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# Pacific CRYSTAL Project: Explicit Literacy Instruction Embedded in Middle School Science Classrooms

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**Abstract** Science literacy leading to fuller and informed participation in the public debate about science, technology, society, and environmental (STSE) issues that produce justified decisions and sustainable actions is the shared and central goal of the Pacific CRYSTAL Project. There is broad agreement by science education researchers that learners need to be able to construct and interpret specific scientific discourses and texts to be literate in science. We view these capabilities as components in the fundamental sense of science literacy and as interactive and synergetic to the derived sense of science literacy, which refers to having general knowledge about concepts, principles, and methods of science. This article reports on preliminary findings from Years 1, 2, and 3 of the 5-year Pacific CRYSTAL project that aims to identify, develop, and embed explicit literacy instruction in science programs to achieve both senses of science literacy. A community-based, opportunistic, engineering research and development approach has been utilized to identify problems and concerns and to design instructional solutions for teaching middle school (Grades 6, 7, and 8) science. Initial data indicate (a) opportunities in programs for embedding literacy instruction and tasks; (b) difficulties generalist teachers have with new science curricula; (c) difficulties specialist science teachers have with literacy activities, strategies, genre, and writing-to-learn science tasks; and (d) potential literacy activities (vocabulary, reading comprehension, visual literacy, genre, and writing tasks) for middle school science. Preinstruction student assessments indicate a range of challenges in achieving effective learning in science and the need for extensive teacher support to achieve the project's goals. Postinstructional assessments indicate positive changes in students' ability to perform target reading and writing tasks. Qualitative data indicate teachers' desire for external direction and the need for researchers to expand the literacy framework to include oral discourse. A case study of teachers' use of a specific literacy task and its influence on students revealed indications of robustness and effectiveness. Experiences

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revealed procedural difficulties and insights regarding community-based research and development approaches.

**Keywords** Science literacy · Middle school science · Literacy instruction · Embedded instruction

## Introduction

Pacific CRYSTAL is one of five *Centres for Research in Youth, Science Teaching and Learning* (CRYSTAL), a pilot project funded by the Natural Sciences and Engineering Research Council of Canada (NSERC) in 2005. While other science bodies such as the National Science Foundation (NSF) in the USA and the National Science Council (NSC) in Taiwan have a history of funding science education research, the CRYSTAL initiative is the first attempt by NSERC to influence policy and improve science, mathematics, and technology education in Canada. Each centre, funded for 5 years, has a unique focus, with Pacific CRYSTAL concentrating on science and technology literacy, particularly in the context of underserved and underrepresented populations (e.g., First Nations people, new Canadians, female students) with topics including environmental issues, weather, water, and computer engineering. Pacific CRYSTAL is a hub–spoke–node structure consisting of 15 distinct projects involving community partners, science awareness outreach providers, scientists, engineers, professors, graduate students, teachers, and students from the Faculties of Education, Engineering, and Science at the University of Victoria, Simon Fraser University, Vancouver Island University, school districts, First Nations communities, and nongovernmental agencies. The research and development plan is to (a) trial authentic learning experiences in nontraditional contexts; (b) utilize those experiences to develop innovative classroom approaches as well as school-wide applications and develop leadership within the educational system—such as lighthouse schools, and resident experts and advocates for science and technology literacy; and (c) influence education policy and practice. This article reports on one project's aims to embed explicit literacy instruction into middle school science programs to enhance science literacy and implement systemic change across a school district.

## Background

The clear connections between language and science have emerged from research (Yore et al. 2003, 1994) and continue to be the central focus of many researchers with articles in major language arts and science education research journals and special issues of education leadership, literacy and literature, and science education journals. The consistent trend across these articles has been the reaffirmation of the cognitive role that language plays in doing, learning, and reporting science and identifying specific classroom cultures and strategies to enhance science literacy. However, despite the progress that has been made, there remain unmapped connections within and between the functions of the language arts (reading, writing, speaking, listening, viewing, and representing) that distinguish the orientations of the literacy and science education communities. Despite renewed interest and progress in defining science literacy, consensus has not been reached amongst science education experts that could provide classroom-based reformers a road map for change.

## Language and Science Education Communities

Historically, language arts education has been segregated into four strands: reading, writing, speaking, and listening—with the recent additions of representing and viewing. The rationale for the separation is unclear and not easily determined. This somewhat artificial division becomes problematic in science classroom-based efforts where the uses of language are unified and when language is examined for its essential functional roles, in particular doing/learning science while enacting and fully achieving science literacy. This traditional segregation can be seen in much of the research involving language arts in science education where studies focus separately on oral discourse, reading, or writing in science classrooms with little explicit consideration of the other language arts (Yore et al. 2003). This lack of cohesiveness has been recognized and addressed in some lengthy, ongoing research programs (Gunel et al. 2007; Hand and Choi 2010; Hapgood and Palincsar 2006/2007; Magnusson and Palincsar 2004; McDermott and Hand 2008; Romance and Vitale 1992, 2006, 2008). The project reported here has taken a holistic view of language in science learning where text is the permanent representation of oral discourse and mental images and includes printed words, symbols, and visuals, acknowledging the integrative and interactive nature of science literacy and constructing understanding.

