significant differences at the first and at the second observation time point. The ratings from the second observation point show that the difference between the intervention and comparison teachers increased, suggesting increased proficiency with the READI approach over the course of the implementation. It might also be the case that the deepening of the science and modeling practices called for by the READI module later in the semester afforded more opportunities for higher ratings. We are pursuing further analyses to better understand the loci of the significant changes in ratings.

Closing Comments

In this paper we have described our responses to two of the challenges of conducting RCTs in educational settings when the goal is change in both teaching and learning processes and outcomes. As we noted at the outset, the kinds of changes needed to meet the challenges of the 21st century call for approaches to instruction that are complex to implement and complex to observe. We hope we have provided some insights into responses to the challenges of inherent in these research and educational improvement efforts.

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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. READI Observation Protocol: Constructs and Dimensions

Construct	Dimensions within Construct
1. Science reading opportunities: Is reading central to the intellectual work or not?	Role of Reading
	Breadth of Reading
	Teacher support for Breadth of Reading
	Accountability for Reading
2. Teacher support for student efforts to comprehend science content from text.	Task Structure- Social Support for Reading Comprehension
	Nature of Teacher Support
	Student Practice
	Accountability/ Formative Assessment of Content from Reading
3. Metacognitive inquiry into science reading and thinking processes.	Task Structure
	Teacher Support
	Student Practice
4. Specific reading and science reading comprehension routines, tools, strategies, and processes.	Teacher Support (Explicit Instruction and Modeling)
	Student Practice (Routines, Tools, and Strategies)
5. Science argumentation and/or building explanatory models from multiple sources.	Task structure – science argumentation and/or model building through reading
	Teacher support -science argumentation and/or model building through reading
	Student Practice- science argumentation and/or model building through reading
6. Collaboration	Student Practice- Collaboration
	Task Structure- Collaboration
	Teacher Support - Collaboration
7. Student engagement and participation	Engagement (beginning of class)
	Engagement (middle of class)
	Engagement (end of class)

Table 3. Construct 1, Role of Reading Dimension			
Score Point: 4	Score Point: 3	Score Point: 2	Score Point: 1
Text plays a central role in science learning (e.g., texts provide access to ideas of science, build science thinking, model science inquiry and literacy practices, and/or is integral to students' understanding of content.) Students cannot meet class expectations without reading and students are doing the intellectual work.	Text plays an important role in science learning (e.g., to build interest or provide an overview of the topic, make connections to contemporary events, support students' firsthand science inquiry, and/or support students' understanding of content.) Students cannot meet some class expectations without reading and students are doing some of the intellectual work.	Text plays a supplementary role in science learning (e.g., individual research papers, one-time scientific fiction reading project). Students can meet most class expectations without reading. Reading-related assignments may be required but are occasional/sporadic and peripheral to classroom learning	Text plays little role in science learning. Students can meet class expectations without reading. Regardless of whether or not teacher assigns reading, reading carries little weight in science learning.
If observing lab: In the context of a science lab, there is reciprocity between reading and hands-on science—e.g., students work back and forth between texts and lab. Little apparent boundary between reading and science investigation. Reading approached as an investigation.	In the context of a science lab, there is often reciprocity between reading and hands-on science—e.g., students generally work back and forth between texts and lab. Some boundary between reading and science investigation; though reading is part of the lab, it is not central to the work.	In the context of a science lab, there is minimal articulation between reading and lab work—reading assignments may generally correlate with lab, e.g., students read textbook to learn about lab.	In the context of a science lab, there is no connection between reading and lab work.

