The Manitoba Education Research Network (MERN) Monograph Series

In 2008 the Manitoba Education Research Network, with the support of the Manitoba Council for Leadership in Education (MCLE), launched the MERN Monograph Series. The purpose of this monograph series is to publish peer-reviewed educational research in hard copy and electronically, in English and French, at least twice a year. Each monograph will normally report on Manitoba educational research—research that is conducted by Manitoba researchers, in Manitoba, and/or is timely, accessible, and relevant to a broad audience of Manitoba educators and their partners. A call for proposals is posted on the MERN website at <www.mern.ca> and widely circulated across the province twice a year with deadlines in the fall and spring.

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University of Manitoba Centre for Research in Youth, Science Teaching and Learning: Applications and Utility of Urie Bronfenbrenner’s Bio-ecological Theory

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EXECUTIVE SUMMARY

Introduction

This monograph documents the outcomes of some of the research activity conducted between 2005 and 2010 by the University of Manitoba Centre for Research in Youth, Science Teaching and Learning (CRYSTAL). The primary underlying theoretical framework of the University of Manitoba CRYSTAL is Urie Bronfenbrenner’s bio-ecological model of human development—a model that Bronfenbrenner himself lamented, prior to his death in 2005, had had minimal application to and impact upon educational development. Although the Centre’s research activity, collectively, involved 17 research projects, this monograph focuses upon eight projects that provide diverse education contexts for evaluating the utility of Urie Bronfenbrenner’s bio-ecological theory of human development. The first part of the monograph introduces Urie Bronfenbrenner’s bio-ecological model. The second examines the focus, organization, and activity of the University of Manitoba’s CRYSTAL. The third section reports on findings from eight research studies conducted by the authors on the utility of Bronfenbrenner’s model. Finally, a summary presents a synthesis of the findings from the eight studies, with a focus on evaluating the utility of Bronfenbrenner’s model for educational development efforts. Based upon this utility, recommendations are made.

Part 1: Urie Bronfenbrenner’s Bio-ecological Theory

Bronfenbrenner’s bio-ecological or bio-ecological systems theory considers the influences on a child’s development within the context of the complex system of relationships that form his or her environment. The theory suggests that a child’s development is a product of a variety of critical dimensions including context, process, time, and the individual’s personal attributes. Drawing upon the pioneering work of social psychologist Kurt Lewin, Bronfenbrenner’s theory emphasizes the “joint function” that personal attribute and environmental characteristics have in influencing an individual’s development. In brief, Bronfenbrenner’s theory defines the construct of development and the multi-system layers of the environment that influence child development. Furthermore, he describes the nature of the processes within the environment that influence development. By so doing, Bronfenbrenner’s bio-ecological theory goes beyond providing a framework for identifying and conceptualizing the multi-system factors that influence development. It considers an individual’s topology—his or her setting and the way in which individual and external forces interplay to influence development. It, most importantly, attempts to underscore processes and the dynamics of these processes that might influence development. This monograph proposes that his model provides insight for those working within contexts to successfully foster development individually and collectively.
Part 2: The University of Manitoba Centre for Research in Youth, Science Teaching and Learning

Although Bronfenbrenner’s bio-ecological model has been the foundation of a limited number of development projects, the management team responsible for the conceptualization of the University of Manitoba CRYSTAL believed that Bronfenbrenner’s theory provided a valuable theoretical framework for informing the Centre’s research activity because the focus of the Centre’s work was developmental in nature. In all, CRYSTAL’s research was organized into seventeen research and development projects, eight of which are described herein.

Part 3: Research Applications: Eight Studies Applying Bronfenbrenner’s Theory

Research Study 1: Chemistry Teacher Development towards a Tetrahedral Orientation in the Teaching of Chemistry
Brian Lewthwaite and Rick Wiebe

This research study responds to a new curriculum introduction in Manitoba advocating a tetrahedral orientation (Mahaffy, 2006) to the teaching of chemistry, a pedagogical orientation unlikely to be consistent with traditional chemistry teaching practice. Bronfenbrenner’s bio-ecological model is used primarily as a framework for conceptualizing and organizing the professional development initiative and for monitoring the development of three cohorts of chemistry teachers’ pedagogical practice. Further, the model is used to identify and apply multi-system instigative influences upon teacher change towards a tetrahedral orientation. Through the use of a Chemistry Teacher Inventory and associated teacher responses, statistical analysis of perceptions of their own teaching and comments made by teachers suggest they are showing limited development towards a tetrahedral orientation, albeit in a manner consistent with the curriculum. As well, teachers are able to identify the instigative influences upon their changed practice. In conclusion, Bronfenbrenner’s bio-ecological model is used to conceptualize primary motivators, mainly at the individual and microsystem level, for fostering pedagogical change.
Research Study 2: Learners and Learning in Middle Years Classrooms in Nunavut  
Brian Lewthwaite, Barbara McMillan, and Robert Renaud  

This study investigates Northern Qikiqtani (Baffin Island) of Nunavut Inuit Middle Years (Grades 5 to 8) students’ perceptions of learning success and the classroom pedagogical and interactive processes influencing their success. It focuses upon investigating the premise that successful classroom learning environments at the individual-microsystem level of Bronfenbrenner’s bio-ecological model are responsive to the social interactive patterns and norms of a school’s community, that is, the exo- and mesosystem. The project attempts to determine from the perceptions of Aboriginal students what teaching practices contribute to their success as learners. This authority is then used to question the protocols of the mainstream classroom and, in response, promote a dynamic and synergistic relationship between home and community culture and school culture (Ladson-Billings, 1995). This questioning ultimately and purposely “problematizes” teaching by upsetting the orthodoxy of classrooms by encouraging teachers to ask about the nature of student-teacher relationship, their teaching, the curriculum, and schooling. By creating this disequilibrium, educators are pushed to seek resolution of these issues so that their classrooms move towards becoming more culturally responsive as they employ a culturally preferred pedagogy. Through a variety of data collection methods, Inuit students, and to a lesser extent their Inuit and non-Inuit teachers, identify a variety of pedagogical and interactive processes that influence their educational success and learning, in particular their learning in science. Most processes identified as contributors to learning are seen to be culturally located. Of significance is the importance students place on teachers that care not only for them as people, but also for their performance as learners. Based upon this information presented by students, a profile of what constitutes the characteristics of an effective teacher in promoting learning within a positive learning environment in Inuit schools is presented.

Research Study 3: The Development of Elementary Mathematics for Teaching—Challenges and Supports  
Ann Kajander, Anthony Bartley, and Jennifer Holm  

The mathematical content knowledge of elementary teachers has been identified as a critical factor in determining student success. The reforms in pedagogy proposed by the National Council of Teachers of Mathematics (NCTM) Standards documents support students’ construction of mathematics ideas, rather than a mastery of rules and procedures. This new vision of mathematics learning places considerable emphasis on inquiry and problem solving, the facilitation of which requires deep teacher knowledge of mathematics. Our five-year study examines the development of such appropriate pedagogical content knowledge (mathematics for teaching) for both experienced and pre-service teachers in and around Thunder Bay. Professional learning groups (PLGs) of Grades 7 to 10 teachers were studied.
with the intent of examining growth within and across group members. The first proposition of Bronfenbrenner’s (1979) bio-ecological model is relevant here, as the “proximal processes” of the PLGs took place regularly and over an extended period of time. The deliberations of the PLGs and their intended developmental outcomes varied with group membership, personal development, and individual member’s professional environment and self-identified needs. Bronfenbrenner’s second proposition emphasizes these interactions in a process-person-context-time-model (ppctm); here he notes that “in the bioecological model the characteristics of the person are both a producer and the product of the development” (1979, p. 5). Bronfenbrenner’s bio-ecological model and Rutter’s evolving model of resilience influenced our agenda in the provision of a new “mathematics for teaching” course for pre-service teachers; these are to be seen in the protective factors of a supportive learning environment and the focused instruction. For both populations, our evidence, both qualitative and quantitative, indicated growth in conceptual understanding of mathematics as needed for teaching and indicated positive changes in beliefs about mathematics, with reduced levels of anxiety.

Research Study 4: Integrating Interactive Whiteboard Technology in Classroom Instruction—An Ecological Transition Study

Shannon Gadbois

The purpose of this longitudinal study was to examine the expectations and experiences of nine Middle Years teachers as they implemented interactive whiteboards (IWBs) into their classrooms. These data were examined in the context of Bronfenbrenner’s (1979; 2005) bio-ecological framework, in particular, in regard to Bronfenbrenner’s construct of ecological transitions, as the introduction of IWBs into school classrooms represents an ecological transition that shifts the role and behavioural expectations for teachers. Results of the study showed that teachers do report unique demands associated with the technology as well as unique experiences that demonstrate a shift in the role of students. Specifically, when IWBs are used for instruction, teachers’ experiences indicated that students have a unique opportunity to showcase their skill in technology use. In effect, these teachers showed that IWB use can functionally change the classroom such that there are two expert types in the room, content experts and technology experts. As such, this ecological transition for teachers may also allow students to gain academic self-efficacy that can have an impact on academic interest and motivation as a by-product of IWB use.
Research Study 5: Fostering Teacher Candidate Development
_Brian Lewthwaite and Rick Wiebe_

This research inquiry investigates the factors influencing chemistry teacher candidates’ development during their extended practica. The tenets of Bronfenbrenner’s bio-ecological model provide insight into both the identification of factors influencing chemistry teacher candidate progress and methods for systematically documenting and supporting reflective consideration of the practicum experience for both teacher candidates and those involved in fostering their development. The reflective considerations of teacher candidates are used to foster improvement in the practicum experience for subsequent groups of teacher candidates. Bronfenbrenner’s suggestion as to what contributes to constructive environments and development, especially pertaining to the construct of proximal processes and role allocation, is utilized to foster chemistry teacher development.

Research Study 6: Supporting the Professional Development of Francophone Science Teachers in Minority Language Contexts
_Rodelyn Stroeber and Léonard Rivard_

This longitudinal study responds to the complex demands faced by francophone teachers in minority language contexts related to the growing influence of the language and culture of the English-speaking majority in Canada. These challenges are especially prevalent in the small, isolated rural communities outside of Quebec where small groups of francophones are frequently located, but are now present even in urban communities across the country. In response to this dilemma, this project evaluates the influence of a professional development program that addresses the identified needs of these science teachers, and supports the use of teaching strategies that promote reading and writing for learning science. Bronfenbrenner’s bio-ecological model is used to conceptualize a program to foster teacher development in response to these challenges. Bronfenbrenner’s model of the ecology of human development suggests that humans do not develop in isolation, but rather in relation to their family and home, the school, the community, and society. Each of these continuously changing and dynamic environments, as well as the interactions among these, is important to an individual’s development. The adaptation of the model for francophone science teachers described earlier depicts the different layers of an individual’s ecosystem that have an impact on his or her development and reveals where interventions for professional development might be implemented, enhanced, or impeded. It is evident that each of the different layers interacts and affects the professional learning of science teachers. The outcomes of this study affirm that Bronfenbrenner’s theory provides a framework with which to effectively plan for and implement professional development strategies in order to effect changes in teacher practices and support experimentation as strategies are tested at the classroom level.
Research Study 7: The Importance of Local Environment for Promoting Student Engagement in Learning

_Janet McVittie and Danette Senterre_

This program development and evaluation project responds to a call from an Aboriginal community to foster community-based involvement in science curriculum development and implementation in order to improve student engagement with and participation in science. It answers the following question: What kind of science and math program would a community develop if provided the opportunity to do so?

Based in one northern Saskatchewan Aboriginal community, the study describes processes used in the development of such a program. Three different groups of people were asked for their opinions: community leaders, including elders and town councillors; school leaders, including teachers and administrators; and students. Based upon the interviews and a review of research literature, a pilot Grade 10 program was developed and has been implemented. In this project description, the program and its potential for engaging the students is described in light of the examination of Bronfenbrenner’s model of human development. The most important aspect of Bronfenbrenner’s theory for this study has been its conceptual aspect, especially in conceptualizing the multi-system influences on students and his assertions about transition zones. The findings from this study demand that educational planners, especially those involved in community-based program development, need to look beyond the classroom microsystem to other Microsystems the students participate in. Especially important is identifying and understanding the nature of transition zones as critical factors influencing student engagement with school science.

Research Study 8: Sustainability Science—A Systems Approach

_Mona Maxwell, Gordon Robinson, and Amanda Tétrault Freedman_

If a sustainable world is to become a reality, it is necessary that students be provided with the tools and necessary critical consciousness to become fully global citizens. This work is a modest response to this challenge that aligns, albeit not entirely, with Bronfenbrenner’s ecological model, in that the outcomes are primarily (but, due to complexity, not exclusively) a response to the interaction of science teaching and learning with the global environment, that is, the “macrosystem.” It is also a study of the utility of science in sustainability education. Reported are Middle Years (Grade 8) and Senior Years (Grade 11) studies in which sustainability-related curricular resources were taught to samples of classes (see [www.umanitoba.ca/outreach/crystal/sustainability.html](http://www.umanitoba.ca/outreach/crystal/sustainability.html)). Pre- and post-testing of critical consciousness of human-nature and science-sustainability relations demonstrated significant increases in the Grade 8 study, even although the curriculum had been constructed to completely embrace provincially mandated outcomes. In the Grade 11 study, which was constrained by curricular learning outcomes (chemistry) for some
classes, but not to the same degree in others (current topics in science), only increased consciousness of the human-nature relationship could be attributed to the curricular intervention, suggesting that the increasingly discipline-bound conditions of Senior Years science may not be particularly conducive to effective sustainability education. If one assumes that the intended outcomes of both studies are the emergent properties of many dynamic interactions (Senge, 1990), there seems little advantage to the strict application of the Bronfenbrenner model, and some other simple systems model (see Meadows, 2008) might be more appropriate.

