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A Designer Speaks: Jacqueline Barber

How to Design for Breakthrough: A story of Collaborative Design across Disciplines

Abstract

How does one design for breakthrough? The goal of this paper is to communicate the potential for working across disciplines and domains in order to design breakthrough approaches and solutions to persistent problems in education. By breakthrough I mean a discovery that leads to new understanding and removal of barriers to progress. I reflect on a particular design experience that brought together players with different expertise; specifically, I describe the challenges we faced, and share the discoveries we made about how to take best advantage of what the diverse set of individuals brought to the table.

Introduction

Every designer strives to make significant advances through innovative designs. Progress comes from incremental change, but seeking something that results in 'that breakthrough' is something to which all educational designers aspire but few achieve. Reaching the bar for innovative —something new and creative—is relatively achievable. But, achieving innovation won't necessarily result in significant advances. The question I tackle in this paper is: *How does one design for breakthrough?*

The insights shared below come from the collaborative work of a team that I (a science curriculum designer) led, with P. David Pearson (a literacy researcher) to create a combined science and literacy curriculum program for elementary grade students. Our initial motivation in setting out to create an integrated science and literacy program was to address the problem of a crowded and disconnected curriculum. Together, our teams designed and developed *Seeds of Science/Roots of Reading,* a combined science and literacy curriculum.

Integrated curricula

Using the definitions outlined in the framework created by Stoddart et al (2002), our vision of an *integrated* curriculum is one in which the emphasis on two or more domains is balanced. *Seeds of Science/Roots of Reading* includes an equal number of science and literacy learning goals, and divides the available instructional time accordingly. This is in contrast to what Stoddart et al refer to as *interdisciplinary* approaches, in which the content or processes in one domain are used to support learning in another, or *thematic* approaches, in which overarching themes are used to create connections among domains (Stoddart, Pinal, Latzke, and Canady, 2002).

It's important to say that we were not the first to set out to create an integrated science and literacy curriculum. Our work follows and builds on the work of others, including: Romance and Vitale (1992, 2001), Palincsar and Magnusson (2001), Pappas and colleagues, (2003), as well as Guthrie and colleagues (1999). I will say that though we were not first to design an integrated approach to science and literacy curriculum, our effort resulted in what would become the first broadly-disseminated, commercially-available combined science and literacy curriculum.

Aim of this paper

The story I tell in this paper is not meant to be about science and literacy integration per se. The main aim of this paper is to share our particular design story, from which some lessons have been learned. While it is hoped that the design story and lessons learned could be useful to others, these are not intended as a recipe for achieving breakthrough. It's the story of how groups from different disciplines (in our case, science and literacy) found a way to work together that pushed everyone's thinking, and created something that neither group could have done on its own. This story of cross-disciplinary collaboration holds what I believe to be of potential value for the design community as a case study.

Why is this a Story Worth Telling?

The Big Picture

From afar, one can see that the *Seeds of Science/Roots of Reading* program has captured considerable attention. Currently, the program and its components are used by thousands of teachers in 42 states (within the United States) and in at least nine additional countries. There are currently five groups who have requested to create and publish translations/cultural adaptations of *Seeds of Science/Roots of Reading*—in Norway, the Netherlands, Mexico, China, and Nigeria. The recognition and impacts of our curriculum have been many. These include having influenced the approaches described in the Common Core State Standards for English Language Arts (2010) and the Framework for Science Education (NRC, 2011) that gave rise to the Next Generation Science Standards (Achieve, 2013), as well as being called out as one of just two promising and innovative approaches to science instruction in Carnegie's influential report, *The Opportunity Equation* (Carnegie Corporation, 2009).

Efficacy Results

Considering a more close-in and rigorous view of the promise of the program involves looking at evidence of efficacy. *Seeds of Science/Roots of Reading* is grounded in existing research and developed through systematic trials with broad numbers of teachers and students from diverse situations. In addition, more than 300 teachers and their students have participated in studies to test the efficacy of the *Seeds of Science/Roots of Reading* curriculum units. An independent evaluator, the National Center for Research on Evaluation, Standards and Student Testing (CRESST) at UCLA, has conducted randomized control studies on two of the Grade 2-3 units, one of the Grade 3-4 units, and one of the Grade 4-5 units. Results were analyzed using hierarchical linear models, with students nested in classrooms (teachers), and teachers nested within schools.

Looking across the studies, students using *Seeds of Science/Roots of Reading* curriculum have consistently outperformed students using business-as-usual, content-comparable science units on measures of science understanding and science vocabulary and scored equivalently or better on measures of science reading and science writing (Cervetti, Barber, Dorph, Pearson, & Goldschmidt, 2012; Duesbury, Werblow & Twyman, 2011; Wang & Herman, 2005). See Table 1 and 2 for a summary of the efficacy studies and their results.

Table 1. Descriptive Information for Four Seeds/Roots Efficacy Studies

Unit	Grade level	Study Year	# classes	Study Location	Comparison group
Shoreline Science	2-3	2004-05	35	21 states	Content-comparable inquiry science unit
Soil Habitats	2-3	2004-05	23	21 states	Content-comparable inquiry science unit
Light Energy	3-4	2007-08	94	1 state	Content-comparable business as usual
Planets and Moons	4-5	2008-09	86	10 states	Content-comparable business as usual

Table 2. Notable Effect Sizes of Seeds/Roots Efficacy Studies

	Effect Sizes			
	Shoreline Science **(Grades 2-3)**	***Soil Habitats*** **(Grades 2-3)**	***Light Energy*** **(Grades 3-4)**	***Planets & Moons*** **(Grades 4-5)**
Science Understanding	.484**	.843**	.65**	.21*
Science Vocabulary	.34**	.41**	.34**	.38**
Science Writing	not measured	not measured	.40**	--
Science Reading	.58*	.51*	--	--

****p<.01; *p<.05;**

These effect sizes are particularly promising given that: the 'treatment' consisted of a single 8-week unit; and units were presented by teachers who had not received professional development in the use of the curriculum.