The separate theoretical foundations, priorities, traditions, approaches, and canonical knowledge of language arts and science education communities are not fully documented in the academic and professional literature, leading researchers and reformers to overlook or underestimate inherent problems in integration. Language educators have idealized goals for learning, teaching, and curriculum (e.g., National Council of Teachers of English & International Reading Association 1996) as do science educators (e.g., American Association for the Advancement of Science 1993; United States National Research Council [NRC] 1996); document analysis revealed the intersection between these standards converges on a few recurring nodes, such as *all students*, *literacies*, *constructivism*, and *authentic assessment* (Ford et al. 1997). This cross-disciplinary result suggests core competencies for discipline-specific literacy, which vary to reflect the ontological and epistemic nature of the target discipline. Our earlier projects made assumptions about background knowledge of language arts and science instruction that underestimated the awareness levels of participants and overestimated the anticipated ease of combining best practices in language arts and science education (Holden and Yore 1996; Spence et al. 1999). The current project strives to avoid these difficulties by more accurately estimating the demands on teachers with a 5-year (2005–2010) professional development effort focussed on discipline-specific language functions, metalanguage, discourse patterns, informational text, genre, modes of representation, argumentation, content knowledge, scientific inquiry, and alternative instructional approaches to achieve an acceptable end result in science literacy achievement and effective classroom practices.

## Science Literacy

Science literacy is viewed as the central goal of many science education reforms, but the construct *science literacy for all* has multiple interpretations. Ford et al. (1997) asserted from an analysis of the English language arts, mathematics, science, social studies, and technology reform documents in the USA that discipline-specific literacy involved three clusters of outcomes: first, cognitive and metacognitive abilities, habits of mind, and thinking; second, the big ideas in the specific discipline; and, third, communications. More recently, Hand et al. (2001) found that these themes were common across several English-speaking countries' education reforms. Norris and Phillips (2003) interpreted science literacy from philosophical and linguistic perspectives and identified similar features that they described as two interacting senses—the fundamental sense consisting of a classical interpretation of literacy and the derived sense consisting of understanding science. We take the fundamental sense to subsume the cognitive and metacognitive abilities, thinking, habits-of-mind, and communications and the derived sense to subsume the big ideas of science mentioned in the science reform documents. Other researchers suggest that enhancing and engaging these senses leads to participation in the public debate about STSE issues (Council of Ministers of Education, Canada 1997; Hand et al. 2001; US NRC 1996). In order to promote both fundamental and derived senses of science literacy, Yore and Treagust (2006) noted that programs needed to focus on "the roles of discourse in doing, teaching and learning science [and on] the demands on teacher education and professional development in the current reforms in language and science education" (p. 291). More recently, Yore et al. (2007) elaborated on this earlier work to define scientific literacy in terms of benchmarks, standards, and learning outcomes found in current reform documents, curricula, and literature using the fundamental and derived framework (Table 1). This model is not intended to fragment science literacy or to reignite the either/or process-product wars of the 1960s; rather, its intent is to articulate the construct somewhat more explicitly so that teachers, researchers, and curriculum developers can identify the components of science literacy. This view emphasizes the symbiosis between the fundamental and derived senses where one supplements or results in the other: knowledge and thinking, argument and the nature of science, habits of mind and scientific inquiry, information communication technologies and STSE debates, etc.; and within each sense where components are related: inquiry and understanding, design and STSE solutions, reading and writing, print and visual representations, critical thinking and habits of mind, etc. The literacy and science education research are replete with support for these associations (Yore et al. 2003). Collectively, these interactive aspects of science literacy should not only improve school science but, more importantly, promote global citizenship—the fuller and more informed participation in the public debate about STSE issues leading to justified decisions and sustainable actions.

These suggestions about the composition of scientific literacy have influenced the foci of the projects undertaken by Pacific CRYSTAL: science literacy, science education, and authentic science. Science is people's attempts to search out, describe, and explain patterns of events in the natural world where claims are based on evidence and can be generalized and where explanations involve physical causality and cause-effect mechanisms (Good et

**Table 1** Interacting senses of scientific literacy (Yore et al. 2007, p. 568)

| Fundamental sense | Derived sense |
|---|---|
| Cognitive and metacognitive abilities | Understanding the big ideas and unifying concepts of science |
| Critical thinking/plausible reasoning | Nature of science |
| Habits of mind | Scientific inquiry |
| Scientific language arts (reading, writing, speaking, listening, viewing and representing in science) | Technological design |
| Information communication technologies | Relationships among science, technology, society, and environment |

al. 1999). In this project, we treat science as a *verb*—the intellectual enterprise of constructing knowledge claims using evidence-based arguments, disciplinary conventions, traditions, and practices—along with science as a *noun*—the knowledge claims or products of these enterprises. There are parallels between design, inquiry, and problem solving; scientific, mathematical, and technological discourses; nature of science, nature of mathematics, and nature of technology; and classroom content and pedagogical-content demands on teachers in these subjects that have implicitly influenced this project.

The diversity of participants in the Pacific CRYSTAL projects provides an excellent context to derive a general consensus about science literacy. At a general level, it has been understood as knowledge about—and willingness to participate in—public debates about STSE issues, leading to informed habits-of-mind to construct understandings of science, and to inform and persuade other people to take action based on these science ideas. The articulation of the specific components of the fundamental and derived senses is less well accepted across the individual projects and researchers.

