Pacific CRYSTAL Centre for Science, Mathematics, and Technology Literacy: Lessons Learned

Larry D. Yore, Eileen Van der Flier-Keller,
David W. Blades, Timothy W. Pelton
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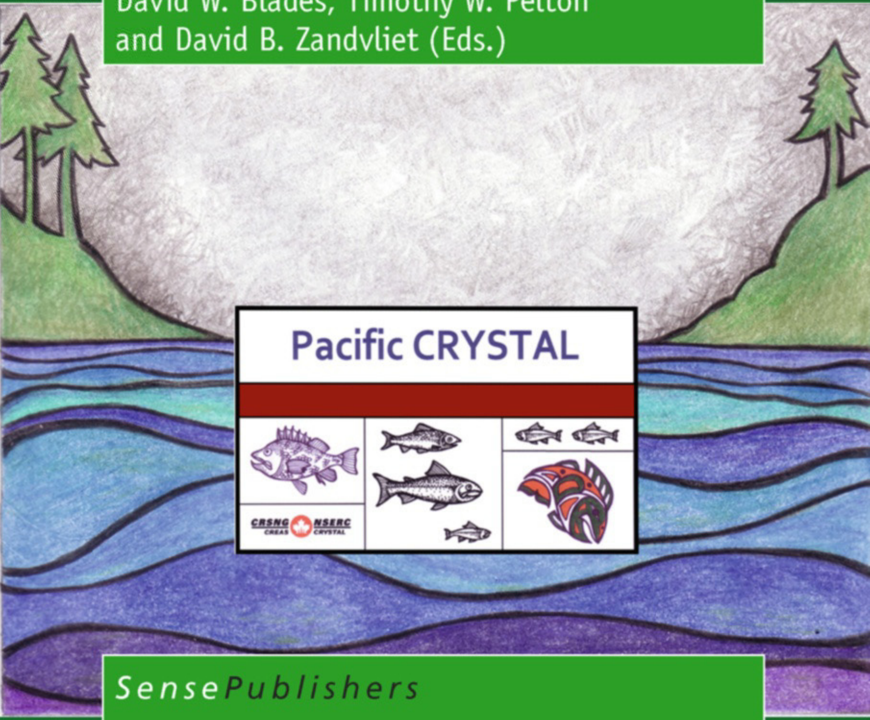

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I. OVERVIEW, COMMON THEMES, AND THEORETICAL FRAMEWORKS

LARRY D. YORE AND EILEEN VAN DER FLIER-KELLER

1. PACIFIC CRYSTAL CENTRE FOR SCIENCE, MATHEMATICS, AND TECHNOLOGY LITERACY: LESSONS LEARNED

Overview

The Centres for Research in Youth, Science Teaching and Learning (CRYSTAL; Natural Sciences and Engineering Research Council of Canada [NSERC], 2009) were funded by NSERC as a 5-year pilot project (2005–2010) to foster science and mathematics education research and development (R&D). These five Canadian centres (see Notes) focused on science, mathematics, and technology (SMT), including engineering and computer science, in response to the widespread and growing recognition that the SMT literacies are vital skills in the 21st century economy. CRYSTAL has provided a forum for the many partners who share an interest in developing and enhancing the skills of and resources available to teachers, nongovernmental agencies, and public awareness educators and in enriching the SMT preparation of young Canadians. The CRYSTAL projects have attempted to:

- improve understanding of the skills and resources needed to enhance the quality of science, mathematics, and technology education (K–12), and
- improve understanding of the best ways to enrich the preparation of youth in these foundation subjects.

The five interuniversity and interdisciplinary centres are composed of one or more universities and colleges, faculties of education, science and engineering, local community partners, and nongovernmental agencies. Partners and agencies were recruited from user groups that focused on the public awareness of SMT, First Nations, informal learning environments, public and private schools, and ministries of education.

CONCEPTUAL FOCUS AND ORGANIZATION OF PACIFIC CRYSTAL

Pacific CRYSTAL consisted of a partnership of universities (University of Victoria, Simon Fraser University, and Vancouver Island University [formerly Malaspina University College]), faculties within the universities (Education, Science, and Engineering), British Columbia school districts on Vancouver Island and the Lower Mainland, First Nations (Saanich First Nations including Tsartlip and Tsawout), and nongovernmental agencies (Canadian Geological Foundation, Centre for Excellence in Teaching and Learning Science, Constructivist Education Resources Network,

L. D. Yore et al (Eds.), Pacific CRYSTAL Centre for Science, Mathematics, and Technology Literacy: Lessons Learned, 3–22.

EdGEO, Victoria Foundation, SeaChange, and WestWind SeaLabs). Pacific CRYSTAL examined ways to improve SMT teaching and learning in elementary, middle, and secondary schools by building on Canada's successful foundation, as demonstrated by recent (2003, 2006, 2009) general mathematics and scientific literacy performances on the Programme of International Student Assessment (PISA; Organisation for Economic Co-operation and Development [OECD], n.d.). General SMT literacies are focused on citizenship and active participation in society. Improving SMT literacies among youth as a whole helps address access and equity issues and increases the supply of students qualified for and interested in science, mathematics, engineering, and technology programs at postsecondary levels, thereby addressing the higher-level elite literacies related to SMT careers and the needs of the provincial, national, and international economies.