Table 4. Construct 2, Teacher support of student efforts to comprehend science text			
Score Point: 4	Score Point: 3	Score Point: 2	Score Point: 1
Teacher MOVES promote student comprehension of science content from text (e.g. Teacher moves support students to engage in meaning-making -- elaborating, problem solving, evaluating)	Teacher MOVES OFTEN promote student comprehension of science content from text (e.g. Teacher moves support students to engage in meaning-making -- elaborating, problem solving, evaluating)	Teacher MOVES OCCASIONALLY promote student comprehension of science content from text (e.g. Teacher moves support students to engage in meaning-making -- elaborating, problem solving, evaluating) While teacher MOVES provide opportunities to discuss science content from text, teacher routinely answers students' questions about science content or leads "discussions" in which teacher tests students' understanding (I-R-E pattern) rather than supporting student meaning-making.	Teacher MOVES NEVER promote student comprehension of science content from text (e.g. Teacher moves support students to engage in meaning-making -- elaborating, problem solving, evaluating)
Construct 2, Student practice: Comprehend science text			
Students did the work of reading and comprehending science content from text (e.g. made use of annotations, talking to the text, science talk stems, evidence/ interpretation charts, silent sustained reading)	Students OFTEN did the work of reading and comprehending science content from text. (e.g. made use of annotations, talking to the text, science talk stems, evidence/ interpretation charts, silent sustained reading)	Students OCCASIONALLY did the work of reading and comprehending science content from text. (e.g. made use of annotations, talking to the text, science talk stems, evidence/ interpretation charts, silent sustained reading)	Students NEVER did the work of reading and comprehending science content from text, or there was no work with text.

Table 5. Construct 6, Teacher support for collaboration			
Score Point: 4	Score Point: 3	Score Point: 2	Score Point: 1
Teacher mentored, facilitated, and/or modeled collaborative processes and disciplinary reading, thinking and discourse routines.	Teacher OFTEN mentored, facilitated, and/or modeled collaborative processes and disciplinary reading, thinking and discourse routines. Teacher was focused on collaborative processes or meaning-making routines.	Teacher OCCASIONALLY mentored, facilitated, and/or modeled collaborative processes and disciplinary reading, thinking and discourse routines. Teacher was more focused on task procedures, rather than collaborative processes or meaning-making routines.	Teacher NEVER mentored, facilitated, and/or modeled collaborative processes and disciplinary reading, thinking and discourse routines.
Construct 2, Student practice: Collaboration			
In conversations, students attended to evidence, built off of one another's ideas, asked probing questions, and offered alternative explanations.	In conversations, students OFTEN attended to evidence, built off of one another's ideas, asked probing questions, and offered alternative explanations.	In conversations, students OCCASIONALLY attended to evidence, built off of one another's ideas, asked probing questions, and offered alternative explanations.	In conversations, students NEVER attended to evidence, build off of one another's ideas, ask probing questions, or offer alternative explanations.

Table 6. READI Observation Protocol: Comparison of Intervention and Comparison Teachers at Observation 1 (4^{th} week) and Observation (15^{th} week)

Construct	Dimensions within Construct	OB1	OB2
1. Science reading opportunities: Is reading central to the intellectual work or not?	Role of Reading	**	***
	Breadth of Reading	**	**
	Teacher support for Breadth of Reading	ns	***
	Accountability for Reading	*	***
2. Teacher support for student efforts to comprehend science content from text.	Task Structure- Social Support for Reading Comprehension	***	***
	Nature of Teacher Support	*	***
	Student Practice	***	***
	Accountability/ Formative Assessment of Content from Reading	ns	**
3. Metacognitive inquiry into science reading and thinking processes.	Task Structure	***	***
	Teacher Support	*	***
	Student Practice	***	***
4. Specific reading and science reading comprehension routines, tools, strategies, and processes.	Teacher Support (Explicit Instruction and Modeling)	ns	***
	Student Practice (Routines, Tools, and Strategies)	***	***
5. Science argumentation and/or building explanatory models from multiple sources.	Task structure – science argumentation and/or model building through reading	***	***
	Teacher support -science argumentation and/or model building through reading	**	**
	Student Practice- science argumentation and/or model building through reading	**	**
6. Collaboration	Student Practice- Collaboration	*	***
	Task Structure- Collaboration	**	***
	Teacher Support - Collaboration	ns	***
7. Student engagement and participation	Engagement (beginning of class)	ns	ns
	Engagement (middle of class)	ns	ns
	Engagement (end of class)	ns	ns