In summary, three large-scale gold standard efficacy studies showed that students in classrooms that used the *Seeds/Roots* integrated approach always performed better than students in content-comparable comparison classrooms in science understanding and science vocabulary, and scored equivalently or better on measures of science reading and science writing. (Cervetti, Barber, Dorph, Pearson, & Goldschmidt, 2012; Duesbury, Werblow & Twyman, 2011; Wang and Herman, 2005).

Results for English learners

Of particular note, is that in the first CRESST efficacy study, described above, whose focus was on Grade 2-3 *Seeds/Roots* units, over 1/3 of the 89 classrooms had at least 30% English learners. The English learners in that study made equivalent gains on all science measures and most literacy measures to their English-speaking counterparts (Wang & Herman, 2005). This result fueled additional research and evaluation efforts towards better understanding and building an effective approach that maximizes the effectiveness of the program with English learners. These additional studies are described in the following.

In a small, 10-classroom quasi-experimental study, Bravo and Cervetti (2012) investigated the efficacy of the *Seeds of Science/Roots of Reading* curriculum with English learners. Ten 5th Grade classrooms, with at least 20% of English learners, were randomly assigned to either the treatment group (the *Seeds/Roots Planets and Moons* unit), or to their business-as-usual space science unit. English learners in the *Seeds/Roots* classrooms outperformed English learners in the comparison condition in science understanding and science vocabulary, but no statistically significant differences were found in science reading.

Interesting qualitative findings from this same study by Bravo, Barber and Cervetti (in an unpublished Final Report to the Noyce Foundation, 2010) also provide evidence for how *Seeds/Roots* classrooms differ from those of the control group. Observations of treatment and control classrooms made during the study point to three revealing impacts of the *Seeds/Roots* materials on classrooms.

- On average, teachers using the *Seeds of Science/Roots of Reading* curriculum devoted 50% more time to science instruction than teachers in the control group. Despite increased time spent on science, *Seeds/Roots* students' literacy outcomes were equivalent or greater than control classrooms that spent more time on status quo literacy instruction.
- In addition, teachers using the *Seeds/Roots* approach seemed to change the ways they interacted with their students: students in *Seeds/Roots* classrooms generally engaged in more science-related talk during science sessions.
- More specifically: students in *Seeds/Roots* classrooms engaged in significantly more science-related talk with their peers and with their teachers during science instruction than did students in business as usual classrooms. While correlations such as this can only be suggestive, they provide a basis and direction for future inquiries into the active ingredients of the *Seeds/Roots* approach and how to further magnify the curriculum's impact for ELL students.

In addition, data from our Grade 4-5 unit efficacy study regarding English learners were further analyzed by Duesbury, Werblow, and Twyman (2011). They focused on just the English learners in the study (n=769) and found similar results. Using results from the randomized control design they found that English learners in the *Seeds/Roots* classrooms outperformed English learners in comparison classrooms in the areas of science understanding, understanding of the nature of science, and science vocabulary. For these students, no significant difference was found on tests of science reading and attitudes towards science.

A separate study allowed us to follow the pilot work we conducted with a more thorough examination of science-literacy integration for English learners, in addition to testing the potential of a curriculum design framework (educative curriculum materials) for advancing teacher learning about strategies for supporting linguistically diverse students. The study provides a comparison between teachers randomly assigned to teach a *Seeds/Roots* unit with educative features, or the same unit without educative features. Results demonstrated that teachers who had access to educative curriculum features that described strategies for English learners, used more strategies as they taught the treatment unit and used a wider range of strategies as they taught. In addition, the use of strategies in the treatment classes had a stronger impact on student learning than the use of strategies in the comparison classes, suggesting that the educative curriculum features impacted the quality of strategies that the teachers used (Billman & Cervetti, 2012).

Taken together, these studies show growing evidence that the *Seeds of Science/Roots of Reading* model of instruction provides English learners with greater access to science knowledge than typical science programs, helps English learners develop academic language, and changes the nature of classrooms using the curriculum by increasing the amount of science-rich talk between students and between students and teachers.

About Breakthrough

There are different ways of defining what constitutes a breakthrough. Here I use breakthrough to mean *an important discovery that leads to new understanding and the removal of barriers to progress*. Rather than competing for a limited resource (class time), our approach to science and literacy integration intentionally blurred the distinction between the two, increasing the amount of science taught in classrooms using *Seeds of Science/Roots of Reading*. Rather than believing that English learners must be provided with diluted science content, our approach to multi-modal instruction and provision of research-based supports worked to amplify all students' access to learning. In fact, the resulting combined approach not only resulted in more science being taught in elementary classrooms, and providing better access to science learning for English learners, but it turned out to be a better way for all students to learn science and literacy. This is the meaning I intend in reaching for the word breakthrough.

Whether or not the *Seeds of Science/Roots of Reading* will actually achieve breakthrough results in schools requires a longer-term determination. But in the short term, the results are promising. It is important to note that the question, *How does one design for breakthrough?* is not the same as *How does one achieve breakthrough?*, the latter requiring far more than materials that are different. But that is not the subject of this paper.

Connection to the Research Literature

As I reflect on our design story, it is not without acknowledging and delighting in the work done by others who have waded into the same territory and puzzled over the collaborative learning processes of cross-disciplinary teams (Akkerman & Bakker, 2011; Fischer and Ostwald, 2005; Flood, Neff & Abrahamson, 2015; and Wenger, 2000). Wenger's work on *communities of practice* and his conceptual framework describing social learning systems explores the dimensions of community, boundaries, and identities, painting a useful backdrop for understanding the work of our team. Fischer and Ostwald's analysis of the biases and barriers inherent in different types of design communities provides important distinctions between disciplinary and cross-disciplinary teams (Fischer & Ostwald, 2005). In particular, their discussion of the value of *asymmetry of ignorance* resonates with our situation. Flood, Neff & Abrahamson's description of having resolved persistent collaboration challenges through the use of boundary objects—artifacts that bridge boundaries—caused me to think differently about the artifacts that facilitated the work of our team. Finally, Akkerman and Bakker's examination of the claimed learning potential of *boundaries* between social and cultural practices (as embodied through different domains or disciplines), provides a thoughtful analysis of what's become known as *boundary crossing* and *boundary objects* and posits potential mechanisms for their role in promoting learning. I reflect more specifically about the connection of this literature to our experience at the end of this paper.