Pacific CRYSTAL and its projects emphasized research inquiries that develop and evaluate knowledge about SMT literacies, underserved and underrepresented peoples, and science and technology fields including biology (ocean ecosystems, botany), environmental science, earth science (weather, climate, geologic history, plate tectonics, natural hazards, resources), chemistry (water quality, qualitative and quantitative analyses), computer science (problem solving, graph theory, foundation concepts, programming, robotics), and mathematics (data displays, probability, geometry) in Years 1–3 (2005–2008). Greater emphasis was placed on education, professional development, and leadership for teachers, wider implementation, dissemination and outreach activities to influence public policies, education and curricular decisions, classroom practices, and instructional resources in Years 4–5 (2008–2010). A no-cost extension request was approved to complete ongoing projects, finalize resources, disseminate outcomes, and influence policy makers (Year 6, 2010–2011). Over the duration of the project, the participants changed (~30%) as projects were completed and graduate students finished their research programs. As well, the focus of the Centre and projects morphed to meet changing emphases and interpretations of the CRYSTAL program and to reflect the Centre's successes, progress, and opportunities.

Pacific CRYSTAL established a mission statement through a deliberative process involving faculty members, partners, and research associates as a centre *to promote scientific, mathematical, and technological literacy for responsible citizenship through research partnerships with university and educational communities.* A strategic Build–Expand–Lead plan was developed in which ideas, resources, and research inquiries would *evolve from small-scale authentic learning opportunities viewed as extra-curricular and outside the prescribed curriculum and school program (Build), to controlled applications of evidence-based classroom practices and resources (Expand), and to scaled dissemination and implementation, leadership experiences, and policy actions (Lead)*. The emphasis changed from small-scale authentic opportunities in the early years to classroom-scale trials in the middle years and finally to systemic-scale implementation, leadership, and knowledge transfer efforts in the final years. The partners identified project foci and intentions within the mission statement and formed three functional nodes under a central leadership and administration node at the University of Victoria, which was guided by (a) an

International Advisory Board of scientists, community members, science educators, and cognitive scientists, (b) an Executive Committee of principal investigators from the University of Victoria and community partners, and (c) Co-directors (see Appendix for complete listing of these groups).

The functional organization involved a hub-and-spoke model for administrative purposes, with the central management node radiating out to the three R&D nodes. However, as the projects developed, much more integration and collaboration occurred among the researchers and participants in the separate nodes. A central, internodal goal was to increase the leadership capacity for SMT education through production of highly qualified personnel (HQP) for schools, partner agencies, and universities. Therefore, wherever possible, internships, graduate fellowships, and research apprenticeships were utilized to provide authentic experiences in SMT areas. While only some projects are featured in the following chapters, a listing of HQP, graduate projects, theses and dissertations, articles, conference presentations, chapters, reports, and instructional products is provided in the book's Appendix.

Node 1 (*Build*) involved developing authentic experiences designed to provide real SMT opportunities to students and then documentation and evaluation of what happened in these experiences to assess their effectiveness in improving SMT literacies, fostering interest in the disciplines, and establishing disciplinary identity. Innovative experiences and approaches to SMT literacy included self-exploration of identity, career awareness, attitudes toward the disciplines; internships in university science laboratories, community education groups, and traditional and western knowledge about nature; field-based ecology programs; intertidal systems and aquaria in classrooms; hands-on earth science field trips and activities; and problem-solving workshops with computer science concepts. These experiences, applications, and resources were informed by constructivist pedagogies and self-efficacy as well as inquiry, design, and problem-solving based learning in both formal and informal learning environments.

Node 2 (*Expand*) involved implementing classroom experiences that provide a variety of instructional approaches regarding thinking, language, mathematics, and engineering design with unique resources and information communication technologies (ICT) to enhance SMT literacies. Research conducted on these approaches focused on establishing interdisciplinary relationships amongst science, mathematics, and language arts; integrating instructional resources and strategies developed in Node 1 into classroom experiences; examining science literacy through reading, writing, and oral discourse; and developing weather units and online assessment tools. Projects included explicit literacy instruction in middle schools; community mapping in environmental studies, socioscientific issues, earth science activities and strategies in teacher education and professional development; and use of automated weather stations, a weather unit, and an inventory of weather concepts. Teachers collaborating with researchers benefited and contributed professionally through involvement in the research projects, professional development workshops associated with the projects, and individual graduate research projects integrated with the node's objectives.

Node 3 (*Lead*) involved researchers seeking to engage and build partnerships with teachers and to better understand and support the teacher's role in improving students' SMT literacies and instruction. This node focused on hierarchical linear modeling (HLM) analyses of the PISA datasets for science, mathematics, and reading literacies to better understand the relationships between student performance and student, home, and community characteristics; implementing change, establishing a foundation for educational policy involving SMT education, developing model programs, and producing a legacy of SMT advocates and lead teachers. This node emphasized leadership through professional development, cascading leadership in which participants assumed responsibility for professional development activities as projects evolved, demonstration or lighthouse schools, teacher workshops, teacher involvement, and programs for preservice teachers. Lighthouse schools investigated the development of excellence in classroom instruction with school-wide professional development, resulting in K–5 science units, a water quality exploration, and environmental literacy, awareness, and activities. Teacher education in earth science was fostered through a specialized laboratory section for pre-Education students in a first year Earth and Ocean Science course. Leadership and knowledge transfer (also termed *knowledge mobilization* and *knowledge utilization*) were central to all projects in this node.