Significance of difference between Intervention and Comparison teachers at each observation point: *$p < .05$; ** $p < .01$; ***$p < .001$

Figure 1. READI Learning Progression for 9th Grade Biology Semester

PROJECT READI

Example Semester Overview

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Date	8/25 to 8/29	9/2 to 9/ 5	9/8 to 9/12	9/15 to 9/19	9/22 to 9/26	9/29 to 10/3	10/6 to 10/10	10/13 to 10/17	10/20 10 10/24	10/27 to 10/31	11/3 10 11/ 7	11/10 to 11/14	11/17 to 11/21	11/24 10 11/26	12/1 to 12/ 5	12/8 to 12 /5	12/15 to 12/19
READI Science Learning Goal Progression	Building Classroom Routines To Support Science Literacy and Meaning Making Students begin to see text as a part of scientific practice, and that scientific knowledge is built through close reading of text and also through class-wide, knowledge-building discourse. Students begin to see themselves as readers of science, increasingly interact with texts and view the classroom as a place where their knowledge is valued.				Building a Repertoire of Science Literacy and Discourse Processes Text is increasingly used as a way to deepen their understanding of scientific phenomena. Attention is given to the kind of evidence that are embedded in various text types (written, visual/representations), the kinds of interpretations one can make given this evidence, and how this helps students construct explanations for scientific phenomena. Students utilize a READI science module to build knowledge of the conventions of scientific models and the criterion for evaluating scientific models is the curricular foundation of these weeks. Students' awareness, confidence and ownership of science reading and reasoning practices grows				Deepening Scientific Literacy And Discourse Practices For Reasoned Sensemaking Students dig into a READI science module to continue building the practices of close reading and multiple text synthesis for the purpose of developing a causal explanatory account for scientific phenomena. Students take an active role in building explanations of scientific phenomena in the world and increasingly view models as representations that facilitate their own sense making activities: to clarify, refine, and modify or revise their own science thinking.				Utilizing Scientific Literacy And Discourse Practices For Disciplinary Knowledge Building Students utilize a READI science module to deepen close reading and multiple text synthesis for the purpose of constructing, justifying and critiquing a causal explanatory accounts for scientific phenomena. Students work more independently in building explanations of scientific phenomena in the world as well as taking an active role in justification and critique of scientific explanations.				
READI Modules	Use of READI candidate texts					Reading Models (3 days)	Homeostasis Module (15-20 days)				MRSA Module (18-23 days)						
Science Topics	<u>Introduction to Biology</u> • Community and Ecosystem Ecology (interdependence and energy flow in ecosystems) • Energy production in plants (Photosynthesis) • Scientific evidence of Evolution Cell Biology: cell division and communication		<u>Cell Biology</u> • Basic cell biochemistry • Enzymes/substrate interactions • Cell differentiation and specialization • History of Cell Biology • Technology and advancement of science knowledge				• Feedback mechanisms • Cell communication • Homeostasis (on both cellular and organism level – focused on humans) • Role of specialized organs and systems (e.g. kidneys, pancreas, endocrine system) in maintaining balance in the human body • Diabetes and hypo/hypernatremia as cases of homeostasis disruption • Behavior and its impact on homeostasis				• Natural selection (variation in traits, genetic inheritance, selection) and adaptation • Antibiotic resistance (focused on staphylococcus aureus) • Microbes: bacteria and viruses; Human microbiota (staphylococcus aureus in particular); Binary fission of bacteria • Human contributions to evolution and evolutionary engineering						
READI Assessments (details on next page)	**Consents** **Assessments:** • Epistemology • Self efficacy Surveys • EBA pre test • RISE **Observation**															**Assessments** • Epistemology • Self efficacy Surveys • EBA post test • GISA **Observation**	