Below, I provide some context to our work, a brief description of the *Seeds of Science/Roots of Reading* program and an overview of how it is structured. This is followed by the heart of the article: reflection on the challenges we faced, and what turned out to be most valuable in taking best advantage of what this diverse set of individuals brought to the table. I end with some musings about the value of collaborating with dissimilar colleagues and outline some connections to the research literature.

Pre-design Work

I will admit to being mainly driven by the fairly narrow goal of trying to capture more time in the school day for science teaching and learning. High stakes testing focused on literacy and mathematics had had the unintended consequence of squeezing science out of the elementary school day (Fulp, 2002; Weiss, Banilower, McMahon & Smith, 2001). Focus groups we conducted with elementary grade teachers, especially early elementary grade teachers, made clear that if a science curriculum unit could not do some work for them in helping students learn to read and write, then they would be unable to devote much time to it. Over the coming years this would play out more visibly across the United States as school districts responded to the pressure for increased student achievement by requiring daily blocks of time devoted to literacy (Dorph, Goldstein, Lee, Lepori., Schneider, Venkatesan, 2007; Dorph, Shields, Tiffany-Morales, Hartry, McCaffrey, 2011). In some places these literacy blocks (as they came to be known) were as long as 3 hours—half the instructional time in a day. Clearly, if time was to be found in the school day for science, it would need to come from the time reserved for literacy instruction—a territory that we as science curriculum designers knew little about.

So I set out to find some literacy educators. There were a couple of false starts, but through serendipity, I ended up speaking with P. David Pearson (then the brand new Dean of the Graduate School of Education at the University of California, Berkeley). David is fond of saying that literacy is a domain in search of content—reading comprehension involves making sense of text, and that text needs to be *about* something. Unfortunately, especially at that time, the texts that young students were provided in school were largely fictional (Duke, Bennett-Armistead, & Roberts, 2003). David immediately recognized the chance to work together to create a combined science and literacy curriculum as something that could provide needed opportunities for students to develop strategies for making sense of non-fiction text. David assembled a literacy team to join my science team at the Lawrence Hall of Science.

The *Seeds of Science/Roots of Reading* Curriculum

Motivated by increasing the number of learning opportunities students have (for making sense of informational text and for engaging with science), I don't think that either David or I realized that our quest to integrate the domains of science and literacy would set us on a path to finding a qualitatively different and better way of teaching and learning both science and literacy. However, over time, the evidence that emerged would show this to be the case. Following is an overview of the *Seeds of Science/Roots of Reading* curriculum.

Seeds of Science/Roots of Reading is an effective curriculum program for Grades 2–5 that offers students the opportunity for intensive engagement with high-level science concepts through multiple modalities (firsthand investigations, student-to-student discussion, reading science texts, and writing—the "Do-it, Talk-it, Read-it, Write-it" model). An explicit focus of the curriculum is *disciplinary literacy*, the specialized skills involved in reading, writing, and talking about science. The program involves students in deep dives into learning about the natural world by searching for evidence through firsthand experiences and text in order to construct more and more accurate and complete understandings of the natural world. Students engage in written and oral discourse with the goal of communicating and negotiating evidence-based explanations, and evaluating and revising explanations. Table 3 shows a sample instructional sequence, featuring multiple modalities and the "Do-it, Talk-it, Read-it, Write-it" model.

Table 3: A Sample Instructional Sequence from Shoreline Science, a curriculum unit for Grades 2-3 in the *Seeds of Science/Roots of Reading* program

Instruction Sequence related to the Composition, Origin and Age of Sand				
Do	**Read**	**Do**	**Talk**	**Write**
Using hand lenses, students observe the different shapes, sizes, and colors of individual grains of sand from a variety of sand samples. Why are they all different?	Students read a book called *Gary's Sand Journal*, about a sand scientist who shares the inferences one can make about origin of sand, age of sand, composition of sand by what the individual sand grains look like.	Students use the knowledge they gained and the practices they used to search for evidence about sand to make inferences about the composition, origin, and age of a mystery sand.	Students choose their favorite sand samples and work together in 'expert groups' to discuss the inferences they each made about the composition, origin and age of their sand samples.	Students construct scientific arguments by making evidence-based claims for the origin, age, and composition of their sand sample. They reflect on how what they did is what Gary the sand scientist does.

Seeds of Science/Roots of Reading is designed to address critical needs of students and teachers, many of which are not typically part of solutions offered by designers of curriculum materials. These include: the need for an expanded vision of science proficiency to include reading and writing science text, and engaging in science talk; the need for more science to be taught at the elementary level; the need to address the backdrop of changing demographics in the United States and the growing achievement gap in science; and elementary teachers' needs for professional learning in science, as well as in instruction for English learners.

The program includes features designed to meet these needs/goals and in so doing provides added value to teachers in several ways. For instance, the program is designed to enable teachers to address both science and literacy goals at the same time, strengthening instruction in both domains while providing a way to fit science into a school day that is dominated by English language arts instruction (Cervetti, Pearson, Bravo, & Barber, 2006). The materials provide research-based accommodations for English learners, providing teachers with supports in adapting the curriculum to their own situations at a time in the U.S. when the number of non-native English speakers is in rapid growth. (Bravo & Cervetti, 2008; Bravo & Cervetti, 2012). The teacher's guides are designed to be educative for teachers as well as students, infusing explicit teacher learning opportunities into everyday practice by providing just-in-time information, advice and support (Billman & Cervetti, 2012; Cervetti, Kulikowich, Drummond, & Billman, 2012).