INTEGRATIVE THEMES AND IDEAS

Early efforts were devoted to shaping the mission statement and strategic evolution plan and to ensuring shared understanding of the goals and working frameworks amongst a diverse group of scientists, educators, and partners. These efforts identified a set of interconnected themes and ideas that crossed and integrated many of the independent projects within Pacific CRYSTAL, for example, constructivist learning and teaching approaches, SMT literacies, learner resources, informal and formal environments, professionalism, teacher education, professional learning and leadership, evidence-based practices, knowledge transfer, and policy advocacy.

Constructivist Learning and Teaching Approaches

Education—a horizontal knowledge structure—has conflicting or alternative views of learning that coexist without the normal evolution, integration, or replacement of competing views found in the vertical knowledge structure in the sciences and mathematics (Lerman, 2010). This allows views of learning, curricula, instruction, and assessment practices based on outdated or questionable foundations to exist (United States National Research Council [NRC], 2000, 2007). Science education and mathematics education are no exceptions since some views of learning and instruction are based on behaviouralism (drill and practice, objective test items), while others are based on cognitive development (developmental appropriate tasks, performance assessments), and still others are based on cognitive psychology (sociocultural, sociocognitive perspectives, authentic assessments). Some of these views do not recognize the importance of learners' prior knowledge (including misconceptions, informal experiences, metacognition, language, and intuition), and they stress rote content learning and emphasize learner deficits (NRC, 2005a, 2005b, 2007).

"Students often have limited opportunities to understand or make sense of topics because many curricula have emphasized memory rather than understanding" (NRC, 2000, pp. 8–9).

The diverse participants in Pacific CRYSTAL embraced constructivism and recognized that this view of learning includes a spectrum of views from information processing, interactive-constructivism, social constructivism, and radical constructivism (Henriques, 1997; Yore, 2003). Constructivist approaches consider learning as sense making; the nature of SMT; the constructive, persuasive, and communicative roles of language in doing and learning these disciplines; the importance of prior knowledge, values, and beliefs; cultural perspectives about these disciplines; intuitive reasoning, critical or creative thinking, reflection, and metacognition; and the utilization of these resources to construct understanding.

Most project leaders implicitly or explicitly endorsed centralist views of constructivism with a sociocognitive interpretation that considered sociocultural influences, group dynamics and negotiations, and individual reflection and sense making while emphasizing a balance of self-directed and teacher-guided approaches. Many of the pragmatic teaching approaches utilized some form of a modified learning cycle (5Es [engage, explore, explain, elaborate, evaluate], EECA [engage, explore, consolidate, assess], or EDU [explore**,** discuss, understand]) and inquiry-oriented, problem-solving, and design-based approaches (teacher-structured, teacher-guided, open) involving hands-on experiences, multiple information sources, small-group negotiations, teacher-scaffolded discussions, and assessment for and of learning. These approaches assume that learners construct understanding based on their ontological assumptions, epistemological beliefs, prior knowledge, concurrent sensory experiences, available information sources, and interpersonal interactions within a sociocultural context. Teacher-directed instruction and modelling focused on requisite concepts or abilities are provided as *just-in-time* teaching on an *as-needed* basis, and the instruction considers the metacognitive awareness (declarative, procedural, and conditional knowledge) and executive control (planning, monitoring, regulating) necessary to facilitate students' explorations and learning. Assessment *for* learning involved ongoing formative techniques that empowered learning and informed instruction, while assessment *of* learning involved summative techniques that provided cumulative information for evaluation and accountability purposes.

Science, Mathematics, and Technology Literacies

Participants were generally in agreement that science, mathematics, and technology are disciplines with unique but interconnected and related attributes. They were supportive of the idea that SMT literacies ultimately resulted in *fuller participation in the public debate about science, technology, society, and environment (STSE) issues leading to informed decisions and sustainable solutions and actions*. Science is generally characterized as inquiry, mathematics as problem solving, and technology as design but all involve argumentation (AAAS, 1990; International Technology Education Association, 2007; United States National Academy of Engineering, 2010; United States National Council of Teachers of Mathematics, 2000; NRC, 1996, 2007).

Analyses of the USA reform documents in SMT indicated common goals, pedagogy and assessment focused on all students, disciplinary literacy, constructivist teaching approaches, and authentic assessments (Ford, Yore, & Anthony, 1997). However, even with international support of SMT literacies, there are no commonly shared definitions that provide a working framework and details. The lack of clear working frameworks for each of the SMT literacies, the central goal of the project, was identified as a requirement to improve Pacific CRYSTAL and to encourage integration across projects.

Collaboration among CRYSTAL Alberta, Pacific CRYSTAL, and the National Science Council of Taiwan resulted in mathematical and scientific literacy frameworks that provided fine structure to these literacies building on earlier analyses of the USA reform documents (Ford et al., 1997). The resulting frameworks for mathematics and scientific literacies and the development of a parallel framework for technological literacy are reported in Chapter 2 (Yore, this book). Special issues of the *International Journal of Science and Mathematics Education* (Anderson, Chiu, & Yore, 2010; Yore, Pimm, & Tuan, 2007) sought mathematics and science education research involving forms of these literacies. These IJSME special issues synthesized the current international and Canadian reforms to produce (a) parallel frameworks of mathematical and scientific literacy and (b) a secondary analyses of the 2000, 2003, and 2006 PISA results on literacies in reading, mathematics, and science. PISA, unlike other international assessments, used noncurricular definitions of these literacies, which morphed somewhat over the 2000–2006 period but retained focus on adult needs, real-world applications, and informational text (OECD, n.d.). The very high correlations (0.78–0.88) at student-level performances amongst reading, mathematics, and science literacies illustrate shared variances (61–77%) and potential associations amongst these literacies, which do not necessarily indicate causal relationships but are too large to ignore (Anderson et al., 2010). These results were used to support the interactive nature of fundamental literacy in a discipline and the derived understanding of that discipline found in the proposed frameworks.