Part 4: Summary and Recommendations

The outcomes of these eight individual projects suggested that Bronfenbrenner’s bio-ecological model has several valuable applications in educational development. First, Bronfenbrenner’s model assisted in conceptualizing research, especially in identifying what developmental outcomes might be targeted and, thus, measured. The studies were able to ascertain that development is a measurable outcome. Second, the model assisted in understanding and identifying the multi-system factors influencing development. Based upon this understanding, several of the projects were able to design and implement mechanisms to foster development in response to this understanding. Through awareness of these likely impeding and contributing factors, developmental outcomes were able to be improved. Third, the model helped in identifying and fostering specific processes, especially at the face-to-face level, that are likely to contribute to or impede educational development. Fourth, the model was seen to be a simplistic foundation for understanding the multi-system factors influencing development. Although researchers identify limitations of the model because of its focus on child development, and, thus, obvious lack of specificity to educational development beyond the individual level, we recognize its inherent value for those working in the area of educational development.

The authors of this monograph suggest that Bronfenbrenner’s bio-ecological model’s strength is found in its critical function, that is, its ability to assist in identifying potential contributors or inhibitors to educational development. We see its strength primarily in the conceptualization of programs that are grounded in seeing measurable change in dimensions associated with the individual. We exhort its use in educational development activity, especially in settings where constructive, dyadic relationships are at the heart of the proposed change.
INRODUCTION

Prior to his death in 2005, Urie Bronfenbrenner commented on what he perceived as the limited application of his bio-ecological theory or model of human development within the context of education (Bronfenbrenner, 2005). It is not difficult to agree with Bronfenbrenner because development is at the heart of education. Education is not static. As Dewey asserted, education as growth or maturity should be an ever-present process (1907). It is in an ongoing process of development because it is or should be responsive to context. Conversations about education often focus on aspects that are central to the construct of “development.” We often hear about teacher development or curriculum development in response to identified needs or proposed changes. We know that schools are concerned about students and their development as learners and the development of their teachers and their teaching as response to their students to foster the development of their learners. We hear about educational development at the school level and divisional level, again, often as a response to identified concerns. Programs are developed, curricula are developed, and policies are developed all in effort to, primarily, assist students in their development as learners. At a national and international level we, equally, refer to educational development, primarily for responding to important and, usually, changing educational goals reflective of the voices of its citizens. Education responds to voices and one would expect these voices primarily to be reflective of what is important to its citizens—especially our children. As Dewey asserts, it is our responsibility to institute the conditions for present experience that will have a favourable effect upon the future (1907).

Urie Bronfenbrenner’s bio-ecological theory is equally a response to fostering development—the development of the human being—especially children. It, in itself, was proposed as a theoretical frame for understanding and, in turn, fostering development, especially for children. For this reason, it would appear there is an inextricable link between educational development and Bronfenbrenner’s bio-ecological theory.

The establishment of the University of Manitoba Centre for Research in Youth, Science Teaching and Learning in 2004 was premised upon assisting educational partners within central Canada in their development. There was a need to assist teachers, schools, communities, school divisions, provinces, and territories in being responsive to the identified needs of their learners. Based upon this identified need, the Centre sought to formulate its research response upon the theoretical foundations of Bronfenbrenner’s model. What is presented in this monograph is a sample of the outcomes of this response, primarily focusing upon a description of the Bronfenbrenner bio-ecological theory tenets applied and the processes employed in the research activity. Further, it evaluates the utility of Bronfenbrenner’s model based upon these outcomes.
In order to understand Bronfenbrenner’s bio-ecological theory it is important, first, to understand the historical context from which it was developed. The pioneering work of Kurt Lewin is known to have had a significant influence on Bronfenbrenner, who, in his early professional life, was a social psychologist colleague of Lewin. Lewin, often cited as the forerunner of Learning Environment research (Fraser, 1994), is most renowned for his “field theory,” a proposition that human behaviour is the function of both the person and the environment (Lewin, 1935; Deaux & Wrightsmann, 1988). This means that one’s behaviour is related both to one’s personal characteristics and to the social situation in which one finds oneself. For Lewin, behaviour was determined by the totality of an individual’s situation. In his field theory, a “field” is defined as “the totality of coexisting facts which are conceived of as mutually interdependent” (Lewin, 1951, p. 240). For Lewin, who was well versed in physics, vector forces and their direction and magnitude featured highly as determinants of human behaviour. This premise continues to be affirmed by contemporary researchers such as Harvey (2002) who purports that individuals are a product of co-determination as a result of the dialectic between individual and society. Emphasizing the context-specific nature of development, Lewin asserts that individuals behave and develop differently according to the way in which tensions between perceptions of self and of the environment are worked through. Understanding the nature of this topology is critical to understanding the processes influencing development.

Lewin’s seminal work on field theory has served as the foundation for the development of Urie Bronfenbrenner’s bio-ecological theory, a theory that has only recently been applied to science education (see for example Lewthwaite, 2006, 2008). Within his bio-ecological theory, development is defined as the phenomenon of continuity and change in the biopsychological characteristics of human beings both as individuals and as groups. As cited previously and of central importance to this research program, Bronfenbrenner describes development as the sustained, progressively more complex interaction with, and activity in, the immediate environment (Bronfenbrenner, 2005, p. 97). These descriptions of development are central to our CRYSTAL studies because if there is indeed educational development, there should be evidence of progressively more complex interaction with and activity in the environment in which the individual is located.

For Bronfenbrenner, the ecological environment, unique to each individual’s situation, is seen as a series of nested and interconnected structures. The innermost structure is the individual. Bronfenbrenner suggests that individuals possess developmentally instigative or personal attribute characteristics that invite, inhibit, or prevent engagement in sustained, progressively more complex interaction with and activity in the immediate environment (Bronfenbrenner, 2005, p. 97). The remaining four nested structures range from the immediate face-to-face setting...
to the more remote setting of the larger culture. Bronfenbrenner suggests that the most proximal and significant sphere or setting is the individual’s microsystem: the pattern of activities, roles, and interpersonal relations experienced by the developing person in a given face-to-face setting with particular material and physical features and containing other persons with distinctive characteristics, personalities, and systems of belief (Bronfenbrenner, 2005, p. 148). The remaining three nested structures are more removed from the individual but still of consequence. The developmental processes that occur within the microsystem are in good part defined and limited by the beliefs and practices of the mesosystem, the second of the four nested structures. The mesosystem contains society’s blueprint for a particular culture or subculture. The third structure, the exosystem, refers to environmental influences that do not directly involve the developing person, but even so influence the setting in an indirect manner. Finally, the structure most removed from the individual, the macrosystem, refers to societal and cultural ideologies and laws that impinge on the individual.

Of importance to this inquiry is the acknowledgement that, as Bronfenbrenner suggests, supporting processes within these overlapping environments are “engines” for development. As well, Bronfenbrenner (2005) proposes that these engines are context-, time-, and process-dependent. This implies that the factors that influence an individual’s development cannot be generalized but, instead, are multi-system in nature and unique to each setting. That is, in fostering development successfully one must take into account an individual’s personal attributes, the context in which the development takes place, the time at which the development process is occurring, and the processes each person experiences. Simply put, things need to come together just at the right time for an individual to develop. Similarly, individual or multi-system factors can neutralize any attempt to work towards this aspiration.

Bronfenbrenner’s bio-ecological theory goes beyond providing a framework for identifying and conceptualizing the multi-system factors that influence development. That is, it goes beyond identifying forces within the individual and microsystem levels influencing an individual’s development. It also considers an individual’s topology—his or her setting, and the way in which individual and external forces interplay to influence development. It, most importantly, attempts to underscore processes and the dynamics of these processes that might influence development. His model emphasizes, especially, proximal processes usually within an individual’s microsystem—those patterns of activation closest to the individual that drive or thwart stability and change over the lifespan.

Although much more could be written at this stage about Bronfenbrenner’s model, the authors regard this initial commentary as sufficient to describe, first, the Centre’s overall organization and, then, activity. Following this description, the eight research projects will be described and, by so doing, will further elaborate on Bronfenbrenner’s model.
PART 2: UNIVERSITY OF MANITOBA CENTRE FOR RESEARCH IN YOUTH, SCIENCE TEACHING AND LEARNING (CRYSTAL)

The University of Manitoba CRYSTAL was established as a national pilot program financed primarily by the Natural Sciences and Engineering Research Council (NSERC). The Centre involves researchers from seven universities (Brandon, Winnipeg, Saskatchewan, Regina, Lakehead, Manitoba, and Collège universitaire de Saint-Boniface) and educational partners from Nunavut, Northwest Territories, Saskatchewan, Manitoba, and northern Ontario. Although Bronfenbrenner’s bio-ecological model has been, as yet, the foundation for a limited number of development projects within education, the management team responsible for the conceptualization of the University of Manitoba CRYSTAL believed that Bronfenbrenner’s theory provided a valuable theoretical framework for informing the Centre’s research activity because the focus of the Centre’s work was developmental in nature. In this section, we describe the focus of the research activity undertaken in relation to Bronfenbrenner’s theory and the manner in which the research of the Centre has been organized.

In brief, the initiatives of the University of Manitoba CRYSTAL are guided by two central questions. What factors impede, contribute to, and have the greatest consequence on science and mathematics developmental success for students? How can CRYSTAL use this understanding to empower the user community to contribute to improved science and mathematics developmental success for students? Success in this project is a developmental term broadly defined as a positive outcome or desired end (e.g., better conceptual understanding or improved self-concept as a student or teacher of the subject). Building upon Bronfenbrenner’s ideas, central to identifying the contributors to success is an understanding of the individual and the dynamic between the individual science and mathematics student and his or her environment. If we understand how the science and mathematics education environment has an impact on the individual as he or she progresses through the education system, we are in a position to assist the user communities in providing environments of consequence for students. It is recognized that student success will increase by identifying “risk factors” and minimizing them and identifying “protective factors” and optimizing them (Rutter, 1987a). Risk factors are processes in the individual’s environment (e.g., poor classroom instruction) that contribute to negative trajectories in science and mathematics. Protective factors are processes in an individual’s environment (e.g., a committed family member) that contribute to positive outcomes in school science and mathematics. A qualitative measure of the combined effects of risk factors and protective factors is often referred to as “resiliency.” The Centre aims at increasing resiliency, while recognizing that students as dynamic systems interact with at least three other interacting dynamic systems— their immediate environment (e.g., teacher, family), the even larger environment of the local community, and the yet larger global environment.
(Bronfenbrenner, 2005). This is essentially a dynamic systems model in which the focus is on one particular emergent property: the degree of science and/or mathematics success determined by the interplay between the individual’s risk and protective factors.

This CRYSTAL initiative has worked in four systems reflecting these four types of interaction across cultural (e.g., anglophone, francophone and Aboriginal) and geographical (e.g., urban, rural, northern) gradients characteristic of the geographical central and northern region of Canada that this CRYSTAL initiative represents. It has worked to identify risk and protective factors with a view to having a positive impact on emergent success in science and mathematics through a variety of initiatives. The interaction of the dynamic systems this CRYSTAL research focuses upon can be visualized as illustrated below. Figure 1 below depicts how the research activity has been organized and the management and communication structure of the Centre.

The CRYSTAL research is structured according to the ecological systems identified by Bronfenbrenner (1979). The first system examined is the ecology of the individual learner, whether the learner be a teacher, teacher candidate, or student. This system of the CRYSTAL initiative focuses on the personal attribute factors that influence an individual’s interaction with science and mathematics. Examples of factors considered in this system are teacher’s perceptions of their roles as teachers and their perception of factors influencing their professional learning. The second system examines the impact of the proximal relationships of the microsystem in the
ecology of the individual: teachers, family, and peers. In this system, the research program focuses on science and mathematics learning in the classroom and how social factors such as teachers, family, and peers influence science and mathematics learning and success. The third system examines science learning in the context of the community and investigates how the local community as a component of, typically, the exo- or mesosystem, can work collaboratively to enhance the science and mathematics success of the individual student. Finally, the global system at the macro-level considers the interplay between society and science and mathematics success through participation in global science and mathematics initiatives. The short- and long-term activities and research have focused on one or more levels of the individual-environment interplay outlined in the following sections (e.g., the individual learner; the individual learner and the classroom and school system; the individual learner and the local community system; and the individual learner and global system). By so doing, the research has been motivated to provide a holistic understanding of how the processes within and among each of the interconnected systems an individual experiences can separately and collectively have an impact on an individual’s development and success in science and mathematics education. The following section details the research activity undertaken by some of the researchers.
PART 3: RESEARCH APPLICATIONS: EIGHT STUDIES APPLYING BRONFENBRENNER’S THEORY

In all, the University of Manitoba CRYSTAL’s research was organized into seventeen research and development projects, eight of which are described here. Each of the projects was seen to be resident primarily within one of the systems described in the previous section. For this reason, the projects to be described will be located within one of these systems. Each project is described in terms of

- context
- application to Bronfenbrenner’s bio-ecological theory
- outcomes
- evaluated utility of Bronfenbrenner’s model

The research projects are organized according to the four system interactions described in the previous section.