Valuable outcomes of our work have revealed unanticipated use contexts for the program. While some locales use *Seeds of Science/Roots of Reading* in the way that was intended (as a core science program and a supplementary literacy program), for many reasons, the program is seeing greater use in a variety of other ways, including: as a better way to teach science; a science program well-suited for situations with large numbers of English learners; as an intervention literacy program; as an English language development program; and as a supplementary literacy program. There are also schools and districts who first purchase the program's student science books, and then follow up with purchase of the full program, thus showing that the program can serve as an on-ramp to hands-on science.

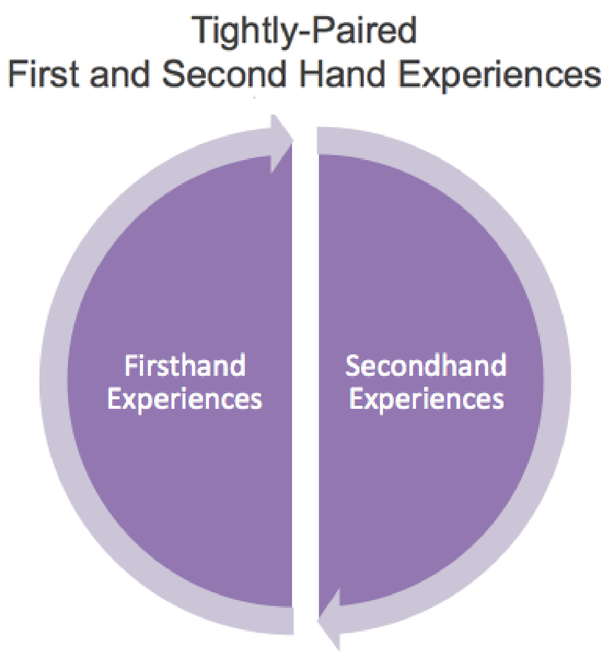
The *Seeds of Science/Roots of Reading* Design-Shell

Over the course of the design and development of *Seeds of Science/Roots of Reading* we created a variety of models that illustrated and exemplified our vision. Using these models as tools guided our different groups of developers in creating curriculum units that all instantiated that same vision—a vision that was different than either our science or literacy team members had used previously. While there are a number of different models to guide different aspects of our development, perhaps the most fundamental model we developed and then used to guide our work was a multi-modal design shell. This is how the design shell worked:

1. Once a science concept was selected as a learning goal for a curriculum unit, the team would construct a tightly-connected pair of firsthand and secondhand experiences that together would provide students with the opportunity to learn deeply about that concept. By tightly-connected, we meant that both experiences would serve the same purpose, but neither would be adequate to communicate the concept deeply by itself.

   An example of this is a pair of experiences designed to help students learn what sand is and where it comes from. As a firsthand experience, students use hand lenses to observe the different shapes, sizes, and colors of individual grains of sand from a variety of sand samples. Why are they all different? The secondhand experience involves students reading a book called Gary's Sand Journal, about a sand scientist who shares the inferences one can make about origin of sand, age of sand, composition of sand by what the individual sand grains look like. By secondhand we mean based on someone else's evidence, in this case Gary's. In this example, neither examining the sand samples alone nor just reading the book would enable students to learn as deeply about the origin, age, and composition of sand.

Figure 1: First layer of the Design Shell

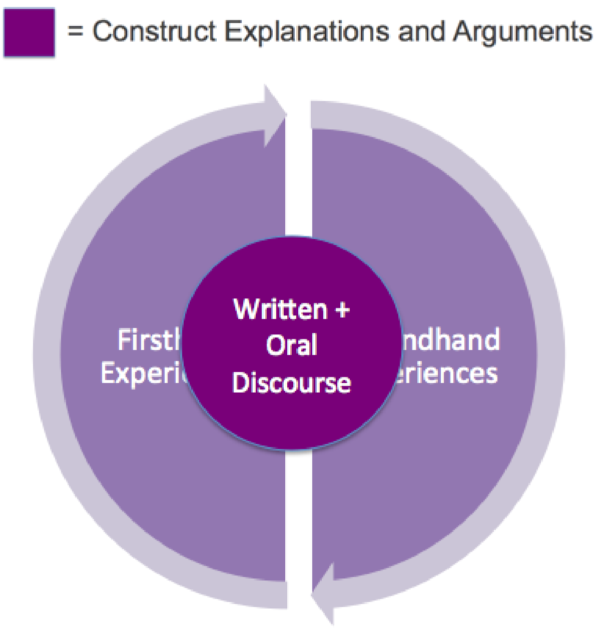


2. Once we have selected a tightly-paired set of first and secondhand experiences, we create written and oral discourse opportunities for students that enable them to construct an evidence-based explanation and to be able to justify their explanation (create an argument). This second step of the design shell is built on the premise that the key enterprise of science is about constructing explanations. We conduct investigations and engage in arguments in order to make more and more accurate explanations about the

world. Thus engaging in written and oral explanation and argument is the general purpose for all of the doing and reading we want students to be able to do.

In the case of the Sand Activities, the overarching purpose is to make an explanation about where they think a Mystery Sand came from. Students use the knowledge they gained and the practices they used to search for evidence about sand (in both firsthand ways and in a secondhand source) to make inferences about the composition, origin, and age of their mystery sand.

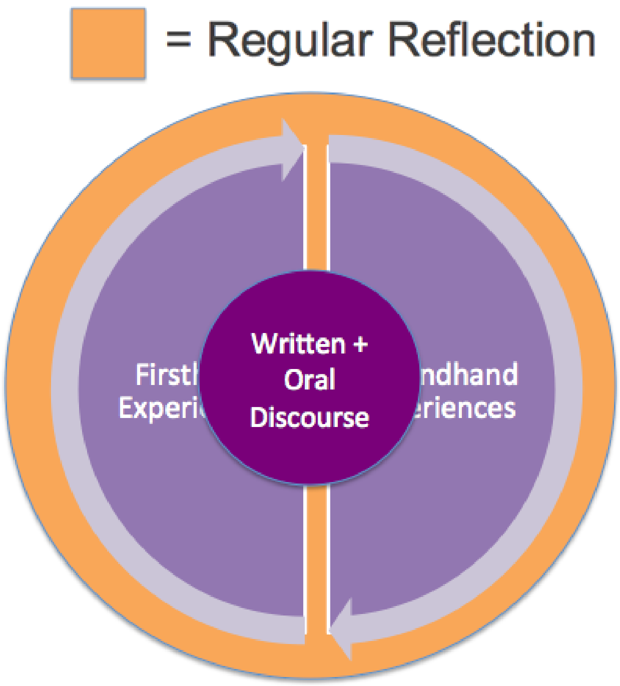
Figure 2: Second layer of the Design Shell



3. Finally, we built in many opportunities for the class, and for individual students to stop, reflect, and make sense not just of what they have been doing, but of what they have been learning, and how they know what they know.