Learner Resources: Prior Knowledge, Experiences, Beliefs, and Perceptions of Self

Learning theories and models prior to constructivism put much emphasis on learner qualities (IQ, logico-mathematical operations, socioeconomic background, etc.) as fixed traits unreceptive to change and growth. Therefore, many teaching approaches using these interpretations incorporated a *deficit model* in which instruction (e.g., learning assistance, special education, etc.) had to first address the deficit before the actual teaching and learning could occur. Applicants of constructivism incorporated the positive and negative lessons learned from these special approaches and re-engineered instruction to view all learner attributes as resources from and on which to facilitate learning. The basic principles are to ascertain what learners know and can do and then teach them accordingly (Ausubel, 1968) and to realize that teaching is in service of learning—without learning, teaching did not occur (Hand, 2007). Prior experiences and knowledge, including misconceptions, become springboards or foundations for further inquiries, designs, and problem solving.

Many students have misconceptions about the nature of SMT that influence learning (AAAS, 1993). Minority cultural beliefs and views of the SMT disciplines can be used to anchor instruction that respects sociocultural perspectives, enables honourable engagement, and guides the learning and teaching progressions.

Language is an important cognitive, persuasive, and communicative tool or technology in learning (NRC, 2000, 2007). It is documented that, like English language learners (ELL), most students in SMT courses face the 3-language problem involving transitions between home, school, and disciplinary languages (Yore & Treagust, 2006). Therefore, SMT students are science language learners (SLL), mathematics language learners (MLL), and technology language learners (TLL). The border crossings for some ELL, SLL, MLL, and TLL involve more than memorizing scientific, mathematical, and technological terminology; it involves being initiated into the culture, discourse, and metalanguage of these disciplines and into how language is used to construct, shape, justify, and report knowledge.

A major resource of interest for the underrepresented and underserved target populations of Pacific CRYSTAL were students' identities in and with the SMT disciplines. The NRC (2007) stated, "Students' motivation, their beliefs about science [and likely mathematics and technology], and their identities as learners affect their participation in the ... [SMT] classroom[s] and have consequences for the quality of their learning." (p. 195). These identity attributes (i.e., cognitive—belief about self; emotional or affective—values, interest, motivation, and attitudes; and behavioural—persistence, effort, and attention) are captured under the general headings of "[s]elf-concept[, which] refers to global ideas about one's identity and one's role relations to others. ... [and s]elf-esteem[, which] refers to the value one places on himself or herself." (Koballa & Glynn, 2007, p. 92). Both self-concept and self-esteem appear to be discipline- and context-specific where young people may have strong to weak interpretations of self in, for example, music, athletics, gangs, and academics.

The NRC (2007) suggested that students who have stronger beliefs and sense of competence in SMT tend to use deep learning strategies and exert more academic effort. Furthermore, there appear to be gender and cultural differences in these beliefs about role-stereotyped domains of SMT that may provide insights into the current and future participation, success, and career choices of underrepresented and underserved populations. The SMT cultures are "foreign to many students, both mainstream and nonmainstream, and the challenges of ... [SMT] learning may be greater for students whose cultural traditions are discontinuous with the way of knowing characteristic of [these disciplines and school programs in these disciplines]" (NRC, 2007, p. 201). de Abreu (2002) stated, that in mathematics education:

> The need for a better account of the interplay between the cultural, social, and person systems is needed. … There were issues related to the uniqueness of the individual and patterns of development in the reconstruction of the cultural tools at the person level and also issues related to the social valorization of knowledge, changes in social structures, and the person's and the group's sense of identity. (p. 341)

The NRC (2007) stated, "some students in a group may disidentify with a particular domain, like school or ... [SMT], due to widely held stereotypes about their lack of ability in it. To protect their own sense of self, some students disidentify with the domain and stop trying to achieve in it." (p. 197).

Self-efficacy is a more specific interpretation of self and identity involving "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments" (Bandura, 1997, p. 3). Self-efficacy has two dimensions: beliefs about abilities and the expectation that these competencies can be successfully applied. Koballa and Glynn (2007) pointed out that self-efficacy within science and specific domains or topics were reasonable predictors of achievement and test performance; however, questionnaires that address specific areas may be more useful than those that address science generally. Such instruments have been developed for science and mathematics but not for technology (Enochs & Riggs, 1990; Enochs, Smith, & Huinker, 2000).

Goal orientations, such as performance and mastery, provide insights into students' intellectual resources and inform teaching. Performance orientation focuses on favourable evaluation while mastery orientation focuses on skill development, conceptual understanding, and learning. Performance orientation is well suited to test-driven learning environments while mastery orientation is well suited to interactive-constructivist learning environments where students and teachers collaborate to set the learning agenda.