Two world-class scientists—Andrew J. Weaver, member of the 2007 Nobel Peace Prize winning UN Intergovernmental Panel on Climate Change, and Terry W. Pearson, 2004 Robert A. Wardle Award winner for contributions to Canadian parasitology—believed that writing is an integral part of modern science and that writing and inquiry were interrelated and recursive in building scientific arguments based on evidence (Yore et al. 2006). Yore et al. (2003) noted that "language is an integral part of science and science literacy—language is a means to doing science and to constructing science understandings" (p. 691). They added that "language is also an end in that it is used to communicate about inquiries, procedures, and science understandings to other people" (p. 691). Such a view posits mathematics—traditionally viewed as the language of science—as only one of the languages of science because "spoken and written language is the symbol system most often used by scientists to construct, describe, and present science claims and arguments" (p. 691). Similar interpretations about the essential role of literacy in science literacy involving discourse, argument, text production and interpretation—writing, visual representations, and reading—are apparent in experimental and commercial science and literacy resources, for example, *Seeds of Reading/Roots of Science* (Regents of the University of California 2008) and *National Geographic Theme Sets* (National Geographic School Publishing [NGSP] 2008). These instructional resources provide thematic textual materials with common content at different levels of reading demand, which could be used to supplement inquiries into the conceptual topic. Furthermore, these texts design opportunities for focused vocabulary development and explicit reading comprehension, visual literacy, genre awareness, and writing instructions and tasks. The NGSP resources align with many science topics addressed across the science education system in upper elementary and middle schools and support constructivist approaches (e.g., modified learning cycles, jig saw cooperative learning, etc.).

## System-Wide Reforms, Professional Development, and Language Strategies in Science

In addition to professional development, state, urban, and local systemic changes in standards-based environments and the roles of local administrators in such projects are emerging fields of inquiry (Banilower et al. 2007; Hewson 2007; Kahle 2007; Klentschy 2006; Klentschy and Maruca 2006; Supovitz and Turner 2000). The results of systemic change projects have not been well documented with published evaluations. However, the limited literature, conference reports, and unpublished documents indicate varied but positive links amongst high-quality resources, high-quality professional development, and desired classroom practice and also inconsistent and weak links between these factors and student achievement. System-wide change sounds like a reasonable alternative to the piecemeal approaches used in the past, but systems-based implementation may be too idealistic and poorly understood to be effective (Huffman and Lawrenz 2003).

Several aspects of the Pacific CRYSTAL initiatives have been explored in large, well-funded projects reported elsewhere. Romance and Vitale (1992) pioneered the integration of language arts and science instruction by combining the instructional times for reading and science into 2-hour daily blocks using a science textbook program (Science IDEAS), which provided explicit instruction on reading strategies and engaged students with trade books and other informational texts to supplement science inquiries. The results revealed that Grade 4 students participating in Science IDEAS demonstrated significantly higher reading scores, science scores, attitudes toward reading, and self-confidence in learning science than similar students participating in separate reading and science programs. They (2006, 2008) are currently exploring systemic applications and scaling Science IDEAS activities to all middle schools of two very large school districts to determine if the instructional model is robust and if it produces similar local systemic changes across a wider variety of grade levels, teachers, and classrooms.

Science–Parents, Activities, and Literature (Science PALs), a 3-year teacher enhancement project, addressed the use of children's literature and trade books in science inquiries across all elementary schools in a school district (Shymansky et al. 2000). Children's literature was used as a springboard into inquiry, introducing topics and engaging students in science modules and informational text to elaborate and enrich ideas explored in the inquiries that used an interactive-constructivist learning cycle (engage–explore–consolidate–assess). The professional development was progressive and utilized a cascading leadership model focusing on two lead teachers (advocates) from each of 16 elementary schools (one each from the K-2 and 3-6 levels) in the first year and increasing the participation to volunteers from all grade levels in Years 2 and 3 with the advocates taking greater leadership. Program evaluations revealed that students, parents, and district administrators believed the professional development facilitated the adoption of interactive-constructivist teaching ideas, the implementation of science inquiry approaches, a strengthening of school-home connections, and an improvement in student attitudes toward science (Yore et al. 2005). Supervisor ratings indicated that the participating teachers internalized the professional development and utilized overall constructivist teaching practices in their classrooms (Shymansky et al. 2004).

The Missouri-Iowa Science Cooperatives (Science Co-op) scaled the basic principles and procedures of Science PALs to a multidistrict approach (46 small or rural districts spread over 40,000 square miles) utilizing summer workshops, local meetings, project-wide meetings, and weekly interactive video programs supplemented with web-based resources and local support to implement the second-generation, NSF-sponsored science modules enriched with literacy and assessment activities into elementary and middle schools (Shymansky et al. 2002). Science PALs features utilized across Science Co-op included the National Science Education Standards (National Academy of Sciences 1996), children's misconceptions, the interactive-constructivist learning cycle, science advocates, and a cascading leadership approach to decentralize decision making and transfer ownership. Capsule ratings by the external evaluator over the 5 years indicated that the professional development activities were judged to be high quality. Random samples of teachers interviewed annually and biannual observations of teachers' classroom practices confirmed these claims (Shymansky et al. 2008). Teacher surveys indicated that teachers on the whole were teaching more lessons per week for longer times but on fewer topics using the inquiry modules.

The Valle Imperial Project in Science (VIPS) explored the teacher and student effects of a comprehensive professional development and integrated inquiry science and literacy activities program involving science notebooks (Klentschy and Molina-Da La Torre 2004). Students used science notebooks to record their inquiry experiences, collect and interpret data, process and reprocess experiences, mental images, and representations; and document construction of ideas in writing (Klentschy 2005). Results revealed (a) significant differences between VIPS participating students and non-participating students, with significant improvements in Grades 4 and 6 science achievement (Stanford Achievement Test, 9th ed.) and in Grade 6 writing (District Writing Proficiency Test), and (b) the performance gaps in reading, writing, and science between native English language students and English language learners narrowed and became nonsignificant after 5 years of participation (Amaral et al. 2002; Klentschy et al., n.d.).