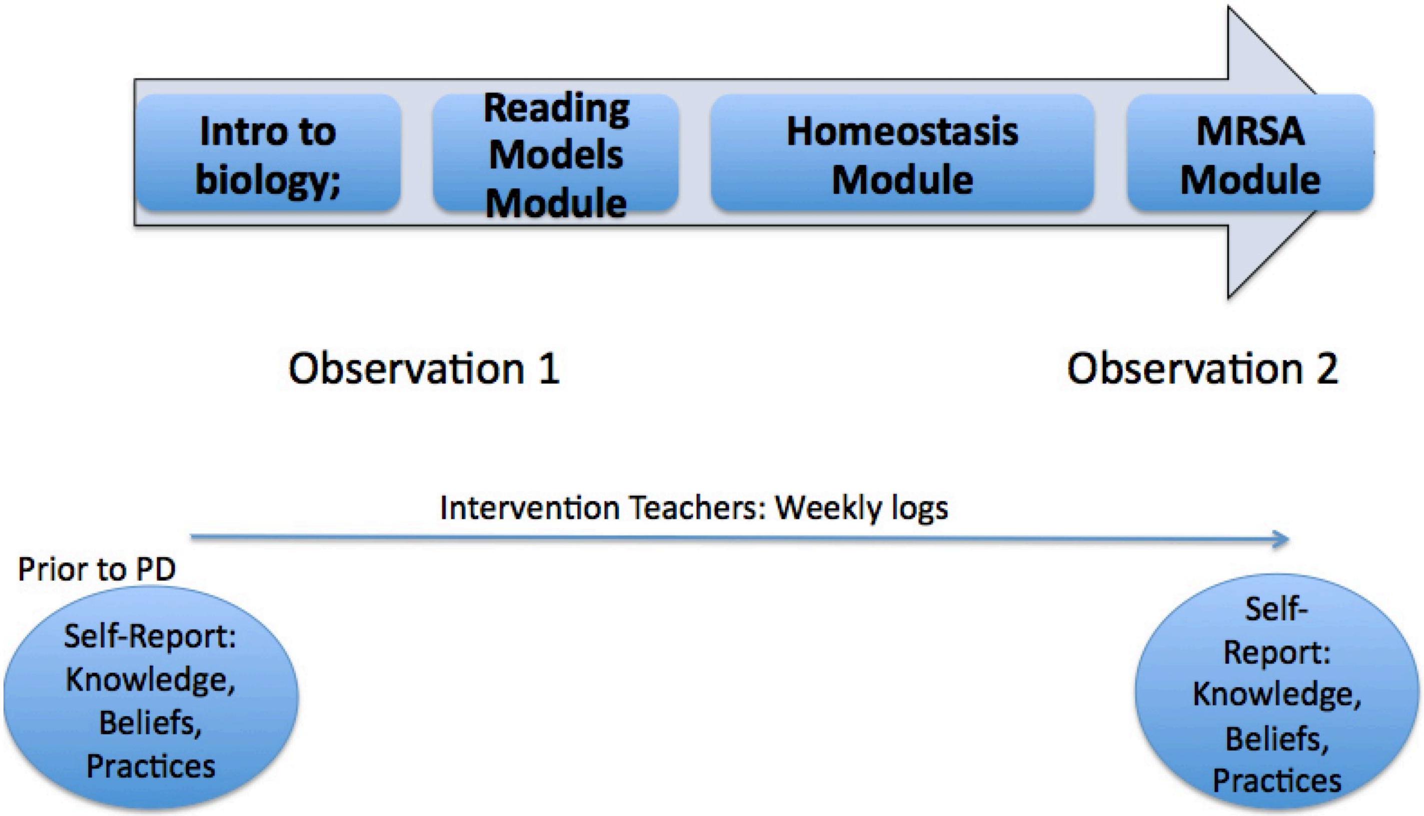

Figure 2. Design of READI intervention and Fidelity Assessments