Informal and Formal Environments

One goal of Pacific CRYSTAL was to use informal environments as an incubator for developing and evaluating authentic SMT learning activities that could then be implemented and disseminated to classroom and school environments and for the public awareness and engagement of SMT. (See comprehensive literature review at http://education2.uvic.ca/pacificcrystal/literature/index.html.) The NRC (2009) provided a comprehensive overview and value-added insights of informal environments beyond classrooms and schools. The "narrow focus on traditional academic activities and learning outcomes is fundamentally at odds with the ways in which individuals learn across various social settings: … in potentially all the places they experience and pursuits they take on" (p. 27). The report recognizes life-long, life-wide, and life-deep learning and the significant contribution that lived experiences make to formal learning within constructivist, people-centred, place-centred, and culture-centred learning. The "[s]tandardized, multiple-choice test, [which] has become monoculture species for demonstrating outcomes in the K–12 education system, is at odds with the types of activities, learning and reasons for participation that characterize informal experiences" (p. 56). Formal assessments *of* learning are antithetical to assessment *for* self-directed learning, and these techniques may threaten learners' self-esteem and self-concept of the SMT activities. "In sum, although the nature and extent of ... [SMT]-related learning may vary considerably from one life stage to another, most people develop relevant abilities and intuitive knowledge from the days immediately after birth and expand on these in later stages of their life." (p. 99).

Informal environments include people-built designed settings, programs for various age groups, and media. Designed settings (including exhibits, demonstrations, and programs at institutions such as museums, science centres, aquaria, and environmental centres) are fluid spaces to be engaged with episodically and navigated freely, with limited or no directions, guidance, and facilitation by external scaffolding or staff to explore the target ideas emphasized by the design features. Programs—including after-school and out-of-school learning programs for children and youth, adult programs such as citizen science programs and teacher professional development programs, as well as programs for older adults—reflect societal changes in childcare, career changes, and leisure time. After-school, weekend, and summer programs (e.g., robotics contests, girls in science, and Science Venture) can cause tensions with in-school programs. However, Pacific CRYSTAL research and learning initiatives clearly supported the belief that "The potential of programs for ... [SMT] learning is great, given the broader population patterns" and require careful consideration, research, documentation, and evaluation (NRC, 2009, p. 199). Informal environments can address diversity, culture, and equity issues faced by underrepresented and underserved populations since many of these issues have their roots in other educational systems and lack of opportunities. "Environments should be developed in ways that expressly draw upon participants' cultural practices, including everyday language, linguistic practices and common cultural experiences" (pp. 236–237). Mass and interactive media (e.g., print, education broadcast, popular entertainment, and other immersive media—IMAX, planetaria, laser-projection systems) have significant roles in the public awareness and engagement. "[SMT]-related media are likely to continue to play a major role in the ways that people learn about ... [SMT] informally. The public often cites broadcast, print and digital media as their major sources of scientific[, mathematical, and technological] information." (p. 277).

Professionalism, Teacher Education, Professional Learning, and Leadership

Professions—communities of practice regulated by defined associations, authorities, or judicial panels—control entrance, acceptable practices, ethical conduct, and discipline. Teaching professions are not as tightly controlled as the accounting, engineering, legal, medical, or other recognized professions. Colleges of teachers or provincial governments control licensure requirements for initial entry into teaching and teacher education programs directly or indirectly in Canada. Some school districts require or encourage continued professional learning or advanced degrees to maintain effectiveness and to progress to higher lanes of salary structures. Universities, professional associations, and school districts can formally offer these experiences as credit or noncredit courses. There is reasonable evidence that high-quality professional development and high-quality instructional resources will change classroom practices, but there is very limited evidence that this triad leads to improved student achievement (Shymansky, Yore, Annetta, & Everett, 2008).

There is a growing realization that initial teacher education programs cannot provide the content (CK), pedagogical (PK), and pedagogical-content (PCK) knowledge for career-long, effective performance in rapidly changing classrooms and curricular contexts. Many teachers desire personalized approaches that value self-directed or community-based professional learning to maintain or enhance effectiveness and to address the ever-changing curriculum and instructional demands. The US National Board for Professional Teaching Standards (NBPTS) certificate is one such post-entry program designed to improve high-quality professionalism, classroom practice, and school leadership (http://www.nbpts.org/). Central requirements of NBPTS certificates are evaluation, reflection, regulation, and justification of curricular, instructional, and assessment decisions about preparing for and establishing favourable contexts, and advancing and supporting student learning by professional teachers. This places prime importance on rational, evidence-based decisions about what to teach, how to teach, and what data justify learning and teaching effectiveness.

Many of the Pacific CRYSTAL projects focused on teacher enhancement, curriculum development, and instructional resources that attempted to utilize authentic learning activities and leadership opportunities from informal environments to develop leaders, evidence-based practices, and tested resources for classroom and school environments. Therefore, internships, professional development experiences, fellowships, and apprenticeships were utilized to provide authentic learning, teaching, research, and leadership experiences for the SMT education areas. These experiences used community-based designs to (a) identify needs and set agendas, (b) deliver professional learning experiences focused on CK, PK, and PCK, and (c) provide mentoring and peer tutoring between and amongst university, school, First Nations, and nongovernmental participants within the realities of SMT research, development, and teaching.

Evidence-based Practices

Millar and Osborne (2009) considered practices that might have sufficient evidential-basis and suggested that wait time (Rowe, 1974a, 1974b), formative assessment (Black & Wiliam, 1998a, 1998b), and cognitive acceleration (Adey & Shayer, 1990) had enough research support for such acceptance and teacher uptake. Interestingly, learning styles and inquiry teaching, although popular with teachers or widely promoted in education literature, do not appear to enjoy the same degree of evidence or actual teacher uptake. These and other instructional practices appear to be popularized by promotional efforts but not empirical research findings.