System A: The Individual

Research Study 1: Fostering Chemistry Teacher Development towards a Tetrahedral Orientation in the Teaching of Chemistry

Brian Lewthwaite and Rick Wiebe

Context

Recent curriculum development in chemistry education in Manitoba explicitly emphasizes a preferred shift in teaching from a more algorithmic orientation to one that is more learner-focused and is consistent with a “tetrahedral” chemistry teaching orientation. It is believed by the Manitoba curriculum development team that this tetrahedral orientation is not, as yet, explicitly underpinning any other chemistry curriculum internationally, but, in the foreseeable future, will be commonly evident. A tetrahedral orientation emphasizes that chemistry understanding is best fostered through the use of pedagogical strategies that foster a “congruency” among chemistry’s four representative dimensions: the macroscopic (laboratory experiences); the sub-microscopic (molecular representations using visual instructional materials such as computer simulations or manipulatives); the symbolic or logical (abstract representations in the form of chemical symbols, equations, and calculations), and the humanistic (situating chemical concepts, symbolic representations, and chemical substances and processes in the authentic contexts of the human beings who create substances, the cultures that use them, and the students who try to understand them). In brief, the orientation encourages students and teachers to be experiencing, thinking, and communicating chemistry on these four levels. This tetrahedral orientation is illustrated in Figure 2 on the following page.
As might be expected, the new Manitoba chemistry curricula (Manitoba Education, Citizenship and Youth, 2006, 2007) with its advocacy for a tetrahedral orientation brings with it an orientation to chemistry teaching that is unlikely to be consistent with current chemistry teaching practice among Manitoba’s chemistry teachers. As suggested by Johnstone (1991) and Gabel (1999), most chemistry teachers focus primarily on the most abstract teaching and thinking level, the symbolic, and thereby, any effort to bring about changes to chemistry teaching practice must be accompanied by significant support. As research asserts, a new curriculum is rarely accompanied by teacher change unless accompanied by significant and strategic support (Fullan, 1992). This project endeavours to monitor its success based upon how teachers are teaching in accordance with students’ responses to their preferences for their teacher’s teaching.

Bronfenbrenner defines development as the progressive change towards identified goals and ends (1979), in this study’s case a tetrahedral orientation to chemistry teaching. Bronfenbrenner’s model purports that personal attribute and multi-system environmental factors influence development and, to foster [teacher] development, mechanisms to minimize the risk factors and accentuate the supportive factors influencing [teacher] change positively are necessary (Bronfenbrenner, 1979; Rutter, 1987a). Central to the success of this particular project was the understanding of what personal attributes and environmental characteristics negatively influence teacher change and how these conditions might be mitigated through supportive mechanisms enacted in the professional development (Lewthwaite, 2004). The first author’s research-based experience in professional development using Bronfenbrenner’s model (Lewthwaite, 2004) provided a clear picture of what supportive factors, both teacher and multi-system environment specific, were critical to successful professional development. These were combined into the organization of the development agenda.
First, several personal attributes and multi-system environmental attributes critical to supporting professional development were considered, and, wherever possible, combined into the organization of the development agenda (see Figure 3 below).

<table>
<thead>
<tr>
<th>Figure 3</th>
<th>FACTORS PERCEIVED LIKELY TO CONTRIBUTE POSITIVE CHANGES IN CHEMISTRY TEACHER DEVELOPMENT</th>
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</table>

1. **Individual Teacher—Personal Attribute Factors:** helping teachers to see the need for change based on the aspirations of a new curriculum implementation; providing a professional development (PD) agenda based upon their identified needs and interests (content knowledge and pedagogical content knowledge); providing concrete learning opportunities for promoting vicarious and reflective experiences during PD

2. **Microsystem Factors:** encouraging colleagues from the same schools and divisions to attend the PD sessions; soliciting student response through the Chemistry Teacher Inventory (CTI) to identify teaching strategies that support student learning; developing an online network among teachers to provide regular contact and support; using effective PD facilitators providing sustained PD sessions over several years

3. **Mesosystem Factors:** informing and gaining support of senior administration; engaging the involvement of senior chemistry teachers in the project to advocate the professional value of PD

4. **Exosystem Factors:** informing and gaining support of school divisions in providing sufficient funding to support teacher release for PD over a long period of time and the purchase of materials advocated by the PD and new curriculum; ensuring divisional consultants support the agenda

5. ** Macrosystem Factors:** ensuring the PD is aligned and timed to correspond with provincial curriculum standards; ensuring the PD materials developed collaboratively as a product of the PD are made available online to teachers
As posited by researchers and educators in science education (for example, Loucks-Horsley, Hewson, Love, & Stiles, 1998; Supovitz & Turner, 2000), the professional development program negotiated by participants and facilitators modelled inquiry forms of teaching and teacher reflection-on-action (Schön, 1983, 1987) was sustained engaged teachers in concrete teaching tasks focused on the development of teachers’ subject matter and pedagogical content knowledge was grounded in specific curriculum and professional development standards would be supported at both the school and divisional level

Second, it was ascribed that teachers would learn new pedagogy and content as a result of their reflections about their practice through their collaborations with colleagues and content and pedagogy experts. As well, this reflection would be supported and possibly even instigated by ongoing feedback from students about their teacher’s teaching and how it supported their learning. In this sense, reform and improvement were seen as a collaborative activity.

Outcomes of the Study

In accordance with these insights the ongoing chemistry teacher development project involved three cohorts of chemistry teachers from different geographical regions of Manitoba for a total of 74 chemistry teachers. Thirty-two of the teachers had been involved for the duration of the project and had attended all 15 sessions, 34 had attended multiple sessions over the five years but not all, and eight teachers had attended only one or two sessions. During the course of a year, teachers from each cohort attended three professional development days focusing on one of the five unit clusters (for example, Gases and the Atmosphere) of either the Grade 11 or Grade 12 curriculum. If teachers collaboratively decided, multiple sessions were spent on one cluster. Since there are 10 unit clusters in total over the two grade levels it was anticipated that all clusters would be addressed by the end of the five-year project. This indeed was the case. The sessions typically involved the identification in advance of specific learning outcomes that require a teaching orientation unlikely to be consistent with current teaching practice. Teachers in attendance and CRYSTAL facilitators participated in tangible teaching examples (for example, demonstrations, laboratory experiments and investigations, practical applications, computer simulations) that addressed these learning outcomes in a manner consistent with the curriculum’s tetrahedral orientation.

The instrument used to gauge teacher development in this project was the Chemistry Teacher Inventory (CTI) (Appendix A). As Bronfenbrenner suggests, development is the progressive change towards identified goals and ends (1979), and this development should be evidenced in the progressively more complex interaction
with and activity in the immediate environment (Bronfenbrenner, 2005, p. 97). As researchers, we reasoned that pedagogical progress could be evidenced by changes in behaviours associated with any of the individual items on the questionnaire and, thus, used the CTI as single items. The data in column two (A: 2006) (Appendix B) represent the mean scores and rank of use for each teacher behaviour and classroom contextual characteristic (n=74) at the onset of the project. Although many comments could be made about these data, what is important to the focus of this study and the tetrahedral orientation of the curriculum is the limited (“rarely”) use of visual images (2.24), computer-based simulations (2.60), use of manipulatives (1.24), demonstrations (2.87), history of chemistry applications (2.10), history of the development of chemistry ideas (2.17), and explaining at the molecular level (1.24). Conversely, the performing of calculations in class (4.52) and on tests (4.56) is given a very high (“often” and “almost always”) level of use. It is inferred from these data that teachers, consistent with Johnstone’s (1991) and Gabel’s (1999) assertions, place a very high emphasis on the symbolic thinking level in their teaching as compared to the macroscopic level, molecular level, and human element.

Subsequent applications of the CTI occurred two years later in March 2008 after the ninth professional development session. At this time, teachers were asked to complete the CTI for the chemistry classes they were currently teaching. The majority of teachers were teaching only the Grade 11 Chemistry course (n=48) and fewer (n=44) were teaching Grade 12. Even fewer were teaching both Grades 11 and 12 courses (n=13) or multiple sections of either or both Grades 11 and 12 classes (n=11). Teachers were asked to complete the CTI for a particular grade level and identify the grade level on the CTI. In some cases a teacher completed two CTIs, one for Grade 11 and one for Grade 12. The data from the second implementation of the CTI in March 2008 are represented in columns three (B 2008: Grade 11) and four (C 2008: Grade 12) of Appendix B. Again, these data represent the mean scores and rank of use for each teacher behaviour and classroom contextual characteristic.

The data presented in Appendix B presents the comparative means and their statistical significance. Although several analyses could be made from these data, the authors believe that the most significant are those associated with teachers teaching in correspondence to the intent of the Manitoba chemistry curriculum and its tetrahedral orientation. That is, do teachers’ changes from 2006 to 2008 indicate a perceived shifting orientation that reflects the human element, macroscopic level, and molecular level? The statistically significant increased changes between 2006 (column two) and 2008 (column three and four) are

- using visual images to clarify chemistry ideas
- talking about the historical development of chemistry ideas
- asking students to explain what has been demonstrated
- using manipulatives to help understand what is happening at the molecular level
- having to explain chemistry ideas at the molecular level
- referring to the history of the development of chemistry ideas while teaching
Despite the statistical increase in their use, these behaviours and characteristics are still predominantly in the “rarely” or “sometimes used” categories. Statistically significant decreased changes between 2006 and 2008 include the following:

- students making notes from textbooks
- students performing calculations in class
- students being assigned problems from texts

As well, although there is a statistically significant decrease in the students performing calculations on tests and in class, the emphasis on performing calculations is still a frequently used classroom characteristic.

In all, these changes indicate that some of the strategies corresponding to a tetrahedral orientation are being used more commonly in both Grades 11 and 12 Chemistry classrooms, albeit only somewhat more frequently. As well, these data suggest that the commonly used strategies (e.g., performing labs, assisting students when they need help, allowing students to work together on problems, providing students with many examples) traditionally used in chemistry classrooms continue to be used frequently. Interestingly, several behaviours and characteristics strongly emphasized within the professional development program are not evidenced as being statistically significant. As an example, the use of computer-based simulations to promote visualization of the molecular level is not used in Grade 11 Chemistry classrooms significantly more despite the considerable time spent developing resources and in the professional development sessions fostering teacher awareness of and capabilities in how to use these resources. In summary, the statistical data suggest that teachers are gradually broadening their use of behaviours that support student learning.

From a Bronfenbrenner perspective, teachers are perceiving that they are progressively showing more complex interaction with and activity in the immediate environment (Bronfenbrenner, 2005, p. 97). From the perspective of the tetrahedral orientation of the curriculum, the data would suggest that teachers are showing a gradual development towards a more balanced tetrahedral orientation using more often strategies corresponding, especially, to the molecular level and human element, albeit retaining a strong affinity towards the symbolic dimension. These findings affirm Gilbert and Treagust’s (2008) assertions that making the connections among these tetrahedral vertices, especially the macro- and microscopic levels, may be, indeed, difficult changes for teachers.
Utility of Bronfenbrenner’s Theory and Implications for Education

Bronfenbrenner’s model has been important for conceptualizing the professional development program described in this study. Of critical importance has been identifying likely supportive multi-system factors influencing teacher development. As well, Bronfenbrenner’s (1979) description of development has also been important. He defines development as the progressive change towards identified goals and ends evidenced in the progressively more complex interaction with and activity in the immediate environment (Bronfenbrenner, 2005, p. 97). The CTI, in essence, represents the many behaviours teachers use to assist students in their learning, and the perceived changes in the use of these behaviours provided teachers and researchers easily recognizable measures of change. This description of development has been important to us as researchers and for the teachers involved in this study. We have all valued this description in assisting us in understanding whether indeed there has been progress towards a tetrahedral orientation. Although teachers’ perceptions of their teaching can only be verified by classroom observation, the data indicate at face value that the supportive mechanisms enacted through the professional development sessions have had consequences in assisting teachers to change their teaching.

Research Study 2: Learners and Learning in Middle Years Classrooms in Nunavut

Brian Lewthwaite, Barbara McMillan, and Robert Renaud

Context

The establishment of the territory of Nunavut in 1999 emanated from a deep-rooted and overwhelming call through years of lobbying by the Inuit of northern Canada to move towards self-governance in all aspects of Inuit society. In no context was there greater resonance of voice for self-determination than in the domain of education. Through the establishment of Nunavut, Inuit in policy gained self-rule and control over their own institutions including schools. Since 1999, Nunavut has moved towards the establishment of an Education Act (Government of Nunavut, 2008) that sets the course for future developments in education across Nunavut. As the past-Minister of Education, Ed Picco, purported in legitimizing the length of time it had taken to come to a collectively accepted document, “Nunavumiut want a made-in-Nunavut Education Act that reflects Inuit values and culture. We want to ensure [it provides the foundation for] the best quality of education for our children” (Picco, 2006).

With the establishment of Nunavut and, ultimately, the Education Act, the territory faces the challenge of reversing assimilation and regaining a sense of identity especially within the classroom processes that influence the education of Inuit children. “Culture-based education” is identified by the Government of Nunavut Department of Education (GN) as one of the foundational principles for school development in Nunavut. The GN policy requires the activities of organizations
in Nunavut communities to create, preserve, promote, and enhance their culture, including arts, heritage, and language. This policy is based upon the principle that culture, in all its expressions, provides a foundation for learning and growth, and that the GN should support individuals, organizations, and communities to promote, preserve, and enhance their culture (GN, 2005). The underlying premise of culture-based education is that the educational experiences provided for children should reflect, validate, and promote the culture and language of Inuit. These experiences should be reflected not only in the management and operation of the school but, arguably more importantly, the curricula implemented and pedagogies used at the classroom level.

Similar to most Indigenous peoples, Inuit presently participate in a school system that has been drawn from the dominant culture, in their case southern Canadian school system models. Although Inuit staff work in the schools, especially elementary schools, the majority of teachers, principals, and school operations administrators are non-Inuit, and the curricula and pedagogy of classrooms are based on southern models. Because of this, school practices such as the content of curricula and pedagogical practices have both intentionally and unintentionally denied the inclusion of those aspects of culture that have value and are important to children (Bishop, 1996, 2003; Bishop & Glynn, 1999; Chisholm, 1994). This study arises in response to a move towards a better understanding of classroom practices that have value in supporting the learning of Inuit. It seeks to answer the questions: What do Nunavummiut Inuit students identify as success? What are the pedagogical and interactive processes at the classroom level that influence their learning?