The Science Teacher Enhancement Program unifying the Pikes Peak Region (STEP-uP) focused on implementing second-generation, NSF-sponsored inquiry modules and on reflective practice, content knowledge, and teacher leaders across five participating school districts (Revak and Kuerbis 2008). The fundamental instruction approach involved a modified learning cycle (invite, discover, elaborate, action, assessment) that was used to plan and deliver the professional development and science notebooks, integration of literacy and science, graphing in science, and integration of mathematics and science. Primary and secondary reading sources were used and mathematics skills were infused into the science inquiry modules to establish interdisciplinary connections among language arts, mathematics, and science. The relationships between STEP-uP professional development and student achievement and between teacher beliefs, classroom practice, and student achievement were examined using statewide student test results. No significant correlations were found for total number of hours of professional development and Grade 5 test scores for 2004. However, significant differences with small to medium effect sizes were found for students of teachers who had specific professional development and teachers who did not have such professional development in the 2006 test results in mathematics, reading, science, and writing. Revak and Kuerbis continue to work on documenting the educational productivity of their STEP-uP efforts by modeling quality, quantity, and placement of inquiry instruction during students' school experience on academic performance.

Klentschy (2005) emphasized that professional development in science and literacy should target teacher practice, be site-based, long-term, and collaborative, and focus on student learning and the actual curricula. Effective professional development changes the culture of teaching to a knowledge-based professional practice that allows teachers to reflect on and respond to the variety of instructional issues faced in today's classrooms. Professional development in science literacy education can be costly and labour intensive, and difficulties can arise in scaling programs to system-wide adoption, as well as in building leadership capacity. Assumptions about the participating teachers' understanding of learning, proficiencies with inquiry teaching strategies (planning, questioning, resources, classroom management, etc.), expertise with creating and interpreting informational text, and knowledge of scientific discourse can also lead to significant problems. Advocates (lead teachers) are the lasting legacy of many professional development projects as they continue to promote science education in their schools long after the formal projects end. Furthermore, little work has been done on how these projects influence policy makers and instructional decisions and the lasting effects on educational productivity—the relationships amongst quantity, quality, and time placement of instruction on student performance and school effectiveness (Yore et al. 2009). The professional development project discussed here attempts to address these demands and barriers to implementing literacy and science approaches and strategies. The distinguishing features of this project are its holistic approach to language in science, the symbiotic relationship between the fundamental and derived aspects of science literacy, a district-wide desire for systemic change for middle school science instruction, a community-based, research and development approach to the project, and an emphasis on building capacity and leadership within middle schools in the host district.

## Design and Methods

Explicit Literacy Instruction Embedded in Middle School Classrooms was initiated in the spring of 2005 upon the request of a small group of teachers from two middle schools in a local school district. Early negotiations connected these teachers with researchers from Pacific CRYSTAL, and they collaboratively outlined a focus and agenda for the project. This preliminary collaboration revealed that an engineering research and development approach would be more appropriate than a typical scientific research inquiry approach. The technological design (identify opportunity/need, design, trial design, evaluate and revise design) approach afforded greater flexibility and allowed capitalization on opportunities occurring during the project. The project has progressed along several dimensions: ongoing assessments of needs, problem solving, designing solutions, and evaluating preliminary designs by conducting focus groups, monitoring of baseline data that consist of repeated measures of student beliefs, attitudes, and strategies in relation to science literacy, school-level assessments of general reading and writing performance, and embedded case studies of classroom practices, teacher reflections, and student performance. These data were used to identify needs, monitor and inform the professional development agenda, and evaluate instructional strategies and literacy tasks.

Key motives for this collaboration were the needs of and opportunities and constraints provided by the middle school communities: the context of middle schools implementing a new science curriculum using new instructional resources, the increased visibility of literacy across the curriculum as school-wide goals, the recognition of the literacy component in science literacy, and a disparity in students' narrative-based and expository-based language arts performance. A community-based approach involving shared authority and responsibility to identify needs, concerns, problems, and resources and to seek solutions was used to plan the research and professional development activities. This meant that the school district, the schools, the teachers, and the Pacific CRYSTAL staff shared funding, preparation, and delivery of professional development opportunities as well as identification and measurement of the target outcomes and variables. The emerging project in Years 1 and 2—entailing professional development for 20 science teachers in two middle schools and involving students in Grades 6, 7, and 8—was intended to address science literacy and to enhance students' discourse abilities, literacy strategies, and conceptual understanding in science. Teachers at a third middle school in the local school district voluntarily joined the project in Year 3.

Focus group results, which are an essential component of community-based approaches, identified successes, areas needing further attention, and additional problems related to middle school science literacy of all students. Early focus group results identified content knowledge and pedagogy for the new curriculum and textbooks, integration opportunities for embedded literacy tasks, and concern about full inquiry's demands on preparation, instructional time, and available resources. Early on in the collaboration, the CRYSTAL team prepared an analysis of the new Grades 6, 7, and 8 science curricula (British Columbia

Ministry of Education [BC MoE] 2005, 2006) and textbook programs in use to identify specific literacy demands as well as opportunities to embed explicit literacy instruction. It was apparent that teachers wanted supplemental resources for their science programs as well as experience with an inquiry-based instructional framework. Some of the topics in the National Geographic Theme Sets (NGSP 2008) corresponded with the content in Grades 6, 7, and 8; the aligned materials were purchased for each school. These materials provided a working framework around which to build and embed explicit literacy activities into existing science programs (Table 2). The analyses of each curriculum topic identified specific vocabulary, reading comprehension, and visual literacy strategies and genre writing activities that could introduce and provide practice in specific science literacy skills.