The evidence-based practice model requires that (a) practitioners (here, teachers of SMT literacy) read the research on curricular and instructional practices, (b) this research addresses teachers as the target audience and end users, and (c) professional codes and recommendations are based on quality research results in sufficient quantity and consistency to define best practices (Hayward & Phillips, 2009). The US Institute for Educational Sciences provided standards for quality of evidence considered to be strong, possible, or weak for specific instructional programs, resources, and practices based on research design, rigorous methods, valid and reliable measurements, comprehensive data sources, appropriate data analysis, and compelling arguments involving legitimate claims, strong theoretical backings, and sound warrants of the data as evidence for or against specific claims or counterclaims (Shelley, 2009).

Recent analyses of science teacher journal articles dealing with scientific literacy from Australia, the United Kingdom, and the United States revealed that most recommended literacy strategies and activities were poorly justified (Hand, Yore, Jagger, & Prain, 2010). A more in-depth analysis of the 1998–2009 National Science Teachers Association journals for elementary, middle, and secondary school teachers on the same topic revealed that 61% of the recommendations were based on no or weak evidence (Jagger & Yore, 2010). Several North American agencies provided synthesis of evidence and have identified best practices:

– Best Evidence Encyclopedia (http://www.bestevidence.org/)
– The Campbell Collaboration (http://www.campbellcollaboration.org/)
– Comprehensive School Reform Quality Center (http://www.csrq.org/)
– What Works Clearinghouse (http://ies.ed.gov/ncee/wwc/)

Pacific CRYSTAL has attempted to provide similar insights by means of its publications, presentations, and resources.

Knowledge Transfer and Policy Advocacy

A central concern of the CRYSTAL project was for wider dissemination of its R&D results and the influence of public policy. It is widely recognized that writing research reports for highly regarded, peer-reviewed academic journals and assuming that end users (i.e., teachers, administrators, parents, bureaucrats, elected politicians) will access and use these results has not worked; few education policies are influenced by SMT education research. Successful knowledge transfer and policy influence involves much more; specifically, considering the end users from the outset and understanding the political structures and policy process, end users' preferred access and sources of information, and normative values of the political context. Reporting to these audiences as intended targets and speaking truth to powerful people is a complex, poorly understood, and time-consuming process. Shelley (2009) stated, "In highly abbreviated form, the essential point is how to reach across the gulf that is created by an unequal distribution of power (researchers having rather little and decision makers having very much more) to transmit understanding to those who are able to compel binding decisions." (p. 444). Unfortunately, "[a]mong policy makers and many scholars, educational research has a reputation of being amateurish, unscientific, and generally beside the point" (Henig, 2008, p. 357).

Research results are not the prime influence on public policy since research evidence or findings are more often used to confirm or justify a position rather than to inform or change positions (Rees, 2008). The structure, information flow, and decision process of most political organizations involve the ultimate decision makers—politicians, high-ranking appointees, etc. (first community), academics (second community), and policy advisers, consultants, research officers, support staff, lobbyists, special interest groups, advocates (third community) in the policy system (Cohn, 2006). Academics infrequently have direct access to the first community but may have direct or indirect access to the third community. The actors in the third community use knowledge and information to produce useful position papers or briefs in the language of decision makers and then disseminate them to influence or advise decision makers.

Effective communication with and persuasion of these end users mean using appropriate sources, format, language, and style; stressing cooperation and collaboration rather than conflict; and recognizing possible claims, counterclaims, and rebuttals. Members of the K–12 education and policy communities are more likely to rely on ICT and generalist journals rather than high-level, peer-reviewed research journals (Henig, 2008). Knowledge mobilization and lobby efforts need to provide information that recognizes the central function (persuasion) and the window of opportunity. The Society for Research in Child Development (n.d.), for example, prepares 2-page, research-based briefs on social policy topics concerning children, families, and other issues in print and electronic form that are concise and informative.

Canada, unlike many nations, does not have a national ministry or office of education. Education is a provincial or territorial mandate that is vigorously guarded; therefore, provincial and territorial ministries of education are the focal point for any lobby actions and policy influence. However, there have been nonbinding cooperatives of governmental education agencies focused on policy, curricula, and assessments. The Council of Ministers of Education, Canada (CMEC) is one of the few national entities—it is a collective of the ministers of education from the provinces and territories that comprise the nation.

The *Victoria Declaration* was developed by the ministers of education in September 1993 and provided a directive to harmonize education by promoting curriculum compatibility and assessment. The first initiative related to the Declaration was the development of the *School Achievement Indicators Program*, which assessed reading, writing, mathematics, and science performance of 13- and 16-year-old students until it was replaced by the *Pan-Canadian Assessment Program*. The CMEC next adopted the *Pan-Canadian Protocol for Collaboration on School Curriculum*, which recognized provincial jurisdiction for education and that, by sharing human and financial resources, the quality and efficiency of education could be increased. The first curriculum effort led to the *Common Framework of Science Learning Outcomes, K to 12* (CMEC, 1997), a nationally (albeit that Quebec did not officially participate) developed curriculum document that harmonized learning goals and science instruction in Canadian schools to provide the highest quality of education.

The Western and Northern Protocol for Canada (WNPC; http://www.wncp.ca/) is a regional interprovincial and interterritorial collaboration (composed of British Columbia, Alberta, Saskatchewan, Manitoba, the Yukon, Northwest Territories, and Nunavut) formed to develop coordinated perspectives on some common curricular areas. The WNCP *Common Curriculum Framework for K–9 Mathematics* (2006) is a guide with learning outcomes that reflects general trends in international mathematics education reforms. No similar national or regional effort has addressed K–12 computer science, engineering, environmental, and technology education.