Over the past four years the authors, both experienced Middle Years teachers and now researchers at University of Manitoba’s Centre for Research in Youth, Science Teaching and Learning (CRYSTAL), have been working with three northern Canadian Qikiqtani school communities to assist these schools in achieving their aspirations for science education—aspirations grounded in a desire to see Inuit culture affirmed in the school science experience provided for their children. The communities chosen for the project were some of those Nunavut schools that were relatively geographically close to each other (albeit at least one hour of flight time apart and at least six hours of total flight time north of Ottawa, Canada) and were willing to work towards a development project based upon local aspirations for science education in a language of instruction decided by local community, in their case Inuktitut. A variety of goals were anticipated for this project. First, for the school communities, the ultimate goal was to see the establishment of a science education program that honoured community aspirations. Although the results of this preliminary discussion and preliminary outcomes are detailed elsewhere (Lewthwaite & McMillan, 2007; Lewthwaite & Renaud, 2009), the common theme, without exception, was for a science education experience that combined the views of “both worlds,” that is, one that combined the knowledge, values, and skills of both Inuit ways of knowing and western science.
A second goal anticipated for this project was that the practical teaching resources emanating from and an understanding of the processes influencing the realization of these goals would assist by means of example other Nunavut and Aboriginal communities in achieving their own curriculum goals. That is, it was anticipated that the factors and processes influencing an individual teacher and his or her school community’s ability to achieve these aspirations would be identified and communicated through professional and academic publication, and in turn would provide clarity to others in their similar endeavours. These outcomes are communicated in other publications (Lewthwaite & McMillan, 2007; Lewthwaite & Renaud, 2009).

Finally, and central to this study, it was anticipated that the learning experiences provided for students currently, and through the CRYSTAL efforts, would help identify classroom-based pedagogical and interactive processes that influence students’ perceptions of their own school success. This component of the study was premised upon Stairs’s (1994, 1995) assertions that resource development and first language use are only a starting foundation for a classroom that operates upon a broad culture base. She asserts that a broad culture–based classroom experience for Aboriginal children will be manifest in the adoption of social and cognitive processes operating within local Aboriginal culture at the school and classroom level. Although this stage of the project is ongoing, preliminary data collection based primarily upon conversations with children and teachers and observations of successful classrooms provides ample evidence to make some assertions about classroom pedagogical and interactive processes influencing student success which are valuable to many, especially teachers in these communities and Nunavut schools in general. This latter outcome is the focus of this study. That is, what do students and teachers of these students identify as the pedagogical and interactive processes that influence Inuit students’ perceptions of their own school success?

**Applications of Bronfenbrenner’s Bio-ecological Model**

This research is informed by the ideas and explanations of culturally responsive teaching, which is defined as using the cultural knowledge, prior experiences, frames of reference, and performance styles of students to make learning encounters more relevant to and effective for them (Gay, 2000). Although several studies have focused on the identification of the critical elements of instruction influencing the school success of Aboriginal students (for example, Berger, 2007; Clifton & Roberts, 1988; Deakin University Press, 1991; Kleinfeld, McDiarmid, & Hagstrom, 1985), few have focused on grounding the studies in the voice of Aboriginal students themselves, their communities, and their Aboriginal educators.

This project attempts to determine from the perceptions of Aboriginal students what teaching practices contribute to their success as learners. Further, it seeks to determine whether these practices are in students’ home culture, typically regarded as the mesosystem. This understanding is then used to question the protocols of the mainstream classroom and, in response, promote a dynamic and synergistic
relationship between home and community culture and school culture (Ladson-Billings, 1995). This questioning ultimately and purposely “problematises” teaching by upsetting the orthodoxy of classrooms by encouraging teachers to ask about the nature of the student-teacher relationship, their teaching, the curriculum, and schooling (Ibid). By creating this disequilibrium, educators are pushed to seek resolution of these issues so that their classrooms move towards becoming more culturally responsive as they employ a culturally preferred pedagogy. As suggested by Gay (2000), culturally responsive teachers respond to the cultural knowledge, prior experiences, and performance and learning styles of students to make learning more appropriate and effective for them. They teach to and through the strength of their students, attempting to reduce the discontinuity between the home cultures of these students and the processes and environments of the school (Kanu, 2002, 2006).

As Bishop, Berryman, Tiakiwai, and Richardson (2003) assert, at the heart of many school systems’ practice is a belief or, at least, an assumption that western ways are superior and Aboriginal culture, and specifically students, may bring deficits, not assets, to classrooms. Not only is their background experience and knowledge of limited importance, but so are their cultural foundations for promoting learning. Deficit thinking or theorizing, as it is called, is the notion that students, particularly low income minority students, fail in school because they and their families experience deficiencies such as limited intelligence or behaviours that obstruct the learning process (Bishop, 2003; Castagno & Brayboy, 2008; Valencia, 1997).

As mentioned, the underlying premise of culture-based education is that the educational experiences provided for children should reflect, validate, and promote the culture and language of the Inuit of Nunavut. If so, what is most apparent from this assertion is that the microsystem that the teacher and classroom represent needs to be more reflective of the cultural patterns and practices of the school community, that is, the exosystem. The suggestion would be that conflicting practices within classrooms are most evident where there is a lack of synchrony among an Inuit student’s learning orientation, the teacher’s manner of teaching, and the practices for learning represented within the cultural norms of the student’s home culture. Instead, in a culture-based classroom, student experiences should be reflected not only in the management and operation of the school but also in the curricula and programs implemented and pedagogies utilized. It assumes that students come to school with a whole set of beliefs, skills, and understandings formed from their experience in their world, and that the role of the school is not to ignore or replace these understandings and skills, but to recognize the teaching practices and understandings within the cultural context and affirm these in formal classroom settings (Wyatt, 1978–1979).

This advocacy has long been held in Nunavut schools. As Stairs (1995) asserted, Inuit students’ lack of educational success can be attributed to the inability of northern schools to meet the learning needs of their Indigenous citizens through the experiences offered and pedagogies used in classrooms. She stated that this not only includes the use of resource and language materials appropriate for each context, but, more importantly, the culturally located pedagogical processes that
move beyond the what of classrooms to the how of classrooms. Stairs identified in her ethnographical research that the formal learning (referred to as ilisayuq) of Qikiqtani (Baffin Island) schools is radically different than the informal learning of Inuit home culture (referred to as isumaqsayuq) and that successful classrooms are likely to reflect these home practices (Government of the Northwest Territories, 1996). These claims have been advocated for but tragically ignored for decades in Indigenous settings (Wyatt, 1978–1979). Although culture-based education may be rhetorically premised as the foundation of Nunavut classrooms, what would classroom environments and teacher practices look like that are, indeed, reflective of Inuit students’ preferences?

Outcomes of the Study

In answering these questions, a variety of data sources have been employed to triangulate data and increase the reliability and validity of results, that is, to ensure confidence in the findings (Bogdan and Biklen, 1998). These sources of student data include the following:

- completion of a questionnaire in English or Inuktitut by a total of 36 Grades 5 to 8 students in two of the communities
- individual interviews with 24 Grades 7 and 8 students in three communities
- group interviews with 39 students from three Grades 7 and 8 classes from three communities

These three sources of student data included all of the students available through informed consent on the days when the data collection occurred. In all, 89 percent of students, all Inuit and Inuktitut first language speakers, and their parents/caregivers consented to participate in the study. In both the questionnaire and interviews, the questions asked focused on students identifying the following:

- the last time they felt they had been successful in school
- what the teacher does to help them to learn
- what is happening in their classroom when they are learning best
- what they would change about their teacher’s teaching or what is happening in their classroom to assist them in their learning

As well, six teachers (two Inuit, one First Nations, one Indo-Canadian, two Caucasian) identified by their teaching peers, principals, and CRYSTAL researchers as successful classroom teachers in regard to creating positive learning environments were observed during CRYSTAL researcher visits to the schools twice each year over a three-year period. In all six cases, these teachers were observed each year with a different student group. The total observation time of each classroom is estimated to be about 10 hours. Since the researchers have spent on average two weeks per year in each school over four years, they have been able to observe the same students in, typically, four different classrooms with four
different teachers. Students are quite familiar with the researchers as both have worked alongside their regular teachers in teaching science-related activities that are developed as the other component of this research and development project.

Further, eight teachers (six non-Inuit) who were completing their employment with Government of Nunavut were interviewed and asked to consider teacher, student, and classroom characteristics that promoted the creation of positive learning environments and facilitated engagement and learning. Finally, in two schools, results of the interviews with students were shared with teachers at a staff meeting. All teachers were invited to respond to students’ comments about teacher behaviours that influenced their learning. These meetings involved the entire Early and Middle Years teaching staff, which in Nunavut settings is typically predominantly Inuit at the Early Years level and non-Inuit at the Middle Years level. All interviews were audio-recorded. Transcribed sections of the conversations were verified as accurate. As suggested by Bishop (1996), in all cases the formal interview was more of a conversation because of the relationship of the researchers to the students and teachers, and the informal interview was a chat based upon the need for collaboration between researchers and researched in constructing the final story, as evidenced in the vignettes and themes that are to follow.

The primary focus of the CRYSTAL conversations was to try to elucidate through student responses the pedagogical practices that influenced students’ learning—an aspect encouraged by Stairs (1994) in her description of broad culture-based Aboriginal education. In this analysis, the researchers attempted to identify through consensus the low-inference teacher behaviours that influenced student engagement and learning. As suggested by Murray (1999), low-inference behaviours are specific and observable teacher behaviours that help students to learn. The following behaviours were consistently identified by students and teachers. They are not presented in a priority list and are abbreviated because of the limitations of this forum.

**The Importance of First Language Use and Effective Oral Communication**

It is not surprising that since most Middle Years students and their teachers were in classrooms where the students’ first language is Inuktitut, but teachers are not of the majority language and are unable to communicate in students’ first language, effective oral communication was deemed a major factor influencing student learning.
The Importance of Multiple Instructional Strategies

Associated with the previous point is the importance of teachers using multiple instructional strategies to support student learning. It is probable that the most common statement by teachers and students was associated with how they tried to communicate ideas, especially when the learning was associated with abstract ideas. Students commonly referred to learning through an instructional sequence that involved the teacher first modelling, often repeatedly ensuring students visualized what was required to be learned. The classroom observation of effective teachers often revealed this modelling was done in silence and then, the second time around, with a limited verbal account of the procedure or explanation. Following this, teachers would then provide opportunities for students to independently provide an explanation or carry out a task and if necessary, seek teacher help or the help of a peer.

The Importance of Allowing Time and Initial Support for Completion and Mastery

Since students perceive success to be commonly associated with accomplishing a task through to the end, students commonly cited that an effective teacher provides repeated opportunity and the time necessary for students to work through to the end. Where students faced difficulty, teachers were able to provide initial support in order to alleviate possible frustration and instead boost initial confidence.

The Importance of Providing Individual Attention to Support Learning

Building upon previous comments, students repeatedly made mention of the importance of someone, usually teachers, being near students to observe them completing tasks and to repeatedly assure them that they are doing something properly. These comments were typically associated with mathematics where students were asked to complete something on their own. When asked about their most recent examples of success, students often referred to completing numeracy- or literacy-related tasks. Students often required some form of temporary framework or scaffolding, at least until they were able to develop the skills to learn independently. Repeatedly classroom observations showed that these effective teachers or peers were supportive of others’ learning through provision of direct guidance and assurance.
The Importance of Local Contexts and Resources

Consistent with the communities’ aspirations for science education, students repeatedly responded positively to teachers and their inclusion of the local context as examples in their teaching. The underpinning mandate for the CRYSTAL initiative is to honour community aspirations for a two-way learning experience that advocates Inuit cultural knowledge and processes as thoughtful and purposeful (McKinley, 2000). The development of CRYSTAL resources is based upon the premises of culture-based education and the legitimization of local knowledge and processes (Bishop & Glynn, 1999) detailed previously in this paper and a declared foundation of education in Nunavut. Of particular importance to students was storytelling, either hearing stories told directly by elders or the reading of transcribed stories from elders or other members of their community, especially when the stories were in Inuktitut.

The Importance of Reciprocal Learning

Several teachers reported that they found that making provision for students to share their skills, experiences, and knowledge in contributing to the class’s learning was a significant strategy in promoting learning and a positive learning environment. Teachers, especially those who were non-Inuit, emphasized that they quickly realized that encouraging students to help each other was an important and positive vehicle for promoting learning.

The Role of Novel Opportunities

An interesting theme recognized by students was a sense of the unexpected and less orthodox experiences students might be introduced to as a result of their teachers’ efforts. This comment was mentioned repeatedly in one school’s conversations and clarified through conversations in another school. As is mentioned in Inuuqatigiit: The Curriculum from the Inuit Perspective (Government of NWT, 1996), students want a positive learning environment where there is fun, laughter, and a sense of anticipation (p. 17). Embedded within these comments are suggestions that students see that these novel and unexpected opportunities provide evidence to students that a teacher cares about their progress and is willing to tangibly honour their collective successes.

As stated earlier, the data collected from these multiple sources provide evidence of some prevalent themes associated with student perceptions of success and teacher-specific and, most likely, culturally determined classroom characteristics that influence student learning. In all cases, ideas presented are limited to those comments held consistently by teachers and students. These preliminary themes assist teachers in giving consideration to their own teaching practices and environments, primarily as a starting point for reflection upon whether their own classroom practices are responsive to the voices of their own students and their home cultures. As mentioned previously, a culturally responsive teacher should be
able to “problematize” his or her teaching and question the nature of the student-teacher relationship, the curriculum, and schooling in general. At the focus of this consideration are teacher perceptions of the source of problems if they are evident within their classrooms. Are problems located within the nature of students and their culture at the exosystem level or are problems manifest in their own interactions and relationships as teachers with students? If they are located within their interactions and practices within classrooms, are teachers willing to respond so they are able to work towards the establishment of a positive learning environment?

Similar to the work of Bishop and colleagues (2003) and Goulet (2001) and based upon the comments made by students and the information collected from teachers and Inuit educators (GNWT, 1996), an effective teaching profile for teachers of Middle Years Inuit students in Qikiqtani is presented below. The authors acknowledge that these data and points to consider are presented by non-Inuit researchers who have interpreted the data through non-Inuit understandings. Nonetheless, the following list is a starting point for teachers, both non-Inuit and Inuit, to consider and build upon to identify successful practices for fostering the establishment of positive learning environments and pedagogy.