In the case of the Sand Activities, students reflect with others at their table about the different sand samples they observed. After reading Gary's Sand Journal, students each choose one sand sample, and they get together with an 'expert group,' other students who chose the same sand sample, to begin to make inferences about the composition, origin and age of their sand samples. They reflect on what their evidence was, why we have to make inferences about sand, what questions they still have, and how they could be more sure of their inferences. They reflect on how what they did is like what Gary, the sand scientist does in his job.

Figure 3: Third layer of the Design Shell

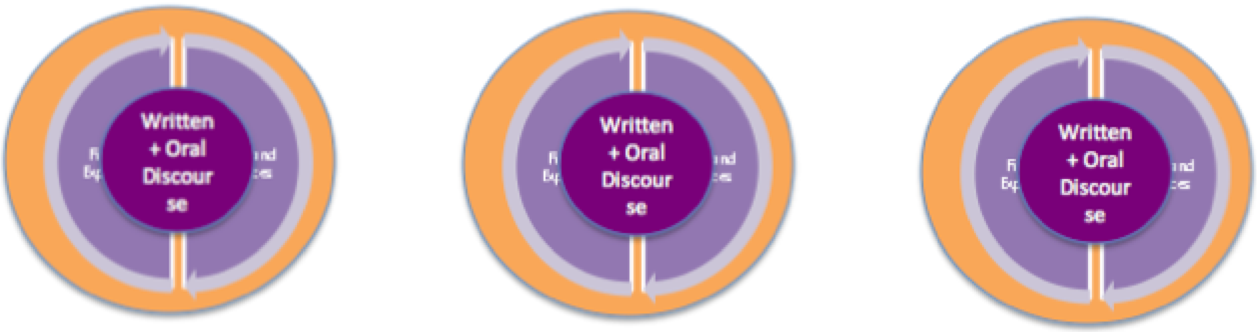


We call this completed instructional sequence, built around a conceptual learning goal, an 'essential multi-modal experience.' While other curricula sometimes claim to use a multi-modal approach, few allow students to experience *the same concept* in multiple ways, with each modality providing access to additional information and an opportunity to understand that concept more deeply.

This design shell in Figure 3, serves many purposes, it: a) supports the coherence of each essential multi-modal experience; b) balances the ratio of firsthand and secondhand experiences within that instructional sequence; c) ensures that the doing and reading serve a higher purpose—of providing students with the evidence from which they can make an explanation about the natural world; and d) ensures an adequate amount of reflection time within that instructional sequence.

A complete curriculum unit includes a sequence of essential multi-modal experiences. The conceptual relationship between each essential multi-modal experience is important, but a much longer story than there is room for in this article. It is likely the topic of a future article.

Figure 4: A unit is a sequence of multi-modal experiences



It was not difficult to come up with the basic idea for our approach—for every important concept to be learned, we would provide students with opportunities to "Do-it, Talk-it, Read-it, and Write-it." While this design shell was enormously helpful, actually enacting it brought about many questions and differences in our team. The next few sections describe some of the challenges we faced and what things turned out to be important in order to move together creating this jointly-constructed curriculum.

Similar Goals but Different Tactics

The touch point for me throughout this 7-year collaboration was the fact that regardless of a person's disciplinary identity, or particular specialty within that discipline, that we all shared the same set of goals for students. To illustrate the point, one need only look at the following list of student outcomes and ponder whether it represents the goals of a science educator or that of a literacy educator:

Table 4: Desired Student Outcomes

Desired Student Outcomes
Build strong content knowledge
Comprehend and critique
Value evidence
Use technology and digital media strategically and capably
Respond to the communication demands of the discipline
Demonstrate independence

This particular set of student learning goals happens to come from the Common Core State Standards for English Language Arts (Achieve, 2013) but arguably could easily be those of a good science educator. The fact of these shared goals was something that kept the collaboration going even when the going got tough—and it did.

While we agreed on the "what," we differed on the "how." The go-to strategies and approaches favored by those from our science team and those from our literacy team had many differences, as did each others' internal checklists for what constitutes good instruction. There were things that each team thought and did that were an affront to what the other team's members thought and did.

Table 5: Different Instructional Tactics

Science team preferences	Literacy team preferences
Open and authentic opportunities for exploration and investigation	Structured and includes heavy use of scaffolds
Begin with exploration	Prepare students for exploration with explicit instruction
Do before Read	Read before Do
Privilege firsthand experience	Privilege texts
Averse to vocabulary-driven approaches	Focused on vocabulary

For instance, the science team wanted to ensure that there were open and authentic opportunities for students to explore and investigate the natural world as scientists would, while the literacy team worked to add more structure to students' experiences by providing plenty of scaffolds. The science team liked to begin a unit or a session with exploration whereas the literacy team maintained that it was necessary to prepare students for exploration with explicit instruction.

What's more, many of those on the science team initially had an aversion to reading born of the reading-dominated, science textbook-driven programs that have characterized a majority of the approaches to science instruction in the United States. In this typical approach to science instruction, students would be assigned to read a chapter of the textbook and to answer the questions at the end of the chapter. In these typical reading-dominated approaches to science instruction, even when hands-on science experiences are added, they typically serve as illustrations or verifications of scientific phenomena rather than as opportunities to learn about the natural world by asking questions, collecting and analyzing evidence, and drawing conclusions. Because of what many science educators have considered to be a broad spread misuse of texts in science, many have tended to avoid the use of text at all (Digisi and Willett, 1995; NRC, 1990). This bias relates to our science team's overall privileging of firsthand experience and of evidence gathered in a firsthand context, whereas, the literacy team preferred to privilege texts and textual evidence over firsthand evidence. This played a part in the science team's desire for students to first engage in hands-on experience with a phenomenon before reading about it, whereas the literacy team leaned towards having students read first before doing.