Royal task forces and commissions are used to build consensus and lay the foundation for policies in Canada and other countries. The deliberative mechanisms appear to be democratic processes, but they are not without political difficulties. Membership in these groups may be based on expertise, representation, or other criteria but, once formed, they all involve negotiation, persuasion, controversy, and compromise. Participants involved in science and mathematics education deliberations and reforms have attested to the internal and external struggles in producing a document based on diverse input and lengthy deliberations.

Three international reports have potential for influencing science literacy around the world and to illustrate potential pathways for mathematics and technology literacies (Fensham, 2008; Osborne & Dillon, 2008; Rocard et al., 2007). These 'plain talk' reports identify problems, provide recommendations, and supportive justification that could be used by policy and decision makers to craft policy briefs and procedures that would improve the articulation and coordination of science education goals, resources, and efforts regarding formal schooling and public awareness of science. They serve as reasonable models for what could be done for mathematics and technology education.

Knowledge transfer and policy influence require synthesis of qualitative and quantitative research using metasynthesis, meta-analysis, and systematic review techniques or secondary analysis of data sets and multiple results. The Pacific CRYSTAL HLM project that analyzed the PISA 2003 and 2006 results (Anderson et al., 2010; Milford, Anderson, & Luo, Chapter 11 this book) illustrates attempts to repackage international survey data into meaningful evidence for policy makers and decision makers. Milford, Jagger, Yore, and Anderson (2010) used document analyses and informant interviews to document the influence of the Pan-Canadian Science Framework (CMEC, 1997) on provincial and territorial K–12 science curricula. They found that the Framework was pervasive in both general directions and design elements and in the specific direct use of the document in curriculum development initiatives in the ministries of education throughout the nation. However, the influences of reform-oriented actions take significant time to influence educational policy and depend on curriculum development and implementation itself, which functions in a 7- to 12-year cycle.

Another issue identified was the need for specific operational definitions for implementing and evaluating the reform. For example, the centrality of scientific literacy is not matched by a specific definition of its meaning in terms of curriculum and instruction. Furthermore, given that the Pan-Canadian Science Framework is now in its second decade, there is a need for attention to currency and relevancy to science and science education. These findings also likely apply to mathematics and technology education reforms.

OVERVIEW OF BOOK, SECTIONS, AND CHAPTERS

This book addresses lessons learned during 5 years of R&D. These lessons provide insights for funding agencies regarding SMT literacies and instruction and into collaborative partnerships involving multiple agencies, scaling implementation from single teachers and classrooms to wider dissemination to schools and district-wide settings, building leadership capacity amongst SMT teachers, knowledge transfer, and influencing SMT educational policy and decisions.

Section I provides readers insights into CRYSTAL and especially Pacific CRYSTAL. **Chapter 1** provides an overview of the contextual and organizational goals, conceptual foundations, theoretical constructs, and integrative themes across the projects as they evolved from concept to testing and dissemination. The integrative themes of many of the projects are constructivist learning, SMT literacies, community-based R&D models, partnerships, learner attributes, informal environments, professional learning or development, teacher education, leadership capacity, systemic change, evidence-based practices, knowledge transfer or mobilization, and policy advocacy. **Chapter 2**, *Foundations of Scientific, Mathematical, and Technological Literacies—Common Themes and Theoretical Frameworks,* provides the working definitions and theoretical backings and research support for the central focus of Pacific CRYSTAL. These discipline-specific literacies have been discussed for many years and serve as the focus of international education reforms, but they lack well-accepted definitions that incorporate conceptual understanding, literacy, and contextual applications.

Section II, Authentic Learning—Informal Environments and Extracurricular Science, Mathematics, and Technology Opportunities: Anchoring and Bridging Real-world, Cultural, and School Experiences, describes projects from Node 1 that focused on building conceptual ideas and transforming them into instructional practices. **Chapter 3**, *Adolescents' Science Career Aspirations Explored through Identity and Possible Selves*, addresses making career decisions in secondary school—a challenging and often stressful experience for adolescents involving self-concept related to identity and self-efficacy. The Possible Selves Mapping Process is an experiential activity that is future-oriented and a personalized form of self-concept; it has direct relevance to how students' views of themselves guide their work and educational behaviours. **Chapter 4**, *Giving Voice to Science from Two Perspectives: A Case Study*, reports on an ethnobotanical program involving six First Nations members over 6 years in which opportunities to explore traditional and western knowledge about nature and naturally occurring events were made available at the University of Victoria and SN̲ITȻEȽ (pronounced *sneakwith*, SENĆOŦEN language for The Place of the Blue Grouse)—part of traditional territory utilized for hunting, fishing, shellfish gathering, and sacred ceremonies. **Chapter 5**, *Seaquaria in Schools: Participatory Approaches in the Evaluation of an Exemplary Environmental Education Program*, reports on the successful partnerships amongst nongovernmental agencies, schools, universities, and their communities that helped enliven a community of practice for public school educators in which all partners actively participated in setting agendas and developing programs. The successes and challenges provide insights into how to achieve long-term sustainability through active community partnerships and how this approach can be applied elsewhere. **Chapter 6**, *Teaching Problem Solving and Computer Science in the Schools: Concepts and Assessment*, explores expanding the age range of students exposed to computer science and computer science concepts (i.e., recursion, concurrency, graph theory) through the development and deployment of interesting and engaging hands-on computer science activities. It discusses encouraging findings from three studies as well as the strengths and weaknesses of assessment techniques in various classroom settings. **Chapter 7**, *Outreach Workshops, Applications, and Resources: Helping Teachers to Climb over the Science, Mathematics, and Technology Threshold by Engaging Their Classes*, illustrates how elementary and middle school teachers who lacked confidence and competence to teach SMT topics effectively adopted constructivist approaches. The outreach workshops made SMT topics more accessible to teachers by modelling the successful use of effective pedagogies, appropriate technologies, and authentic learning activities.