- Effective teachers give consideration to how their students define educational success. They consider what their students perceive as success based upon recognition of where students themselves are proud of their achievements. Accordingly, they reposition their efforts to acknowledge success in students’ terms, especially in giving regard to perseverance and “working through to end” as opposed to simply evaluating the product and placing greater regard on the evaluation outcome. Accompanying this attribute is ensuring that the experiences provided for students have “working to end” opportunities based upon practical, first-hand experiences.

- Effective teachers reconsider what they believe to be the attributes of a positive learning environment in response to what their students identify as a positive learning environment. They reposition themselves in their role and interactions with students to develop a more co-operative, co-generated learning environment. They are caring, consistent, interested, and connected teachers.

- Effective teachers communicate to their students that they care about students’ educational success and that students can succeed. They do not see deficits in their students. They communicate that they work to foster that success and that they want to succeed and are committed to fostering students’ success. They are willing to enter into conversations about what they can do to foster their students’ learning. As Noddings (1996) suggests and as affirmed by Berger (2007), caring is manifest in actions: it delights, challenges, responds, and affirms.
Effective teachers allow room for the use of students’ first language in the classroom. They respond to how students seek to understand their instructions and develop new strategies and protocols such as using the human resources available to them, including other students and support workers in the classroom, to communicate in the students’ first language.

Effective teachers communicate clearly and concisely with their students. Their communication in English is appropriately abbreviated and direct. It simplifies appropriate to the language proficiency of the student rather than complicates.

Effective teachers foster learning by using multiple instructional strategies such as direct instruction and modelling. They reconsider and change their pedagogical practice in light of how students respond to their teaching.

Effective teachers allow time and provide individual support to promote student learning. They develop an awareness of the pace at which their students work and need to complete work satisfactorily and the amount of individual attention they require in their learning.

Effective teachers establish reciprocal learning opportunities within their classroom. They recognize that others can contribute to the overall learning and will promote students to both seek out and provide support in learning as the need arises.

Effective teachers use local contexts and resource materials in their teaching. They do not believe that they are the central figures able to contribute to their students’ learning. They use the local community and the resources within it to support students and their learning. They legitimize the knowledge and practices of the community by endorsing it within the classroom, especially through narratives directly from or about local people.

Effective teachers recognize that they can and must change their teaching to help students learn. They don’t believe that students must learn the teacher’s way and that the student-teacher and student-student interactions need to be controlled or defined by the teacher, but, instead, see the processes influencing student learning as opportunities to change their teaching to better suit their students. They make adjustments and even transformations to the orthodoxy of their practice to provide for the inclusion of practices reflective of the home culture (Harker, 1979).

A question that arises from this study is the uniqueness of these effective teacher attributes for Inuit. Are they not, simply, good teaching practices for all students? The literature, especially in science education, identifies characteristics commonly evidenced of effective teachers (for example, Tobin & Fraser, 1990). As one might expect, the general education literature contains a plethora of citations referring to effective teaching characteristics. One study of significance is Hattie’s (2009) meta-analysis of over 800 studies associated with effective teaching practices as they
relate to student achievement. His meta-analysis is distilled to identify five broad dimensions common to effective teachers. Effective teachers

- identify essential representations of their subject
- guide learning through classroom interactions
- monitor learning and provide feedback
- attend to affective attributes
- influence student outcomes

Although these attributes are evidently linked to some attributes of effective teachers identified through this study for the students of Qikiqtaani, what is most apparently missing in Hattie’s list is any explicit mention of pedagogies that are consistent with students’ cultural norms.

Utility of Bronfenbrenner’s Model and Implications for Education

Although Bronfenbrenner’s bio-ecological model has had much more utility in organizing the overall Nunavut science education project, it has had limited application to this part of the project that focuses specifically on developing an understanding of the characteristics of effective Middle Years teachers. Two aspects of Bronfenbrenner’s model are applicable to this component of the project. First, it is evident that one of the issues associated with schooling in the North is that classrooms typically fail to respond to the microsystem-exosystem cultural norms of the home and community settings students represent. Several of the themes of effective teaching practices identified within this study (e.g., use of first language, succinct communication patterns, use of local resources and contexts) are manifest in students’ home and community culture—the exosystem. Culturally responsive teachers are effective teachers by responding to the cultural norms of the exosystem settings students represent. They are able to use the cultural knowledge, prior experiences, frames of reference, and performance styles of students to make learning encounters more relevant to and effective for them (Gay, 2000). They change their practices and allow for the expression of the cultural norms associated with the social and interactive processes of community in their classrooms. Second, effective teachers become a significant member of students’ microsystems by becoming connected to students’ lives. Their caring is manifest in actions: it delights, challenges, responds, and affirms. Their behaviour underscores the processes and the dynamics of these processes that have an impact on student development—especially the proximal processes—those patterns of activation closest to the individual that drive or thwart stability and change.
System B: The Classroom and School System

Research Study 3: The Development of Elementary Mathematics for Teaching: Challenges and Support

*Ann Kajander, Anthony Bartley, and Jennifer Holm*

**Context**

Mathematical content knowledge for teaching can be a significant stumbling block for many teachers (Kajander & Mason, 2007), yet such knowledge has been cited as critically important for student success (Ball, Hill, & Bass, 2005; Heck, Banilower, Weiss, & Rosenberg, 2008). Exacerbating the problem has been a series of curriculum changes that took place in Canada following a re-visioning of mathematics teaching and learning based on *The Principles and Standards of School Mathematics* (National Council of Teachers of Mathematics, 1989; 2000). In Ontario, for example, the elementary mathematics curriculum was fundamentally changed in 1997, with further revisions following in 2005 (Ontario Ministry of Education). These new curriculum documents are dramatically different from those of earlier generations. Changes were proposed both in content and delivery to include a much broader set of topics as well as significantly different classroom interactions. These learning processes were influenced by social constructivist notions described in the *Standards* and elsewhere, which placed further demands on teachers. What was lacking in the unveiling of this new elementary curriculum was a concerted attempt to provide associated professional development opportunities and to update elementary teacher education. Thus, elementary teachers were expected to teach an expanded set of mathematical topics, using a new pedagogy based on deep understanding rather than memorization, and they were expected to do this without a program of professional support.

Our research has focused on the mathematical aspects of the preparation of elementary teachers. Elementary teachers, mostly subject generalists, have not often been specially prepared in mathematics, and may enter teacher preparation programs with a conceptually weak understanding of the subject (Kajander, 2005; 2007). As well, Ball, Thames, and Phelps (2008) and Silverman and Thompson (2008) have argued that a specialized body of knowledge particular to teaching, initially termed *pedagogical content knowledge* (PCK) by Shulman (1986, 1987), is also needed; indeed Wong and Lai have gone so far as to describe pedagogical content knowledge as the “crucial factor” (2006, p. 1). Yet it is rare for pre-service programs to include specialized mathematics preparation for prospective elementary teachers (Kajander & Jarvis, in press), and a lack of clarity in fact exists as to what should be included in mathematical preparation for elementary teachers (Silverman & Thompson, 2008).
Applications to Bronfenbrenner’s Bio-ecological Theory

That few teacher candidates at the elementary level have connected with mathematics beyond their own experiences as learners has had major implications for the design of this research and its situation within a framework based upon resilience and Bronfenbrenner’s bio-ecological model (1979). Low levels of achievement and interest in mathematics of elementary pre-service teachers demonstrate the characteristics of being “at risk,” particularly in terms of their development as teachers who will include mathematics as part of their teaching (Bell & Kolitch, 2000; Wilkins, 2008). Rutter’s evolving analysis of resilience is discussed by Fleming & Ledogar (2008). Rutter initially identifies three levels of protective factors—the individual, the family, and the community. These factors are consistent with many of the social constructivist principles (Brand & Wilkins, 2007) that have guided our professional development program for these teachers. Rutter subsequently argued that protective factors may be a necessary component, but they are not sufficient to initiate resilient processes such as “building a positive self-image, reducing the effect of the risk factors and breaking a negative cycle so as to open up new opportunities for the individual” (Fleming & Ledogar, 2008, p. 12). Applying structures from Bronfenbrenner’s bio-ecological model (1979), we can see growing interactions between the environment for professional development and the processes of developing mathematical content knowledge. For his first proposition, Bronfenbrenner argues that “proximal processes” (p. 5)—interactions that take place fairly frequently over an extended period of time—are necessary for interactions to be effective. The second proposition states the following:

The form, power, content, and direction of the proximal processes affecting development vary systematically as a joint function of the characteristics of the developing person and of the environment—both immediate and more remote—in which the processes are taking place, the nature of the developmental outcomes under consideration and the social continuities and changes occurring over time during the social period through which the person has lived. (p. 5)

We note that Bronfenbrenner’s second proposition emphasizes these interactions in a process-person-context-time-model (ppctm); specifically that “in the bioecological model the characteristics of the person are both a producer and the product of the development” (1979, p. 5). These propositions, together with Rutter’s model of resiliency, featured in our analysis of factors for consideration in the design of the research and feature in the discussion which follows.

Feiman-Nemser reports pre-service teachers’ assumptions that “content is easy to learn or already familiar because prospective teachers have ‘had’ it in school themselves” (1989, p. 24). This notion of prior experience in mathematics is problematic for both pre-service teachers and mathematics educators. The NCTM-based reforms have led to current mathematics curricula based upon “students’ personal construction of mathematical ideas” rather than more traditional perspectives of “student performance and mastery of mathematical rules and procedures” or “students’ grasp of mathematical concepts and processes” (Feiman-
both of which are more likely to have featured prominently in the mathematics experiences of pre-service teachers. Ball confirms that pre-service teachers have “tended to see mathematics as a body of rules and facts, a set of procedures to be followed step by step, and they considered rules as explanations” (1990, p. 464). In addition, “elementary candidates were more anxious and more convinced that they did not know mathematics . . . . they tended to blame their gaps in knowledge on the arbitrariness of the subject and on their own inadequacies” (p. 464).

Math anxiety is a construct that has been well developed in the literature (Hilton, 1980; Vinson, 2001), with Hembree (1990) reporting the highest measured levels occurring among those “preparing to teach in elementary school” (p. 42). Wilkins reports that “teachers with negative attitudes toward mathematics used instructional methods that were more rule based and teacher-directed than teachers with more positive attitudes (who used methods that focused on understanding, exploring, and discovering mathematical relationships)” (2008, p. 143). Vinson (2001) reports that mathematics methods courses that have emphasized mathematical understanding have contributed to reducing math anxiety.

The methods that have historically been used to develop teachers’ pedagogical content knowledge in mathematics have also been a consideration. Ball questions the assumptions that university or college courses in mathematics “provide(s) teachers with much of what they need to know about mathematics” (1990, p. 449), with the concern that greater levels of course work in mathematics have increased exposure to traditional methods and led to greater resistance to reform-based approaches (Ball, Lubienski, & Mewborn, 2001). Kyle and Kahn (2009) describe the “standard approach to teaching mathematics and its applications as relatively conservative” (p. 247) with formal lectures followed by formal examinations. They question the use of these “natural defaults of lectures and tutorials based around the solution of problems” (Kyle & Kahn, 2009, p. 248) with students beyond the traditional base of science, technology, and engineering.

The current project, while initially conceived to take place in a formal post-secondary environment, was both constrained and informed by the risk and protective factors for elementary teachers as described. Our program changed and developed as the research progressed. While the elementary mathematics education course, judged to follow principles of social constructivism during the study (Zerpa, 2008), remained relatively unchanged throughout the research, a new course in mathematics concepts for elementary teachers was developed part way through the program of research, and became part of the treatments.

Our study used a mixed methods design to investigate and identify factors related to the development of elementary teachers’ mathematical content knowledge as needed for teaching. The research included work with both pre-service and in-service “junior-intermediate” (Grades 4 to 10, in Ontario) teachers, and a number of sub-projects contributed to the overall project outcomes. To date, data from four of the five years of the study have been analyzed fully or partially.
A pilot study which focused on pre-service teachers’ beliefs, knowledge, and understandings about elementary mathematics took place in 2004–2005, the year before the main study began. An instrument was designed to assess teachers’ capacity in a number of domains. The paper-and-pencil survey included items related to teachers’ ways of knowing and understanding elementary mathematics, as well as their beliefs about mathematics and how it should be taught and learned. The survey was tested with a cohort of about 100 pre-service teachers (Kajander, 2005). Item analysis was then performed to increase reliability. The revised survey instrument was then used with a group of about 40 in-service teachers (Kajander, Keene, Siddo, & Zerpa, 2006) participating in a professional development project offered by a group of regional school boards. Slight modifications were once again performed on the survey. The revised version of the instrument, called the Perceptions of Mathematics (POM) survey, was used without changes during all years of the current program of research, with reliability and validity established during year 1 of the main study (Zerpa, 2008).

The mixed methods design of the five-year program of research included quantitative analysis of survey results from both pre-service and in-service teachers (approximately 400 and 40 teachers respectively, to date, with matched pretest and post-test results). Also included with in-service teachers were the analysis of transcripts of professional learning group meetings (years 1, 2 and 4), transcripts of individual semi-structured interviews (year 3), transcripts of focus group meetings (years 3 and 4), and results of classroom observations (year 3) using an established protocol (Horizon, 2003). Semi-structured interviews were also conducted with sub-groups of pre-service teachers using a pretest / post-test format (years 3 and 4, 25 teachers per year), and classroom artifacts related to pre-service teachers’ mathematical development also informed the results.