Vocabulary was another arena where the science team and the literacy team, when left to their own devices, would employ different instructional approaches. Science is replete with new vocabulary—indeed Armstrong and Collier (1990) pointed out that a semester of high school biology had 45-50% more new words than a semester of a foreign language. Perhaps because vocabulary represents such a tangible aspect of science learning, or perhaps because it is considered easy to assess whether students "know" the definition of a word, it is not uncommon to see science instruction treated as an exercise in memorizing new vocabulary rather than understanding the concept for which that vocabulary word is a label. There is no question that the science team was nervous when it came to vocabulary instruction, and tended to de-emphasize a focus on vocabulary learning. The literacy team, understanding the potential obstacle that new vocabulary can play for many students in comprehending a disciplinary text, leaned towards pre-teaching vocabulary.

Initially these differences seemed very large to us all—in fact, there were moments when I was unsure whether the collaboration would survive.

Seek Out Synergies

Guided by the need to create curricula that would address goals in both science and literacy, we set out to find synergies— those moments in an instructional sequence where students could be engaged in learning both science and literacy at the same time. It was through this process, of listening and learning from each other, unpacking our respective jargon, asking probing questions to challenge each others' reasoning that we uncovered a handful of synergies that reside at the core of both science and literacy.

What do inquiring through firsthand experiences and comprehending texts share in common?

Asking this question led us to realize that sense-making strategies used by scientists as they inquire and make sense of the natural world are cognitively very similar to the sense-making strategies used by good readers to make sense of text. For example, a scientist will make a prediction early in an investigation, and based on new evidence collected over the course of investigating, will revise her prediction. A reader can similarly make a prediction at the start of reading a book, and revise that prediction periodically as he gathers new evidence from the text as he reads. In each case, the act of making a prediction focuses a scientist's or a reader's attention on relevant information. Revising predictions based on new evidence helps both the scientist and the reader hone their emerging understanding over time. We engaged in comparing other sense-making strategies, such as making inferences, comparing and contrasting, asking questions, etc., and also found strong parallels (Cervetti, Pearson, Bravo, & Barber, 2006; Greenleaf, Brown & Litman, 2004; Osborne, 2010).

It was through this work of comparing sense-making strategies that we came to better understand the fundamental similarity of both science and reading; in both science and reading we search for a preponderance of evidence, and based on this preponderance of evidence, we draw the best conclusion we can at that point in time. This is different than in mathematics, for instance, where a single piece of evidence can prove something wrong.

We embraced the principle that ***science and literacy share sense-making strategies.*** Practically, this meant that we made multiple opportunities for students to use a strategy in the context of firsthand investigations and to use the same strategy in the context of making sense of text. After repeated opportunities, we encouraged students to reflect on what is similar and different about using the same strategy in two different contexts.

What does it mean to know a word?

Asking this question enabled the science team to hear the literacy team describe what good vocabulary instruction looks like. Knowing what a word means doesn't stop at knowing its definition, being able to read the word and spell it. Truly knowing what a word means also involves being able to provide examples of the word, relate it to other words, and use it spontaneously in speech. It involves constructing a rich network of words surrounding this one word. Together we came to understand that in the end, the goals of good vocabulary instruction are not substantially different from those of good conceptual instruction. We embraced the principle that ***words are concepts*** (Cervetti, Pearson, Bravo, & Barber, 2006).

Why do scientists use text?

By asking this question, our teams were able to come to the understanding that scientists don't only investigate in firsthand ways, but they also investigate in secondhand ways, by inquiring into, and searching for evidence in text. Seeing reading as an investigation of text—a secondhand investigation— shaped how we framed and talked with students about reading as an act of inquiry. The principle that ***scientists investigate in firsthand and secondhand ways*** enabled us to see the authenticity of making sense of, and searching for evidence from, text as science practices (Cervetti & Barber, 2007).

How and when do scientists read, write and talk?

This question enabled the group to see, for instance, that scientists read different kinds of texts for different kinds of purposes, and that the timing of the use of a text depends on the purpose for which that text is used. If a scientist is reading to find out what is known in the field about a particular topic in preparation for situating a new investigation, she would do that reading before conducting a firsthand investigation. But if a scientist is reading to gather additional information to help make sense of data from an investigation, then that would occur after having completed a firsthand investigation. Parsing out the purposes and types of writing and talk in which scientists engage similarly helped us figure out the purposes and therefore the timing of the use of writing and talk in our units. Further, it enabled us to embrace a broader range of science practices in service of the principle that ***science is a discourse***—not just a way of doing and thinking, but also a way of reading, writing, and engaging in talk (Cervetti, Pearson, Bravo, & Barber, 2006).

Table 6: Science-Literacy Synergies

Probing Question	Principle/Synergy
What do inquiring through firsthand experiences and comprehending text share in common?	Science and literacy share sense-making strategies.
What does it mean to know a word?	Words are concepts.
Why do scientists use text?	Scientists investigate in firsthand and secondhand ways.
How and when do scientists read, write and talk?	Science is a discourse.

While in particular the latter two of our synergies are now reflected in the Next Generation Science Standards (Achieve, 2013) and the National Research Council's *Framework for K-12 Science Education* (2011) on which the NGSS are based, neither of those documents existed when we were designing and developing our integrated science and literacy program (2003-2009). In fact, at the time we were working on designing and developing our approach to science and literacy integration, the principles on which we had arrived were met with some alarm from science education colleagues, some of whom viewed the 'replacement' of any hands-on investigation with texts as heretical.