Section III, **Moving Tested ideas into Classrooms**, illustrates how conceptual ideas and practices were expanded and moved into larger settings. **Chapter 8**, *Explicit Literacy Instruction Embedded in Middle School Science Classrooms: A Community-based Professional Development Project to Enhance Scientific Literacy*, reports on the community-based project that identified, developed, and embedded explicit literacy instruction in science programs to achieve fundamental literacy in science and science understanding. **Chapter 9**, *Enhancing Science Education through an Online Repository of Controversial, Socioscientific News Stories*, reports an interactive teaching technique that employed controversial, socioscientific news stories as a means of developing scientific literacy and follows the development of the Science Times resource, its effectiveness and potential uses in similar learning opportunities and the larger learning community via Internet delivery. **Chapter 10**, *Promoting Earth Science Teaching and Learning: Inquiry-based Activities and Resources Anchoring Teacher Professional Development and Education*, focuses on developing teachers' interest in and positive attitudes toward Earth Science and to increase PCK and experience with scientific reasoning and practice. A series of inquiry-based activities and accompanying resources were developed for teacher professional development workshops, an Education Laboratory in a first year Earth and Ocean Sciences course that demonstrates relevance, constructivist approach, curriculum linkages, opportunities for interdisciplinary associations (including language arts, mathematics, and other sciences) and accompanying resources are key attributes of these successful activities, which are classroom tested and informed by teacher feedback.

Section IV, Knowledge Transfer, Systemic Implementation, and Building Leadership Capacity, addresses the lead phase of the evolutionary strategy. **Chapter 11**, *Modelling of Large-scale PISA Assessment Data: Science and Mathematics Literacy*, investigates relationships and patterns associated with student performance in the literacies of mathematics, science, and reading and student, school, home, and community characteristics. The PISA data sets were the central foci of the investigations using HLM. The findings reported go well beyond simple ranking of participating nations in terms of average performance scores. **Chapter 12**, *Time and Teacher Control in Curriculum Adoption: Lessons from the Lighthouse Schools Project*, reports on case studies involving an elementary and a middle school where teachers were provided with funding that enabled them to have the time to implement a new science education curriculum and total control over the change process. Initially conceived as a lighthouse project of peer interschool development, the teachers involved reconceptualized the lighthouse to serve their particular, local interests. Teacher control translated into unit planning and changes in the direction of funding support toward the middle school receiving students from the elementary school. While teachers were enthusiastic about this change in process and the availability of time to plan, analysis of the science education units developed at both schools revealed that curriculum change is complex and difficult, not easily addressed by providing time for planning, or by locating teachers as the sole agents of the change process. **Chapter 13**, *The Development of a Place-based Learning Environment at the Bowen Island Community School*, describes and documents one elementary lighthouse school's experiences in achieving its environmental literacy goals through the development of a place-based learning environment. The Ecological Education Project studied the complex ecology of the intersection between scientific knowledge, pedagogy, student learning, and curriculum. They identified and developed innovative approaches for the teaching of scientific and interdisciplinary topics around environmental education framed within the context of ecoliteracy.

Section V: Closing Remarks and Implications for the Future, provides a post hoc perspective to highlight themes that evolved from individual projects. **Chapter 14**, *Epilogue of Pacific CRYSTAL—Lessons Learned about Science, Mathematics, and Technology Literacy, Teaching and Learning*, provides a cross-case analysis and discussion of the themes emerging from the studies reported in this book. The common themes across these studies were community commitment and action planning, disciplinary literacy (science, mathematics, technology), evidence-based resources and practices, professional learning (teacher education and professional development), student performance (conceptual understanding, fundamental literacy, self-efficacy, identity), and educational leadership and advocacy.

The Appendix offers a listing of highly qualified personnel—postdoctoral and graduate students, undergraduate research assistants, and community interns—involved with Pacific CRYSTAL. It summarizes their contributions, including theses and dissertations, articles, conference presentations, and instructional resources. This Appendix documents the legacy of the Pacific CRYSTAL Project more so than any other document.

CLOSING REMARKS

Pacific CRYSTAL suggested a number of independent R&D projects in the original proposal to address the changed research and policy expectations of NSERC. As the project unfolded, both NSERC and the principal investigators in Pacific CRYSTAL became more realistic about the complexity of the central problems and the project design. Early R&D efforts involved a loose collection of diverse projects without the internal glue of a shared mission statement and strategic plan. Experiences during Year 1 led to national and project-wide deliberations and considerations of the central goals, organizational structure, operational procedures, and outcomes by the NSERC staff, project directors from the five CRYSTAL projects, and the Pacific CRYSTAL International Advisory Board, Executive Committee, and all participants. The traditional definitions of educational research (i.e., publication of peer-reviewed articles and presentation at international conferences) was revised to focus on teachers, policy makers, instructional resources, and a variety of local, provincial, and national professional conferences. The insights into processes and procedures are equally and likely more important than the number of peer-reviewed research articles, books, and chapters that flow from Pacific CRYSTAL. The following chapters