Outcomes

In-service

During the pilot study, a group of about 40 Grades 7 and 8 teachers from a number of regional school boards voluntarily participated in mathematics professional development which included three days of professionally delivered mathematics training. This mathematics professional development had a strong focus on mathematical models, use of manipulatives, and connections to students’ levels of understanding, which are the kinds of aspects of mathematical understanding currently thought to fall under the domain of “mathematics for teaching” (Ball, Thames, & Phelps, 2008). Using an earlier version of the Perceptions of Mathematics (POM) survey, significant growth in conceptual understanding of elementary mathematics was found in participating teachers (Kajander, Keene, Siddo, & Zerpa, 2006).
In years 1 and 2 of the main study, professional learning group meetings of four to eight teachers took place monthly, with about ten such groups operating each year. Researchers observed (and in some cases audio recorded) about six of these groups each year, and field notes and transcriptions were examined as data sources. It was found that some of these teacher groups were much more effective than others in supporting teacher growth (Kajander & Mason, 2007). For example, some groups made effective use of available resources and agreed on readings or tasks to be done by group members between meetings, while some did not. Some groups focused their deliberations on details of their own teaching capacity and personal understandings of the required mathematical content as needed for teaching, and worked diligently to improve these. Other groups sought to control external factors, for example, by working on ways to ensure that the “right” students took certain levels of courses in Grade 9, and that the paper flow about students was more accurate, rather than focusing on a personal growth agenda.

In year 3, six selected participants from years 2 and 3 were interviewed using an in-depth semi-structured interview format, and all but one were observed by a researcher twice in their classroom. The classroom observations were documented using an established protocol (Horizon, 2003). All these teachers were judged to be working towards reform-based (NCTM, 2000) practices to at least some degree. This group of teachers was formed into a research focus group which met four times each year for the third and fourth years of the study, each time for a half day. The activities and deliberations of these focus group meetings were designed to support further development of our understanding of the kinds of mathematical knowledge teachers needed for effective elementary teaching (Kajander, 2009). The outcomes of this aspect of the research also formed the basis of the deliberations of the Working Group on Elementary Mathematics for Teaching at the Canadian Mathematics Education Forum (Kajander & Jarvis, in press). A major task of this working group was to construct a policy statement on elementary mathematics for teaching in Canada (see Kajander, in press). This statement recommends 100 hours of instruction in appropriate mathematical content for pre-service teachers, a far cry from the reality of most, if not all, Canadian teacher education programs (Ibid.).

**Pre-service**

The POM survey was administered to over 100 pre-service teachers each year for four years, in a pretest/post-test format. One more year is underway, and analysis is ongoing. The instrument examines mathematical understanding using the variables of procedural knowledge and conceptual knowledge. Procedural knowledge is defined as the skills needed to determine correct answers to standard elementary problems such as multiplying two fractions. Conceptual knowledge on the other hand is about deeper understanding of concepts, which is particularly needed for teaching. To demonstrate conceptual knowledge, participants were asked to explain, justify, give an example, draw a picture or model, or do a typical elementary school calculation another way. The two variables of procedural knowledge and conceptual
knowledge showed significant change during the one-year education program that included a 36-hour mathematics methods course (Zerpa, Kajander, & Van Barneveld, 2009).

Procedural knowledge was initially reasonably high, and increased significantly during each of the first three years of the study, as analyzed to date: t(310)=-15.411, p=0.000, $r^2=0.434$. Procedural knowledge means each year, pre-service teachers, as they began the methods course (and without any prior warning of the survey), were about 70 percent, with means of about 85 percent at the post-test. On the other hand, the conceptual knowledge of the pre-service teachers was extremely weak initially with pretest mean scores each year of about 10 percent. This variable also showed a highly significant increase: t(310)=-25.024, p=0.000, $r^2=0.669$ in each year. Means at the post-test were about 50 percent on the same items. See Holm and Kajander (2009) for sample participant responses. The full survey is available in Kajander (2007). In summary, the data indicate that while conceptual knowledge may have improved significantly during the participants’ (one-year) teacher preparation program, most still demonstrated only a partial ability to explain, model, or justify typical elementary mathematics classroom topics at the end of the program.

In an attempt to address the issue of participants’ weak conceptual knowledge, an optional 20-hour course called *Mathematics for Teaching* was designed and offered beginning in year 3. Preliminary results suggest that pre-service teachers choosing to take the course, while weaker initially, outperform their classmates by the end of the program in mathematical understanding (Holm & Kajander, 2009). Fifty participants have been interviewed to date in a pretest/post-test format, with 25 more interviews underway. These data will be helpful in triangulating the survey results. Preliminary analysis indicates that most participants were very nervous about the mathematics portions of the methods course initially, but felt much more confident by the end of the year. This is particularly true for participants who elected to take the supplementary course, who were generally weaker initially in understanding, yet grew to be significantly stronger than their peers by the end of the course (Kajander, 2009). In summary, significant improvements in teachers’ content knowledge as needed for teaching as well as shifts in beliefs have been shown, and growth increases when further opportunities for teachers are available. However, much more remains to be done.

**Utility of Bronfenbrenner’s Model and Implications for Education**

We find resonance with the concept of a dynamic set of domains of mathematical content knowledge for teaching (Ball, Thames, & Phelps, 2008) and have been organizing this project to focus on supporting pre-service teachers in their mathematics learning. Our own work (Kajander, 2005, 2007, 2009; Kajander & Mason, 2007; Holm & Kajander, 2009; Zerpa, Kajander, & Van Barneveld, 2009) recognizes areas of concern as potential “risk factors” that would work against success as a teacher of mathematics. The maximizing of our “protective factors” has
been achieved by the provision of focused mathematics instruction in a supportive environment—as exemplified by the creation of the Mathematics for Teaching course.

Significant evidence has been found to show that specialized mathematical learning opportunities for teachers, founded on principles of social constructivism, support relatively strong growth in conceptual understanding of mathematics as needed for teaching, which occur along with associated changes in beliefs. Shifts in beliefs include the development of a more conceptually based view together with less dependence on the notion of mathematics as a set of formal methods and rules. Concurrently, evidence has been found suggesting that increases in competence are accompanied by reduced anxiety and increased confidence. The further provision of specialized opportunities such as the new Mathematics for Teaching course accelerate such development.

In summary, our findings indicated that while it is desirable to support teachers in overcoming their anxiety, it is helpful to provide specialized opportunities for content-based development, and that increased access to such opportunities supports stronger growth. Further and broader development of all elementary teachers’ mathematical content-based understanding remains a central and critical challenge for the field.

Research Study 4: Integrating Interactive Whiteboard Technology in Classroom Instruction—An Ecological Transition Study

Shannon Gadbois

Context

Technological advances are changing the learning environment across all levels of education. Students in post-secondary institutions are using laptops in classrooms with wireless Internet access, learning from electronic textbooks, searching electronic databases for research papers, and communicating to faculty members through online course management systems. Similarly, youth in elementary, middle, and secondary schools are experiencing enhanced access to new technology as an essential part of their learning and development. One prominent technology, the interactive whiteboard (IWB), is fast becoming a key instructional tool in elementary and Middle Years education.

Research has shown IWBs offer significant entertainment value for students as well as teachers (Reimer & Moyer, 2005). In addition, for students, IWBs provide a unique tool that promotes learning engagement (Hall & Higgins, 2005), and for teachers, they offer a versatile and professional presentation format (Miller & Glover, 2002). Government support for the purchase of such technology (Haldane, 2007) has meant the implementation of IWBs into British schools to a degree that “many primary schools have equipped every classroom with this technology” (Kennewell & Higgins, 2007, p. 207). Yet, researchers have stated that IWBs have been installed in classrooms despite the fact that there has never been any clear evidence that they
contribute positively to educational outcomes. Furthermore, it has been argued (Burden, 2002) that many teachers may never learn to use the boards to their maximum potential.

Despite research raising these concerns, there continues to be a move towards the educational use of this technology. For example, a visit to Manitoba schools reveals many classrooms have these boards, and in some schools the goal is their installation in every room. This implementation of IWBs in classrooms fits with Manitoba Education and Training’s (1998) emphasis on infusion of technology into instruction. However, their use offers unique opportunities and challenges for teachers. For example, it has been argued that IWB implementation results in less interactivity in the learning environment since the board is perceived to be the agent for interaction rather than the teacher (Rudd, 2007). In addition, with the flexibility and multimedia capabilities of IWBs, it means that classroom teachers have a much broader range of information to consider than ever before. The unique characteristics of IWBs also mean that teachers will have to meet unique expectations from students for their use.

The purpose of this research project is to examine the experiences of nine Middle Years teachers as they prepared for adopted use of IWBs in their classrooms. Findings will focus on the teachers’ ideas about how they would use the boards and their experiences implementing usage as they related to any changes in classroom instruction. These experiences will be examined through the lens of Bronfenbrenner’s bio-ecological framework and, in particular, his concept of ecological transitions (1979, 2005).

Applications to Bronfenbrenner’s Bio-ecological Theory

Bronfenbrenner’s bio-ecological theory (1979, 2005) examines the process of human development taking into account the larger context within which individuals learn. Bronfenbrenner proposed that numerous interconnected systems influence and are influenced by individuals as they develop. Furthermore, he argued that the developing individuals’ interactions with their environment and others, called proximal processes, were the primary factors contributing to development.

Subsequently, he emphasized the four key elements of his theory—process, person, context, and time—which refer to the following respectively: the process of development, the individual characteristics of the developing person, the systems within which the developing person exists, and factors associated with change over time that influence development. Having earlier been dissatisfied with his theory (Lerner, 2005), Bronfenbrenner argued that in addition to process as a key concept in his model, the characteristics of the developing person, like the individual’s disposition, ability, knowledge, experience, and skill, can all have a direct impact on proximal processes. These elements of Bronfenbrenner’s theory are relevant to the research discussed next, particularly his discussion of ecological transitions or changes in the role or setting of the developing person that influence
development. Bronfenbrenner argued that these transitions are developmentally significant because of the resulting change in role and “expectations for behaviour” (Bronfenbrenner, 2005, p. 53) for the developing person.

Specifically, the change in setting and role of the teacher that results from the introduction of IWBs in classrooms may be perceived as an ecological transition. As teachers integrate IWBs in their instruction, their classroom roles and responsibilities change. For example, as facilitators of learning, teachers may experience challenges if the use of the board changes the dynamic in the room such that it becomes the source of interactivity as previous research indicates (Burden, 2002; Rudd, 2007). Furthermore, the characteristics of the teacher, like experience with technology, pedagogical skill, and knowledge of curricula and learning outcomes, will influence how IWBs are implemented. How teachers develop with respect to this technology will be influenced by the time constraints within their microsystem as well as the time they have to share in regular reciprocal interactions with peers teaching similar courses and using the same technology either within their school or in other schools, as well as the number and quality of additional supports (e.g., pedagogical) available to them.

Ultimately, it may be argued that the introduction of IWBs in classrooms constitutes ecological transition. That is, teachers find themselves in an altered setting that changes their role whereby there is increased demand for the board’s technological capabilities by students but also for its potential collaborative capabilities. As a result, at this unique point in time, the roles of students are also uniquely changed by this technology. Specifically, IWB use provides an opportunity for students to become instructional facilitators on some level given that most youth have generally had greater exposure to technology in their short lives in comparison to current classroom teachers who have had to continually develop and change with new technologies as they have arisen.

**Outcomes of the Study**

In this study, nine Middle Years teachers’ (five had at least 18 years and four had between 4 and 10 years of experience) experiences within their first year of implementing the use of IWBs in their classrooms were examined. All the teachers had at least three days of professional development instruction; one day was focused specifically on IWB integration with instructional methods and the remaining days were centered upon resources and lesson planning related to the different clusters in the Grade 6 Science curriculum.*

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* This data was obtained as part of a larger study examining Middle Years teachers’ use of IWBs for the teaching of science.
Prior to using the technology, the teachers were asked to comment on what they thought about how they would use the IWB and how it would change their teaching. Generally, their responses emphasized the potential benefits for the classroom, both for their students and for themselves. The teachers recognized that the IWB would be one more tool for classroom instruction with the added benefit that they would be able to effectively maintain an electronic record of their lessons. They emphasized that they would have to figure out how to fit it into key curriculum outcomes. For example, two teachers summed it up as follows:

“... technology has really changed the way we teach ... in that now we have such a large pool of information available to us that it becomes really difficult for an educator to decide what’s important and where to stop”

“I think the big thing is to realize: Okay, what’s it good for, and what’s it not good for?”

In addition, they typically indicated that they would use it to activate student thought on a topic prior to carrying out a related hands-on task. For example:

“ I think I will set up a lot of my lessons using the SMART Board (a specific brand of IWB) as my sort of beginning part of the lesson and then going on to a lab or whatever.”

When they did their professional development sessions aimed at building lessons, the teachers usually worked in pairs at computers and spent time reviewing IWB information and pre-developed instructional courseware already available for their subject areas. For certain domains, they spent their time trying to put together their IWB lessons. Almost their entire session was spent gradually building the elements for lessons by searching for and reviewing relevant websites. During these sessions, teachers developed lessons collaboratively, sharing information regarding useful web resources and approaches for addressing particular outcomes. Typically, an afternoon was sufficient time only to complete one small lesson. Over the half-day sessions during which they worked, they would typically have assembled all the elements to create a single lesson on a single topic but would not have put together a complete lesson. That is, they still required additional time to create a final product.

Once teachers had been using their boards for several months, they commented on changes in instructional methodology and whether these changes were the same in nature as they had anticipated. Commonly, as they intended, they often used it to start a lesson, as an additional hands-on activity, to help students think about or consolidate what they would be required to do. One teacher gave a specific example:

“... in electricity ... the students come up first and make the circuit first on the SMART Board, so it’s interactive, and then they ... sort of better grasp after the SMART Board of how exactly to make a parallel circuit, or whatever I’m teaching ... it’s an extra visual for them before they build the circuit.”
Furthermore, as a group, the teachers commented that they used the board the first day it was ready for use. They also used it more than they had anticipated. In fact, many of the teachers called it an “essential tool” for the classroom. In addition, several commented that they often used it on the spot as issues arose. Two teachers provided specific examples:

“I use it every day and I use it quite a bit . . . anything I’m teaching, I scan things and pop them up on the SMART Board. . . . It’s great, I can teach a lesson on electricity or flight and use the SMART Board for that.”