This opportunistic approach was used to (a) identify the literacy targets and opportunities afforded by the science programs, topics, and resources; and (b) determine specific opportunities and tasks to be addressed in the curriculum. Early informational sessions and workshops were intended to develop trust and to examine specific textbooks and topics. The fall term was devoted to three textbook series (English- and French-language) that related to the 2005 BC Science Instructional Resources Packages (IRPs): *BC Science Probe* (Nelson Education 2005a, b, 2006), *BC Science* (McGraw-Hill Ryerson 2004a, 2005, 2006), and *Colombie-Britannique Sciences* (McGraw-Hill 2004b). Once topics were identified, specific learning outcomes, science concepts, and vocabulary were identified from the IRPs and textbooks. The National Geographic Science Theme Sets (NGSP 2008) that were used as models to establish the instructional framework were also used, where appropriate, as supplemental resources. The explicit connections between the day-to-day demands of science instruction and the theoretical foundation made this approach very practical and classroom based.

There has been a sequence of 14 professional development activities over the first 3 years of the project, 10 in Years 2 and 3. The organization of topics and content for the workshops has remained consistent with the framework in Table 2, which has lent a sense of coherence to the series. The professional development agenda has reflected ongoing negotiations with the participating teachers and schools to capture their needs

**Table 2** Framework for explicit literacy instruction (adapted from NGSP, 2008)

| Vocabulary/concept development | Reading comprehension strategies | Visual literacy focus | Science reading and writing genres |
|---|---|---|---|
| Topic-specific concept words | Determining importance | Labeled diagram | Information pamphlet |
| Opportunities for general strategies such as defining words from context, using combining forms and root words for understanding, etc. | Synthesizing | Labeled photograph | Pro-con article |
| | Visualizing | Cross-section diagram | Explanation |
| | Making connections | Flow diagram | Cause-effect |
| | Questioning | Cutaway diagram | News report |
| | Inferring | Weather map | Problem-solution |
| | | Resource map | How-to book |
| | | Photo montage | User manual |
| | | Satellite image | Feature article |
| | | | Encyclopedia entry |

and goals while carrying forward the intentions of the Pacific CRYSTAL project. These negotiations have established trust and shared understanding amongst the project participants (administrators, teachers, university staff). Flexibility within the research and development approach and constant monitoring with classroom observations and teacher interviews suggest progress toward a literacy-infused science program (Tippett et al. 2008).

## Monitoring and Evaluating

Monitoring and evaluating were varied and ongoing during each part of this project in order to inform the professional development efforts and assess instructional applications. Starting in the fall of 2006, baseline student assessments were collected using a revised version of the Inventory of Science Reading Awareness (ISRA, Yore et al. 1998) to assess students' metacognitive awareness of declarative, procedural, and conditional knowledge about science reading, science text, and science reading strategies. The schools conducted the Direct Assessment of Reading Tasks (DART) to collect performance data on students' reading ability based on a specific information text and the school-wide write (SWW) to assess students' ability to write in a specific genre. Interpretations of the fall 2006 and spring 2007 results were used only to identify areas for consideration, and comparison of the fall-spring changes were used to establish general trends in informational reading and writing for future considerations.

Data collection is ongoing. The DART and the SWW are administered biannually as part of the district's regular assessment program, and those measures provide quantitative data. Qualitative data in the form of classroom observations, student work samples, and teachers' reflections are collected as part of the ongoing professional development project and are used to inform practice, illustrate assessment demands, and evaluate effectiveness of teaching approaches. A case study consisting of teachers' reflections, usage, informal classroom observations, students' performance, and interviews was conducted on a specific literacy strategy—creating brochures—to provide in-depth insights into instructional applications of literacy tasks.

## Quantitative Results

Although comprehension and creation of informational text were described as weaker than the same skills in a narrative format, the ISRA (Yore et al. 1998) indicated surprisingly good performance on metacognitive awareness of science reading, science text, and science reading strategies when compared to results for students from three other school districts assessed with the same instrument in previous studies (Holden and Yore 1996; Spence et al. 1999; Yore and Holden 2005). However, specific areas for growth were identified for explicit instruction, including comprehension of informational text. Baseline data were provided by Year 2 results for the fall and spring district-wide DART and SWW (Tables 3 and 4). General growth patterns in both the DART and SWW data indicate majorities of students moving from *below and minimal* categories toward *satisfactorily meets*, *fully meets*, and *exceeds expectations* categories over Year 2, as would be anticipated with a regular program of instruction. These results provide the benchmark results for the regular school program. The data were used to inform the current project and will allow an evaluation of results in Year 5.

**Table 3** Descriptive results for direct assessment of reading tasks (DART)

| Scoring category | School 1 (*N*=~400) | | School 2 (*N*=~420) | |
|---|---|---|---|---|
| | Fall | Spring | Fall | Spring |
| Below expectations | 15% | 4% | 14% | 4% |
| Minimally meeting expectations | 41% | 25% | 36% | 23% |
| Satisfactorily meeting expectations | 19% | 26% | 31% | 34% |
| Fully meeting expectations | 23% | 37% | 16% | 31% |
| Exceeding expectations | 2% | 8% | 3% | 8% |

## Qualitative Results

The number of participating teachers decreased from 20 in September 2006 to 15 in June 2007, but end-of-year transfers resulted in teachers at the third middle school becoming involved for Year 3 of the project. Year 3 teacher participation has been variable ($n=5$ to 19) with different groups of teachers attending the six workshops held to date. The variation is due in part to competing priorities within the school districts and schools, retirements, maternity leaves, staffing changes, and the relocation of one school. These key participating teachers (advocates) are required to be away from their classrooms for other responsibilities and leadership roles. Therefore, their participation in this project has been uneven. Professional development workshops moved from teacher-directed to researcher-directed at the request of participants. Participating teachers requested professional development efforts focused on the new curriculum, content, and textbooks as well as literacy strategies and activities.