Embrace Differences

Arriving at the synergies and their associated principles described above went a long way towards addressing differences between tactics used by the science team and those used by the literacy team that seemed so problematic initially. However, some seemingly unresolvable differences remained. It took us longer to figure out that embracing some of our disciplinary differences would be the way we would resolve them. By embracing the differences, I mean learning about each other's tactics and the rationale for using them in more detail, seeing them in action, and observing their impact on student learning. Over time, this is what would enable both the science team and the literacy team to adopt some of each other's tactics, resulting in transforming aspects of each other's approaches to teaching.

Intentional, thoughtful instruction in practices.

One good example of this relates to the very intentional and thoughtful instruction that literacy educators bring to the development of literacy practices. The literacy educators on our literacy team did not assume that students would know how to engage in a practice, such as reading informational text, writing an explanation, or engaging in oral argumentation. Their approach was to provide explicit instruction in how to engage in the practice followed by repeated opportunities to use the practice, first with scaffolds and then with increasing independence over time (Pearson & Gallagher, 1983). This is in stark contrast to how science educators have typically approached instruction. Typically science educators would task students to "read chapter 4," "write a paragraph about x," or "talk with your partner about y" without helping them know how to do that. Knowing how to engage in reading and writing science text and engaging in science talk is not something that students automatically know how to do. For instance, the ACT *Reading Between the Lines* study indicated that nearly half of high school students scored below proficient at comprehending complex disciplinary texts. Further, the study provides dramatic evidence that students who aren't capable of reading and comprehending complex disciplinary texts, don't advance in science, further demonstrating the importance of reading to science (ACT, 2005).

In my experience, generally science educators don't just fail to provide instruction in "literacy" practices, but they also don't provide explicit instruction in science practices, from making observations and inferences, to recording and making sense of data. One typically sees the extreme of providing little guidance (as described above) or removing all of a student's agency by providing an over-scaffolded worksheet. Highly scaffolded worksheets can be beneficial when they are part of an intentional build in which students are provided with increasing independence and responsibility for engaging in the practice. Too often, however, the scaffolding is not faded over time, rather it becomes an approach to creating worksheets.

This is a case where the literacy team's tactics took the day; we do not assume that students know how to engage in practices, but provide explicit instruction and a gradual release of responsibility to students over the course of an intentional build of opportunities to use that practice. In addition, we adopted the literacy team's use of instructional routines as well as regular metacognitive reflection about "what a good reader does…" (or engineer, or scientist).

Authentic, student-centered approach to conceptual learning

Another example of embracing each other's tactics relates to the science team's approach to conceptual learning. The science team worked hard at immersing students in authentic opportunities to learn like a scientist learns. This involves setting up the instruction with a problem to solve or a question to answer thereby providing students with an authentic need to know. Also, by creating the time to dive deep into learning about a topic, students are given the opportunity to develop enough expertise and experience in a topic area that they can be successful in figuring out solutions to problems and answers to questions themselves. Adopting the science team's approaches required: less front-loading of information; accepting that students might encounter a phenomenon before they had a word to describe it; and not always providing closure right away or even at all, as this is an important aspect of learning about how natural and designed worlds work.

Table 7: Instructional Tactics Adopted

From literacy team	From science team
Intentional, thoughtful approach to instruction in practices • Explicit instruction on practices • Intentional build across unit and course • Gradual release of responsibility • Use of instructional routines • Regular metacognitive reflection	**Authentic, student-centered approach to conceptual learning** • Immerse students in learning like scientists do • Create an authentic need to know • Provide opportunity for focused, deep dive • Less front loading • Okay for things to remain unresolved

The tussle between the literacy and science teams often centered around a preference of using more structured/scaffolded approaches versus a preference of using more open/authentic approaches. While we could have chosen something less structured than the literacy team was accustomed to and more structured than what the science team typically chose, it is notable that we did not. Good design is not about compromise. In the end, based on our experience of working together and what we learned from our pilot and field tests, we followed the literacy team's lead for instruction around practices: providing explicit instruction, intentional build, gradual release of responsibility, use of instructional routines, and regular opportunities for metacognitive reflection around all practices (both literacy and science practices). And we followed the science team's lead for instruction around conceptual knowledge: immersing students in learning like scientists do, creating an authentic need to know, and providing the opportunity for focused, deep dives. In hindsight, it makes perfect sense to err on the side of providing students with lots of instruction and support in *how* to find out about the natural world, while choosing a more open and authentic-to-science approach to finding out the *what and why* of how the natural world works.

Reflections on the Journey

Looking back at the journey we took makes a tidy story, but the process was anything but tidy. It was messy, it was frequently uncomfortable, sometimes we lost our way. As I reflect on the factors that seemed critical to our success, a few things stand out.

1. **Shared goals.** Having shared expectations of student outcomes was critical to our collaboration and our ability to try out tactics that were outside of our comfort level. However, identifying and articulating these took some time. Akkerman and Bakker would consider this set of shared goals as a boundary object that facilitated our border crossing by allowing for *coordination* of common values (Akkerman & Bakker, 2011). This also applies to our group's

identification of synergies—learning that comes about through coordination of ideas and practices in different disciplines. This further fits our experiences, as it is the interaction around the boundary object rather than the boundary object itself that creates and communicates knowledge (Fischer & Ostwald, 2005).