“If a question comes up . . . before I would say ‘you look that up and you can tell us about it tomorrow.’ . . . Usually when a student says ‘I wonder about this’ we just say ‘okay, let’s check’ . . . because the whole class can see it at once. It just seems more natural to do it when the question is on their minds.”

An additional and consistent theme in teachers’ comments was that the IWB influenced the way students contributed to lessons. First, teachers gave frequent examples of students’ comfort with the IWB and their eagerness to use it to demonstrate their learning. For example:

“I’ve always tried to incorporate technology but instead of me directing it, saying to the kids, how can you use this? . . . we’ve done projects where I’ve said these are the outcomes I’m looking for, how can you show me them? I had kids say ‘Can we use the SMART Board to make a webpage?’ . . . So it’s them, their eagerness.”

Second, several of the teachers made comments reflective of changes in student interactions in the classroom. In particular, they indicated the classroom IWB created the context for additional interactions between students. The teachers also often reported that when they needed some assistance it was often the case that some of the more technologically capable students would assist by activating particular features of the board or in resetting (recalibrating) the board when it required adjustments. Two examples of teachers’ experiences are indicated here:

“When students have questions about the technology, they don’t come to me, they go to the experts in the class—each other.”

“We, one time, were having problems having some of the tools working on the screen so I had a student who was quite adept sitting at my computer so that if something wasn’t working with the student who was working on the screen she would do it with the mouse at the computer. That was really nice because it made her feel special and important and we certainly acknowledged her skills. And kids are showing each other things like editing or copying and pasting or finding images on the net. They’re showing each other short cuts and how to do things a little more with the SMART Board . . . and I’m not sure why that is because they could easily sit at a computer together and show those things. But I guess it’s because more people can see it. So, if somebody is sitting at the computer and demonstrating how you do it, a large group of kids can see that. I’m seeing that sharing of skills and building of skills more because the SMART Board is in the room.”
Despite the fact that all the teachers were excited and optimistic about the presence of the IWB in their classrooms, key concerns were expressed. First, all the teachers talked about the time demands in preparing lessons for use with the IWB. Two teachers stated a 15- or 20-minute class lesson required between 90 minutes and 2 hours to prepare. These statements are consistent with teachers’ experiences during professional development days when they were planning lessons. One teacher indicated the reasoning behind the time required to prepare:

“These [lessons] would have to be created on our own. The activities need to give information and have an interactive component. They also need to follow what is happening in the classroom and be tied to an outcome. Very time consuming.”

Second, teachers expressed the need for opportunities to work with colleagues and share ideas and IWB lessons. Although most teachers believed they would modify these lessons for their own use, the importance of ongoing collaboration to share ideas and instructional approaches was strong.

Utility of Bronfenbrenner’s Theory and Implications for Education

The introduction of IWBs into classrooms represents what Bronfenbrenner called an ecological transition in that the IWBs have changed teachers’ roles. Now teachers must account for both finding and evaluating materials supportive of the technology and for developing instructional methods that ensure its effective employment. The teachers in this study were uniquely motivated to use IWBs and relatively experienced in terms of content and pedagogical knowledge. Importantly, they reported ways in which students’ experience with technologies introduced some unique opportunities to use IWBs in the classroom. The results of this study demonstrated IWBs could be used directly to change classroom dynamics by relying on teachers as content experts and students as experts in the use of technology. In effect, the ecological transition that may coincide with implementation of IWBs produces a shift in role and expectations not only for teachers but for students as well. With the implementation of this technology, teachers reported situations in which students demonstrated classroom involvement that could have an impact on learner interest and motivation.

To date, research has emphasized that IWBs have motivated students to attend to classroom instruction but has also emphasized the generally superficial level at which teachers have used this technology. However, the research on IWB use has not explored the possible benefits for activating student-initiated learning activities. Through the lens of Bronfenbrenner’s concept of ecological transition, the findings of the present study emphasize the reason why IWB use in the classroom could create the conditions for unique benefits for teachers. At this point in time, many teachers are less knowledgeable about technology than their students and so students have a unique opportunity to contribute to and influence the learning environment.
If the introduction of the IWB creates a genuine ecological transition that can be used to take advantage of students’ technology skills, it would be valuable for educators to explore ways in which this unique technology can affect classroom dynamics. Specifically, this means in addition to encouraging both experienced and pre-service teachers to explore curriculum objectives and learning outcomes for which IWB technology could be utilized, they should also be encouraged to explore situations within which students may be able to take the initiative to establish key learning activities. The result is likely to be enhanced classroom interchange and learning.

Research Study 5: Fostering Teacher Candidate Development

*Brian Lewthwaite and Rick Wiebe*

**Context**

Although teacher education programs overall contribute to teacher candidates’ development, it is commonly regarded that candidates’ professional growth is primarily associated with their practicum experiences. The purposes of the practicum experience for teacher candidates in teacher education are a well-documented and contested topic of discussion (e.g., Dalzell, 1997; Glickman, 1992; Paris & Gespass, 2001). One of the more common themes evident in this literature is the focus on the development of teacher candidates in their multi-dimensional role as teachers during the practicum (Ralph, 2001, 2002, 2003). Although the literature is well established in describing the goal of teacher education in regard to the identification of the capabilities teacher candidates might develop in their multi-dimensional role as teachers, less attention is given to the processes that foster development of the teacher candidate. Specifically, little attention is given to how the environment of the practicum and, more importantly, the interplay between the individual and practicum environment constructively influence this developmental process.

Based upon these introductory comments, this longitudinal study focusing upon chemistry teacher candidates in an after-degree teacher program has three purposes. First, it attempts to understand and systematically conceptualize the individual chemistry teacher candidate personal attributes and microsystem environmental factors that invite teacher candidate engagement in sustained, progressively more complex interactions with their teaching environment. Second, it attempts to foster the development of constructive settings for teacher candidate development by improving the effectiveness of proximal processes based upon the outcomes from the initial purpose of the study. Finally, it examines the efficacy of Bronfenbrenner’s bio-ecological model and its suppositions for constructing such environments and understanding their influence within the context of science teacher development.
Application to Bronfenbrenner’s Bio-ecological Theory

Bronfenbrenner describes development as the sustained, progressively more complex interaction with and activity in the immediate environment (Bronfenbrenner, 2005, p. 97). These descriptions of development are central to this study because if a teacher candidate is indeed developing, there should be evidence of progressively more complex interaction with and activity in their immediate classroom environment. For Bronfenbrenner, the ecological environment, unique to each individual’s situation, is seen as a series of nested and interconnected structures, only two of which—the individual and microsystem—are most relevant to this inquiry.

The innermost structure is the individual. Bronfenbrenner suggests that individuals possess developmentally instigative or personal attribute characteristics that invite, inhibit, or prevent engagement in sustained, progressively more complex interaction with and activity in the immediate environment (Bronfenbrenner, 2005, p. 97). Within the context of this study, a chemistry teacher candidate’s intrinsic motivation to do well during their professional practicum, chemistry teaching efficacy, openness to constructive criticism, and chemistry content knowledge and pedagogical content knowledge are likely to be developmentally instigative or personal attribute characteristics that influence their development during their practicum experience.

Similarly, Bronfenbrenner suggests that the most proximal and significant sphere or setting is the individual’s microsystem: the pattern of activities, roles, and interpersonal relations experienced by the developing person in a given face-to-face setting with particular material and physical features and containing other persons with distinctive characteristics, personalities, and systems of belief (Bronfenbrenner, 2005, p. 148). Within the context of this study, which focuses upon the context of the practicum, chemistry collaborating teachers especially, as well as chemistry students and, potentially, faculty advisors and other teacher candidates within the same setting are likely to be a part of this microsystem. As suggested by Ralph (2003), a variety of collaborating teacher, faculty advisor, and student characteristics are likely to invite or thwart teacher candidate engagement in sustained, progressively more complex interactions with their teaching environment.

Clearly, as Bronfenbrenner suggests (2005), distinctive characteristics, personalities, and systems of belief will contribute to a collaborating teacher’s effectiveness and invite, inhibit, or prevent teacher candidate engagement in sustained, progressively more complex interaction with and activity in the immediate environment—not simply their possession of a broad base of pedagogical and subject matter knowledge and being a good chemistry teacher. His theory foremost considers an individual’s topology: their setting and the way in which individual and external forces interplay to influence development. It, most importantly, attempts to underscore processes and the dynamics of these processes that might influence development. His model emphasizes especially proximal processes usually within an individual’s microsystem—those patterns of activation closest to the individual
(in this case, teacher candidates) that drive or thwart stability and change over the lifespan (in this case the practicum). Proximal processes, according to Bronfenbrenner, allow for the active engagement of the individual, occur often, and are stable over time and provide for increasingly more complex interactions. The proximal process is not simply a resource; it focuses more upon the nature of the resource and how a resource is used.

In the context of a chemistry teacher’s development during a practicum, this construct has obvious applicability. It becomes important for teacher candidates to be actively involved in a pattern of activity that mobilizes and sustains attention, develops knowledge, and encourages the individual to attain slightly higher levels of functioning (Bronfenbrenner & Ceci, 1994). The effectiveness of these proximal processes appears to be at the very heart of what contributes to development. Thus, one can suppose that there can be high and low level proximal processes. The frequency and intensity of the manifestation of a proximal process and whether it invites, inhibits, or prevents engagement in more complex interactions is likely to influence a teacher’s development. As an example, for a chemistry teacher candidate, repeatedly resisting the advice made by a collaborating teacher, is likely to negatively influence the enabling efforts of that teacher and, ultimately, the development of the candidate.

Outcomes of the Study

This research inquiry occurred over a two-year period with two, quite similar in composition, Year 2 cohorts of chemistry teacher candidates, both of which were in their second and final year of their teacher education. Candidates of the first Year 2 cohort (ten teacher candidates) were placed in settings according to a randomized process. The following academic year, candidates of the second Year 2 cohort (twelve teacher candidates) were placed in selected and what were perceived to be “constructive” settings based upon the outcomes of the experiences of the first cohort.

First Cohort of Teacher Candidates: Chemistry Teacher Candidate Aspirations

The developmental aspirations identified by the first cohort of chemistry teacher candidates at the start of their second and final professional year were broadly categorized into two categories: general pedagogical developmental aspirations and chemistry-specific pedagogical developmental aspirations, which promote the attainment of the general pedagogical goals. The general pedagogical developmental aspirations for teacher candidates, for the most part, captured the nature of chemistry as expressed in the provincial curriculum. The curriculum endorses the premise that the study of chemistry should not only introduce and develop in students an understanding of chemistry but also the skills, processes and opportunities that chemistry involves (Manitoba Education, Citizenship and Youth,
Teacher candidate comments indicated that their aspirations for teaching were primarily associated with a more learner-centred approach to teaching focusing on developing student engagement, interest, and learning in chemistry through the use of laboratory-based experiences and teaching strategies that fostered learning.

Teacher candidates also expressed a desire to develop in specific chemistry pedagogical areas. These goals were specific to chemistry, yet likely to be applicable to all curriculum areas. Candidates cited a need to develop in their professional science knowledge base—a complex knowledge base commonly cited as an impediment or contributor to effective chemistry teaching (for example, Gilbert & Treagust, 2008).

Factors Impeding or Contributing to Attainment of Aspirations

The following section provides insight into the several types of factors that teacher candidates perceived either contributed to or impeded the attainment of their developmental aspirations.

Personal Attribute Factors

Teacher candidates were able to identify a variety of personal attribute factors (the “individual” level of Bronfenbrenner’s model) that either impeded or contributed to their developmental success. These included the following:

- **Professional Science Knowledge**: As mentioned earlier in this paper, teacher candidates’ primary concerns were reflected in the inadequacy of their pedagogical content and chemistry content knowledge, an aspect commonly identified in the science education literature (for example, Gabel, 1999).

- **Locus of Control**: Teacher candidates frequently made reference to their sense of autonomy as teacher candidates in influencing what occurred over the period of the practicum. As suggested by Zimbardo (1985), a locus of control orientation is a belief about whether the outcomes of our actions are contingent on what we do (internal control orientation) or on events outside our personal control (external control orientation) (Rotter, 1954). Several perceived that they were constrained within their roles as teacher candidates by having little opportunity to focus on their developmental aspirations and, thus, succumbed to a manner of teaching incongruent with their aspirations.

- **Personal Motivation**: Teacher candidates expressed varying degrees of motivation to achieve their professional aspirations during the practicum. This motivation was largely influenced by the perceived expectations of their collaborating teacher and the responsibilities they had outside of their professional practicum responsibilities.
Clearly Identified Aspirations: All teacher candidates held developmental goals for their practicum. Despite this, only some identified that the possession of a clearly defined pedagogical aspiration actually became a contributing factor supporting teacher candidates in their development towards achieving their intended aspirations.

Efficacy: Teacher candidates’ self-perceptions of their ability to perform the duties (Bandura, 1977) required of them on the practicum was a factor positively influencing their development. This positive perception of their capabilities was an instigative characteristic that fostered their development.

Interpersonal Capabilities: Teacher candidates also identified a variety of interpersonal characteristics that contributed to or impeded their developmental success. These interpersonal characteristics would be best described as those that facilitated or interrupted positive working relationships among students, teacher candidates, and collaborating teachers. These characteristics promoted or inhibited communication and negotiation in an environment of mutual respect.

In summary, the personal attribute factors influencing chemistry teacher development are likely to be common to teacher candidates in other curriculum areas. Although these have been described as discrete characteristics, it is likely that some are interrelated and more important than others in influencing chemistry teacher development. As well, it is apparent that many of these characteristics are influenced significantly by environmental factors, suggesting a strong interplay between the personal attributes of teacher candidates and the environment in which they are situated.