In British Columbia, middle schools (including Grades 6–8 or 6–9) are reasonably new organizations replacing junior secondary schools in some school districts. Few universities have offered a middle school teacher education program; therefore, most current middle school teachers may have generalist training in elementary education (Kindergarten through Grade 7) or they may have specialist training in particular secondary education subjects (Grades 8 through 12). In addition, middle school teaching assignments in the host school district for this project range from general (teaching most subjects to a single group of students) to subject specialization (teaching one or two subjects to a number of different classes). Initially, it had been anticipated that most participating teachers would be science specialists. However, our experience has been that generalist teachers who teach science as one part of their overall responsibilities have been more interested in the project, with most

**Table 4** Descriptive results for school-wide write (SWW)

| Scoring category | School 1 (*N*=~400) | | School 2 (*N*=~420) | |
|---|---|---|---|---|
| | Fall | Spring | Fall | Spring |
| Below expectations | 21% | 9% | 15% | 7% |
| Minimally meeting expectations | 49% | 25% | 36% | 18% |
| Satisfactorily meeting expectations | 3% | 26% | 34% | 38% |
| Fully meeting expectations | 22% | 29% | 14% | 27% |
| Exceeding expectations | 5% | 8% | 11% | 10% |

of the participating teachers being classroom generalists rather than science specialists. While the generalist middle school teachers agreed strongly on the need to focus their instruction more explicitly on the languages of science and for students to have multiple opportunities to interpret and construct science texts, they struggled to devise classroom activities to address these needs. These generalist teachers sought ongoing collaborative support to plan, implement, and reflect on the effectiveness of specific literacy tasks and instructional processes in enhancing science literacy. Project support was provided through demonstration lessons at teacher workshops and in participating classrooms (concept mapping, found poetry, CSI Chemistry—separating mixtures, etc.) and through the development of instructional materials (e.g., PowerPoint® instructions for teaching about labelled photographs, flow diagrams, main idea, informational posters, and other embedded literacy tasks or strategies) using available classroom materials. The more experienced advocates in each middle school directed the identification of possible topics and encouraged their colleagues as we collaboratively developed these topics, tasks and strategies. The few middle school science specialist teachers in the district have appeared less convinced of the need and value of the proposed model of science literacy and instructional approaches, choosing not to participate or discontinue their participation in the program of professional development offered through this project.

## Case Study Results

The emergent opportunistic approach to exploring literacy instruction in science classrooms of this project required the documentation, analysis, and reflection on sometimes unexpected events, as is revealed by the circumstances leading to this case study. During Year 2, visual literacy strategies became a focus of several workshops. The CRYSTAL team prepared several powerpoint slide sets designed for classroom use by the teachers when teaching aspects of visual literacy. In subsequent workshops, teachers requested support with assessing students' multimodal work and, in particular, for informational posters that combined print with visual elements to represent science understanding. Teachers expressed uncertainty about assessing this representational genre, which encouraged embedding visuals and print and required summarization of main ideas with supportive detail. The CRYSTAL team drafted an evaluation rubric consistent with the powerpoint teaching resource for informational posters that teachers adapted during workshop sessions. Two teachers then further modified the poster criteria and the rubric to fit an upcoming assignment in which students were expected to design a powerpoint presentation, an opportunity afforded by the recent access of laptop computers and CD projectors for their classrooms. This willingness to consider multimodal genres as an alternative to the more typical science report provided an opportunity to explore the use of other representational genres such as informational brochures.

The sequence of collaboration between the classroom teachers and the CRYSTAL team resulted in extensions of the initially identified support that demonstrates several key features of community-based professional development, resulting in classroom instruction in the creation and interpretation of informational brochures. This new form of multimodal text became the basis for a case study of the efficacy of this genre for science and literacy learning. Questions guiding this case study were:

1. How does the creation of informational brochures impact the subsequent comprehension and interpretation of novel science concepts that are presented in a brochure format?

2. How effectively can students demonstrate their understanding of science concepts using the brochure format?
3. Does the brochure format allow all students to access and represent information, regardless of academic ability?

A mixed-methods approach was utilized because a blend of qualitative and quantitative approaches matched the problem space in which some aspects were well developed, allowing quantitative considerations, while others were less well defined, requiring qualitative considerations (Yore et al. 2009). Qualitative data sources included classroom observations, teacher focus groups, semistructured questionnaires, and student work samples; quantitative data were obtained from a quasi-experimental comparison using a nonrandomized, treatment-comparison groups, posttest-only design.

The case study participants were the eight participating Grades 6, 7, and 8 teachers who attended the workshop on brochures as a writing-to-learn science strategy. These teachers all had generalist training and most taught a range of subjects to a single class of students. The workshop began with an examination of commercial brochures to identify critical design principles and then teachers worked in grade-level groups to create brochure templates, either electronic or print-based, that their students could use in an upcoming activity. Finally, a scoring rubric for informational brochures was developed by adapting the original rubric for informational posters. Initial response to the strategy was positive with all teachers at the workshop stating that they planned to use brochures in their upcoming science instruction.

By the conclusion of the case study, six (75%) teachers had implemented the brochure strategy with seven classes across two grades. During classroom visits, teachers were observed introducing the brochure activity and students were observed in the process of creating brochures; visits were not made to all classes due to scheduling conflicts. Collected artefacts included samples of students' rough drafts and finished brochures; teachers completed a semistructured questionnaire on the effectiveness of the strategy. Non-randomized treatment and comparison group posttests were conducted on the reading and conceptual effects of a brochure. Teachers asked students to read a specially created brochure on bridges, a topic not included in the BC science curriculum for Grades 6, 7, or 8, and then answer ten questions (multiple choice and short answer) based on the information contained in the brochure. Results from classes that had participated in the brochure activity were compared with results from classes who had not yet created their own brochures.