2. **Different tactics.** The differences in how science and literacy educators approach teaching and learning presented the challenges that come with questioning (and being questioned) about familiar ways, but ultimately turned out to be an asset. It meant that we had a richer array of expertise and approaches from which to draw. Following Akkerman and Bakker's taxonomy, *reflection* on differences such as these facilitates border crossing by expanding each others' perspectives (Akkerman & Bakker, 2011). Further, they might characterize how our group embraced differences and chose instructional tactics from science in some cases and literacy in others as learning through *transformation*, specifically "maintaining uniqueness of the intersecting practices" (Akkerman & Bakker, 2011, p.149).
3. **Development of a shared culture.** Over time, a shared culture emerged in our group born of shared experiences and co-constructed prototypes. It included a growing language, processes, values, and standards that together created the fabric of our joint enterprise. Wenger discusses the importance of a sense of joint enterprise and "a shared repertoire of communal resources—language, routines, sensibilities, artifacts, tools, stories, styles, etc." (Wenger, 2000, p. 229).
4. **Equal number of people from each discipline.** Had we been mainly a science team with a token literacy advisor, we would not have developed the approaches that we did. The lone literacy voice would have been unlikely to impact a team of science individuals. The same is true if we had been a literacy team, with just one or two science team members. Having an equal number of individuals representing the different perspectives that come with being trained in different disciplines meant that we had to work things out to the satisfaction of both disciplinary perspectives. This resulted in prolonged discord but I contend, greater breakthrough. Fischer and Ostwald contrast design communities that function as *communities of practice* (Wenger, 1998) in which practitioners work as a community in a certain domain undertaking similar work, with those that they call *communities of interest*. Communities of interest bring together stakeholders from different communities of practice to tackle a common concern (Fischer & Ostwald, 2005). Communities of interest benefit from group members with diverse backgrounds and perspectives providing the potential for new insights and creativity.
5. **Separate science and literacy teams.** We knew that we needed to make a curriculum that both science-identified and literacy-identified educators would recognize as excellent. While the project leadership and the specific unit teams were comprised of a mix of science and literacy disciplinary

experts, and pairs of science and literacy developers worked together, we maintained separate science and literacy developer teams. There were certainly pluses and minuses in doing it this way. One payoff was that this ensured that what we were designing was informed by strong, intentional science and literacy voices bent on ensuring that the expectations and requirements of science and literacy were tended. In assessing the barriers and biases of different types of design communities, Fischer and Ostwald point to the value of a community of interest regrouping to form communities of practice in order to deepen aspects of their particular practice, what they characterize as "learning when the answer is known" (Fischer & Ostwald, 2005, p.9). They suggest that a community type may shift over time. In our case, having a critical mass of both science educators and literacy educators enabled that shift to occur intermittently over the course of each week.

6. **Interdependencies**. I wonder, whether things would have played out differently if we as a science team did not need the literacy team's expertise. Recall that in attempting to capture part of the literacy block in the school day, we needed to ensure that a significant portion of what we developed (we aimed at 50%) could pass as bonafide reading and writing instruction. Likewise, if literacy teaching and learning was to find a place in science class, the science team's expertise was needed.
7. **Use of evidence in decision-making**. Allowing ourselves to engage in design research cycles, where we tried out variations, some carefully planned, some the result of different designers, and in collecting evidence of student learning was of course key to our ability to make decisions that would over time yield our integrated approach. Regardless of background, all participants placed a high value on looking to the classroom to gather evidence for decision-making. This shared value was essential to the establishment of a shared currency.
8. **Trust, respect, and openness.** Opening up to share deeply-held ideas, and being willing to evolve those ideas is something that not only requires trust and respect, but requires an openness to evolving one's own practice. We needed to be able to question and be questioned, to have conversations that went beyond disagreements, and to value the expertise of the full range of educators, from researchers to practitioners. In particular, I posit that the tone set by the leadership of a group is key to building the kind of environment that can result in teams being able to operate at this high level as well as the existence of individuals on the team who seek growth.Wenger discusses the role that some people choose to play as brokers between communities. These people engage in "import-export" of ideas across boundaries (Wenger, 2000, p. 235).

Additional Thoughts

As alluded to above, in addition to differences in how educators from different disciplines approached instruction, we experienced differences in how educators with different specialties approached the task of the design and development of an elementary, combined science and literacy curriculum. Our teams included individuals that all came from different specialties within the field of education (elementary classroom teaching, educational research, curriculum/assessment design, and experts at working with English learners). Simple things, for example, the question of, "What is a rigorous approach?" produced highly variable thoughts. While at times challenging, there is no question in my mind that those differences of perspective and worldview yielded highly productive outcomes.

Fast forward to today: our science and literacy teams have moved beyond our stormy relationship largely because we have developed a new set of shared norms. However, as we work on an expansion of the Grade 2-5 *Seeds/Roots* program to become a K-8 integrated science and literacy program, designed to address the Next Generation Science Standards (an initiative dubbed as Amplify Science), we are facing another situation where the close integration of two different domains, involving different perspectives is presenting the challenge and opportunity that comes with integration. We have put together an assessment and analytics team working with our combined science-literacy curriculum team. Together we are working to create tightly-aligned curriculum and assessment, featuring diagnostic assessments and the use of analytics to help teachers differentiate instruction. As I assess this new collaboration against the factors listed above, all of the factors seem relevant, but not yet all present. I remind myself, that it took time, failures, and shared successes to get there as we worked to come up with a new, combined approach to science and literacy.

Conclusion

Breaking through to clarity about how a combined approach to teaching science and literacy, turned a competition for class time into an opportunity to benefit learning in both disciplines, and ultimately resulted in the removal of barriers to progress. Obviously there is not just one way to design for breakthrough. What's offered in this paper is what worked for our team—assembling a group of individuals that share the same goals but typically use different tactics and bring in different perspectives. I think of times in the past when I thought I had "a dream team," largely because team members' high degree of similarity of background and perspective meant that we didn't need to spend a lot of time arguing or tussling. Now I think, that while not always an easy path, working with dissimilar colleagues and collaborating across disciplines and domains—a community of ideas—holds greater promise for yielding different approaches. Different practices and perspectives can provide a rich source of ideas for approaching teaching and learning differently, as well as for approaching the process of design in different ways.

Capitalizing on these differences involves focusing on a common set of goals, and giving equal consideration to a range of perspectives. Giving equal consideration does not mean seeking compromise, rather it means consulting with a range of individuals and being open to thinking differently. Ultimately, it is necessary to gather and evaluate evidence of student learning on which to base decisions. Colleagues with diverse perspectives may ask different questions, pay attention to and value different things, or interpret findings differently. Going through this process together provides shared experiences that play out differently than with more similar colleagues. Finally, doing the necessary work to create a design environment that values, respects, and is open to the contributions of those from all perspectives, including those with different levels of education and experience, and those in various roles on the team, is key to a successful outcome.

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