The comparison revealed that classes in which students had the opportunity to produce brochures tended to score higher on an assessment measure than classes in which students had not yet created their own brochures (see Table 5). The quiz consisted of ten questions which ranged from multiple choice to short answer, and included questions that could be answered directly from print information, from information presented in visual form (graphs and diagrams), or by making inferences from the information provided. In 28 out of 30 comparisons, Grade 7 classes who had created brochures scored as well as or better than Grade 7 classes that had not created brochures, indicating that the brochure activity may have a positive impact on fundamental scientific literacy. Due to differences in class composition, including number of students with identified learning needs and general student achievement, these results can only be taken as an indication of the benefits of creating informational brochures, However, in classes where students had not had the opportunity to create their own brochures, there was obvious confusion about how to read the brochure on bridges; in classes in which students had created their own brochures, there were no questions about how to read the brochure. Students who had not created brochures were faced with the simultaneous challenge of learning *how* brochures function while attempting to comprehend

**Table 5** Number of students correctly answering questions on information contained in a brochure

| | Students | Quiz question number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | (*N*) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Class A | 21 | 20 | 20 | 20 | 20 | 10 | 16 | 17 | 18 | 11 | 21 |
| Class B | 21 | 21 | 20 | 21 | 19 | 11 | 18 | 17 | 19 | 9 | 21 |
| Class C | 21 | 18 | 20 | 20 | 18[a] | 9[a] | 15 | 19 | 21 | 10 | 21 |
| Comparison class | 21 | 18 | 18 | 19 | 19 | 10 | 15 | 16 | 18 | 8 | 21 |

[a] Results were lower than those of the comparison class

information contained in a brochure format. Students who were familiar with the genre appeared to be able to focus on the information, thus using a fundamental aspect of science literacy (reading in science) to learn a derived aspect (science content).

Results of the case study indicated that the informational brochure strategy was both engaging and effective across a variety of students. The six teachers who employed the strategy reported that students completed their brochures enthusiastically, with an unusually high percentage of homework assignments handed in on time. Students with a wide range of learning needs were able to produce brochures that met the criteria for the assignment. Student work samples indicated that students were able to represent information in creative ways. The completed brochures also indicated differing levels of understanding of science concepts, and teachers deemed those levels as consistent with or exceeding their expectations based on previous student work.

Students creating brochures to demonstrate their scientific understanding appears to be a robust strategy that could be adapted to meet the needs of teachers and students and that could be used with a range of science topics. Teachers were able to adapt the activity to match their personal teaching approaches and at the same time accommodate the learning needs of a diverse group of students. Several teachers incorporated information communication technologies (ICT, a fundamental aspect of scientific literacy) into their instruction, utilizing readily available software, such as brochure templates, graphing packages, clip art, and drawing programs. Students at all ability levels were able to successfully create brochures. Because the writing area was restricted to six small working spaces, the task was not perceived as overwhelming. In addition, support was readily available in the form of ICT resources so that even students with significant learning needs were able to successfully complete brochures on their assigned topics. The brochure activity was used with a variety of prescribed curriculum topics including earthquakes, sustainable ecosystems, and energy.

The brochure format enables students to demonstrate their understanding of science concepts in a written format that requires higher-level thinking processes, such as synthesis of information. The brochure format also provides an opportunity for students to engage in critical reading and writing; space restrictions mean that only main ideas and supporting details can be included, thus avoiding the *tell all* approach typical of less mature writers, and that words and images must be carefully selected and integrated to convey information in an efficient manner. An inspection of the students' brochures revealed frequent use of visual images in decorational, representational, and organizational functions (Carney and Levin 2002). The images were not always well embedded in the written text with explicit connections between visuals and words, but some brochures revealed that students were aware of the representational power of combining print and visuals for this assignment and other opportunities.

The initial collaborative goal of including some explicit instruction of visual strategies was realized in an expanded repertoire of visual literacy instruction and evaluation that was stimulated by the instructional models prepared by the CRYSTAL team and were then modified and expanded by the classroom partners. The benefit not only enriched instruction and evaluation, but it also appears that when middle school students participate in an authentic science writing task, such as creating brochures, they are highly motivated. As a result, students are able to design personalized and creative artefacts that indicate an understanding of the brochure format as well as of the science topics described in those brochures.

The process of creating informational brochures incorporates critical literacy strategies such as detecting main ideas, writing summaries, and combining visuals with print to enhance meaning and increase comprehension. These tasks, which require the transformation of ideas across two or more modes of representation, appeared to increase students' subsequent procedural comprehension of informational brochures, as indicated by the results of the quiz. The process of creating a brochure was not only doable by a range of students but it provided students with special needs or lower ability greater access to demonstrating their knowledge of science. For teachers, what began as an exploration of using visuals and print in the production of posters became modified to include the use of electronic templates and the diversification of posters into powerpoint and then further into brochures. A student who subsequently participated in a science fair created an informational poster for her exhibit as well as providing judges and visitors with an informational brochure demonstrated the naturalness of this diversity of application. The participating teachers—and other teachers who became aware of these mixed-media approaches to learning and reporting—have applied these *science* literacy tasks in other contexts: social studies, art, and other curricular areas.

## Implications and Closing Remarks

The experiences that arose from Years 1 and 2 have directed the reformulation of our goals and expectations for Years 3 and 4. We have become much more aware of the complexity of implementing curricular change in a school-based collaborative project, especially the receptivity of science specialists and the needs of generalist teachers. Changes in teaching assignments and personnel have brought new participants to the project and removed other key players. The cycling of participants has caused some delay in building the rapport and confidence necessary to implement the instructional innovations envisioned by the research team, but this cycling also extended the reach of the project to many more teachers across the participating schools. Furthermore, these unexpected changes revealed the dynamics of administrative and teaching staff and foreshadow the difficulties of reaching steady state for staff development, building leadership capacity, and saturated implementation of the target innovations in schools.

Informal observations and teachers' self-reports indicate that some literacy tasks initially proposed by the project team at teacher workshops were adaptive and appropriate to various abilities and grade levels. As the partnership between teachers and the project team developed, collaboration between the team and the teachers enriched the classroom instruction. For example, teachers were not satisfied with the initial use of informational posters as a representational genre because of the difficulties they encountered while assessing the posters. This dissatisfaction resulted in a request to the project team for professional development (authentic opportunity) focussing on creating scoring rubrics. The rubric created for informational posters was accompanied by a powerpoint presentation that could be used with students when discussing poster criteria. As some teachers incorporated new ITC equipment (laptop computers and digital projectors) into their teaching, they adapted the now more robust strategy of using informational posters to demonstrate science understanding. The result was the development of another multimodal genre (powerpoint slides) that students could use to represent their learning. Subsequent adaptations involving charts, diagrams, flow charts, and graphs led to the need for further scoring rubrics; and the interactions between teachers and the project team around the generation of scoring rubrics clarified the essential elements of texts consisting of print and visual adjuncts. These negotiations led to the use of multimodal reports as legitimate alternatives to traditional written science reports and to develop much deeper understandings of the distinctions between decorational and informational (representational, organizational, interpretational, and transformational) visual adjuncts (Carney and Levin 2002).

These tasks (posters, powerpoints, and brochures) required connection between print and visual text and offered the transformation of ideas across modes of representation. Research on multiple representations indicates that this transformation is likely to increase the depth of processing and understanding of information (e.g., Ainsworth 2008; Hand et al. 2001). We propose that the fundamental and derived aspects of science literacy interact as multiple representations are created and as visual elements are embedded in print, resulting in enhanced conceptual understanding from the explicit connections and relationships amongst representations. This proposition provides the critical foundation of our future multiple representations research and application. Moreover, the participating teachers and other teachers who became aware of these mixed-media approaches have applied them to other disciplines. Instructional possibilities that were first introduced to participating schools as a science literacy activity were later seen expressed as discipline-specific literacies in social studies, art, and other curricular areas.

The original time frame and design plan for this project did not fully reflect the negotiations, implementation difficulties, changing priorities in schools, or the range of other demands on concerned/involved teachers' time, abilities, and energies. Community-based research and development projects must be based on mutual trust and common understandings and goals. Early efforts to move science instruction toward an inquiry-oriented approach with embedded language tasks and explicit literacy instruction was not a shared goal. Negotiations during Year 1 resulted in the professional development focussing on the new curriculum and on the newly adopted textbooks, with literacy being moved into the background and inquiry-oriented teaching not appearing on the agenda at all. Demands arising from the implementation of new science units, an inquiry teaching approach, and explicit strategy instruction were underestimated by the research team. The foundational premise of the compatibility of the fundamental and derived senses of science was not familiar to the participating teachers. Informational reading strategies were not part of most language arts and science programs when these teachers obtained their teaching credentials. Time was needed to promote a contemporary interpretation of science literacy, to supplement science activities with a range of informational resources, to utilize effective oral discourse, discussions, and argumentation in science, and to implement explicit literacy strategies for scientific discourses and texts that are embedded in science instruction.

Many contextual factors required that long-term plans be revised. British Columbia Ministry of Education and district directives regarding other curricular areas combined with staffing practices forced reordering of project priorities. Too frequently, participating teachers were reassigned to other schools and given other priorities. The leadership capacity in all schools was limited because of these competing demands on staff, and adjustments had to be made repeatedly to reflect these limitations. Therefore, we have grown to appreciate the potential legacy and importance of lead teachers (advocates) in the cascading leadership model that we adopted, which predicts a shift in control and responsibility from project staff to the advocates in each school as the project progresses and leadership capacity unfolds. Furthermore, it became obvious that estimating the costs of systemic professional development was difficult because of changes in both teaching and administrative staff, including the hiring of new teachers who were interested in joining the project, and because of the increased costs of substitute teachers (teachers-on-call) as key staff require release time from their regular assignments.

One further concern that surfaced during the last 3 years was the influence and limitations that the procedures for institutional ethics approval have on community-based, design experiments (Anthony et al. 2009). The cascading leadership model and community-based research and development utilized an opportunistic and responsive approach that made it very difficult to anticipate data collection and ethics consideration involving *a priori* approval for specific tasks, information, uses, and informed consent of teachers, students, and parents. The lag time between the emergence of opportunities to collect information and the ethical approval for the retrieval of evidence resulted in the loss of data. For example, we were required to rely on teachers' retrospective recollection of the implementation of instructional enrichment, even though researchers were present in the classroom with the student artefacts before them but not able to collect these samples for later use. It was necessary to avoid taking advantage of several unanticipated opportunities and to request revisions to the ethics approval certificate in many other situations.

In the dissemination stage (Years 4 and 5), we intend to focus greater attention on the development and support of lead teachers. This will require identification and steady involvement of three or more teachers from each middle school representing all grade levels and English and French programs and also the transfer of leadership for professional development activities to these lead teachers. In addition, we have been asked to return to our earlier goal of identifying baseline and annual gains in the school measures of reading (DART) and writing (SWW) relative to the normal gains made by middle school students in the unenriched program. We have yet to disentangle the gains in the participants' classrooms to determine any advantages demonstrated over the normal programs and other contextual variables. Our participating teachers and schools now share the project team's interest in better defining and measuring the dimensions of science literacy, including the use of multiple representations, which have been the focus of the implementations so far.

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