Environmental Factors

Teacher candidates were able to identify a variety of social and physical factors within their practicum microsystem, the innermost system of Bronfenbrenner’s bio-ecological model, which influenced their development as chemistry teacher candidates.

Collaborating Teacher Expectations: A major factor influencing teacher candidates was the expectation of their collaborating teacher. Clearly, some teacher candidates were in environments that constrained their opportunity to work towards the realization of their developmental goals. Others worked with collaborating teachers who were quite benign in their influence on teacher developmental aspirations. It was uncommon for teacher candidates to work with collaborating teachers who were highly constructive in influencing chemistry teacher development. Discussion with candidates focused upon the nature of the interactions that fostered constructive interactions. Repeatedly candidates referred to collaborating teachers paying little attention to detail in their observations and the limited number of observations. Associated with these observations was little identification, especially through negotiation with the candidate, of what “next
steps” might be targeted in future lessons. In all, collaborating teachers collectively were not perceived to be inviting engagement in sustained, progressively more complex interaction with and activity in the immediate environment.

- **Student Expectations:** Teacher candidates also recognized that their students’ expectations, another constituent of the microsystem, also influenced the attainment of their developmental aspirations. Teacher candidates understood that their students’ expectations were largely a reflection of the classroom learning environment characteristics defined by their collaborating teacher. It was not uncommon for students to respond poorly to a different pedagogical approach, especially one that moved away from a didactic stance. This response typically prevented candidates’ engagement in more complex pedagogy in the teaching environment.

- **Collaborating Teachers’ and Faculty Advisors’ Professional Science Knowledge:** Teacher candidates commonly cited their collaborating teachers’ professional science knowledge as a factor influencing their developmental success. They seldom cited the knowledge base of their faculty advisors as a positive factor influencing their developmental success. Teacher candidates were able to identify that their development was only sometimes influenced by the professional science knowledge of their collaborating teacher. This knowledge was either communicated through conversation or observed through their collaborating teacher’s teaching practice. This knowledge base often invited candidate engagement in more complex pedagogy.

- **Collaborating Teachers’ and Faculty Advisors’ Capabilities in Encouraging Reflection-on-Action:** Henderson furthermore asserts that a reflective teacher must work within an environment that promotes a constructivist approach to learning and development. Only one teacher candidate indicated that the environment was one where candidates were being encouraged or required to reflect-on-action as a form of systematic enquiry specifically within their chemistry teaching context (Baird, 1992; Schön, 1983). Some teacher candidates recognized that their faculty advisors advocated a reflection-on-action approach, but because of their brief observation requirements (possibly two per the entire practicum), they were largely unable to contribute to any sustained, systematic enquiry that might have been promoted if they had a better understanding of chemistry teaching pedagogy.

- **Interpersonal Capabilities of Collaborating Teachers and Faculty Advisors:** It is not surprising that the interpersonal characteristics and capabilities of the collaborating teacher and, to a lesser extent, the faculty advisor were major microsystem factors influencing teacher candidate development, usually neutrally. Ralph (2002) cites the mismatch between teacher candidate and collaborating teacher personal characteristics as a significant factor influencing teacher candidate development. Most teacher candidates indicated a desire to work in settings where there is an open and constructive communication focusing on identifying areas of teacher candidate strength and requirements for development.
Similarly teacher candidates sought collaborating teacher commitment to and interest in encouraging their development as teacher candidates.

- **Curriculum Requirements:** Teacher candidates indicated that the curriculum requirements (a component of Bronfenbrenner’s macrosystem) they were required to address also influenced their ability to attain their developmental aspirations. Some curriculum topics provided supportive contexts for their pedagogical orientations; others did not.

- **Physical Setting:** Similarly, the physical classroom setting in which they taught influenced teacher candidate development. Several taught in classrooms where the actual physical setting (e.g., teaching chemistry in a normal classroom rather than a lab-enhanced facility) limited their ability to teach in a way consistent with their aspirations.

- **Resource Support:** Since teacher candidates’ aspirations were closely associated with providing students with concrete laboratory experiences at the macroscopic level, the resource adequacy of their teaching environment either supported or constrained the attainment of their chemistry teaching aspirations.

In summary, members of the first cohort of teacher candidates were able to identify a variety of social and physical environmental factors primarily within their practicum microsystem that contributed to or impeded their development as teacher candidates. In line with Bronfenbrenner’s bio-ecological model, teacher candidate development can be seen to be strongly influenced by individual instigative characteristics, the environment in which the individual is situated, and the interplay between these factors. Equally, as Bronfenbrenner suggests, the most proximal sphere or setting, the teacher candidate’s microsystem—especially the chemistry collaborating teachers and, to a lesser extent, faculty advisors—had the most significant influence on teacher candidate development. Again as Bronfenbrenner suggests, the proximal process is not simply a resource, but it is more how the resource is utilized or its very nature. Some of these resources by their very nature invited, inhibited, or prevented engagement in sustained, progressively more complex interaction with and activity in the immediate environment.

In all, of the ten candidates in the first cohort, eight perceived they had been placed in benign settings, yet, had a high propensity for success. These eight candidates suggested that they had a considerable, yet not tremendous, developmental success during their placement. Two candidates had perceived their own propensity for success less positively. One of these candidates saw his environment as destructive and the other constructive. Overall, all candidates perceived they had experienced some developmental success, but this had been compromised by primarily their placement environment. Of importance to this study was the repeated comment that collaborating teachers, typically, did not engage with teacher candidates. Teacher candidates perceived that there was an absence of a constructive proximal process—that is, a process where collaborating teachers pay attention to and engage
with candidates in a manner that fosters engagement in a sustained, progressively more complex interaction. Again, Bronfenbrenner identifies the establishment of such “relations” or dyads as central to the development process (1979, p. 56).

**Second Cohort of Teacher Candidates: Outcomes of the Intervention**

The brief results presented in this section are associated with the second cohort, members of which had been placed in settings where considerable effort had been provided to foster constructive developmental settings. A description of the processes employed to support this are described elsewhere (Lewthwaite & Wiebe, in press). Again, all teacher candidates’ aspirations were primarily oriented to a more learner-centred approach to teaching, focusing on developing student engagement, interest, and learning in chemistry through the use of laboratory-based experiences and teaching strategies that fostered learning. In all, of the twelve candidates in the second cohort, ten perceived they had been placed in constructive settings yet had a moderate propensity for success. This contrasts significantly with the first cohorts’ perceptions of self where the majority perceived they had a high propensity but were placed in benign settings. It is inferred from these data that when teacher candidates are located in environments where they are encouraged to be more retrospective and focus upon their identified developmental needs, they self-evaluate more critically and negatively. Without such opportunity for self-critique, candidates perceptions are “inflated.” These ten candidates suggested that environmental factors had a considerable, yet not tremendous, impact on their developmental success during their placement and that personal attribute factors such as pedagogical and subject matter knowledge, chemistry teaching efficacy, and motivation were the major limiting factors to their development. The remaining two candidates identified their environments as destructive despite the effort made to place them all in constructive settings. One of these candidates self-identified his propensity for success moderately, and the other self-identified a high propensity for success. Aside from these latter two candidates, the candidates perceived they had experienced some developmental success, but that, overall, this had been compromised by primarily their personal attribute characteristics. Of importance to this study was the repeated comment that collaborating teachers, typically, did engage with teacher candidates and encourage progression in their teaching. They perceived that there was evidence of a constructive proximal process as shown by such behaviours as having expectations for, paying attention to, and engaging with candidates.
Utility of Bronfenbrenner’s Theory and Implications for Education

This study has focused on understanding the processes influencing chemistry teacher candidate development through teacher candidate perceptions of and reflections on their practicum experiences. It is based upon the premise posited by Lewin and Bronfenbrenner that human development is a joint function of both individual instigative characteristics and the environment in which the individual is situated. It emphasizes that individual attributes and characteristics of the environment, in particular the microsystem, have the ability to enable or constrain chemistry teacher candidate development. Further, it has responded to teacher candidate claims to attempt to improve the quality of the proximal processes between teacher candidates and their collaborating teachers.

Of critical importance to teacher development are the many teacher candidate-specific and practicum environmental characteristics influencing teacher candidate development. Most important is the nature of the proximal processes operating at the face-to-face microsystem level of the practicum, especially those operating between teacher candidate and collaborating teacher. As Bronfenbrenner purports, these proximal processes are those patterns of activation closest to the teacher candidates that drive or thwart stability and change during the practicum. It is these processes that contribute to or inhibit the development of a constructive activity milieu. As evidenced in this enquiry, highly operative proximal processes allow for the active engagement of the individual, occur often, and are stable over time, and provide for increasingly more complex interactions. The proximal process is not simply a resource or an environment; it focuses more upon how a resource or the environment is used or operates, that is, the very nature of the resource. It is apparent that for development to occur, candidates need to be actively involved in an ongoing pattern of activity that mobilizes and sustains attention, develops knowledge, and encourages the individual to attain slightly higher levels of functioning (Bronfenbrenner & Ceci, 1994). For developmental purposes, the role of the teacher candidate is to show openness to consideration and reflection and be motivated and confident in working towards developmental goals. Collaborating teachers and, to a lesser extent, faculty advisors are central to fostering a constructive environment. To be mentors they must be active observers, specific in their identification, encouraging of self-reflection and consideration, and challenging and yet supportive as they enable candidates to improve on and sustain more complex behaviours.

This study is also important because it gives evidence that highly operative proximal resources can be successfully developed and implemented by explicitly identifying and cultivating the individual teacher candidate and collaborating teacher characteristics that assist in co-generating constructive developmental environments. At the same time it shows that the mentoring role is one that can be compromised by the environmental milieu in which the collaborating teacher operates. Simply assisting someone to understand the characteristics of a supportive
developmental environment does not ensure these characteristics will become operative.

It is apparent from this study that Bronfenbrenner’s bio-ecological model not only provides an analytical lens for identifying contributors and impediments to teacher development at the multi-system level, it also provides insight into the nature of the proximal processes that are most effective for fostering this development. Bronfenbrenner’s tenets challenge teacher education institutions and science teacher educators to give thoughtful consideration to the essential importance of fostering development of teacher candidates through the establishment of constructive rather than the all too commonly experienced destructive and benign placement environments.

System C: The Local System

Research Study 6: Supporting the Professional Development of Francophone Science Teachers in Minority Language Contexts
Rodelyn Stoeber and Léonard Rivard

Context

Francophone teachers in minority language contexts face multiple challenges related to the growing influence of the language and culture of the English-speaking majority in Canada (Cormier, 2005; Pruneau & Langis, 2000). These challenges were especially prevalent in the small, isolated rural communities outside of Quebec where small groups of Francophones are frequently located, but are now present even in urban communities across the country. The challenges include the limited availability of French-language services and resources, inadequate pre-service preparation for teaching in minority-language settings, as well as the lack of in-service professional development opportunities in French. Moreover, with the increasing number of exogamous households, those in which two or more languages may be in competition for use by family members, the French language no longer possesses a privileged position in the home environment (Gilbert, LéTouzé, Thériault, & Landry, 2004). In this situation, the task of acculturating students in the French culture and language falls increasingly on teachers. Moreover, the remoteness and isolation of the small francophone communities frequently results in a shortage of specialists with teachers often confronted by multi-level classes and few French-language teaching materials that are suitable for students. These challenges, or risk factors, can have a negative impact on science teaching and learning in minority language contexts.

Science teachers in minority language contexts not only have to deal with the significant risk factors already described, but also have the added challenge of teaching the language of science to students. Rivard and Cormier (2008) have described the pitfalls in moving science learners from the vernacular or home language (L1) to the language of schools (L2) and across the divide to the language
of science (L3). The need for supporting these teachers was made abundantly clear by the results of national and international assessments (Bussière, Knighton, & Pennock, 2007; Council of Ministers of Education, Canada [CMEC], 2008) that showed that Canadian francophone students studying science in minority language settings generally score lower than their anglophone counterparts. These students also tend to have a more negative attitude towards science (Pruneau & Langis, 2000). A strong emphasis on transmission-type teaching strategies, the weak science content backgrounds of teachers, as well as an overemphasis on academic basics, such as mathematics and français, in francophone classrooms may all contribute to this difficult situation (Cormier, Pruneau, Rivard, & Blain, 2004). Moreover, linguistic insecurities now plague many francophones who feel inadequate because of the belief that they cannot express themselves as well as other individuals in French. These obstacles have resulted in limited competencies for dealing with texts among minority language students, both in the comprehension and the production of texts. As the communication of ideas is an important aspect of scientific literacy (Ash, 2008; Castano, 2008; Yore, 2008), these students may require additional support for developing the literacy skills necessary for learning science. These students would also benefit from an instructional environment conducive to sharing ideas and to using scientific language in meaningful ways (Rivard, 2004; Rivard & Straw, 2000).

Application of Bronfenbrenner’s Bio-ecological Theory

The Centre de recherche sur l’enseignement et l’apprentissage des sciences project based out of Collège universitaire de Saint Boniface (CUSB) focused on identifying the risk factors influencing minority-language francophone science teachers and on supporting effective science teaching approaches and learning strategies in the classroom for the purpose of mitigating these. A partnership was established between the Division scolaire franco-manitobaine (DSFM), the Bureau de l’éducation française (BEF) of Manitoba Education, Citizenship and Youth, and science and science education professors at CUSB. The partnership focused on defining and implementing a professional development program to support these teachers. Three research strands framed our work in this project:

- determining the risk and protective factors associated with the teaching of science in the francophone minority language context
- developing and implementing a professional development program that addresses the identified needs of these science teachers
- supporting the use of teaching strategies that promote reading and writing for learning science

A common thread running through the three research strands was the exploration of Internet technologies as a protective factor for supporting science teachers as they observed and practised various strategies for teaching science that they could integrate into their own instructional repertoire. In order to promote sustained changes in how these teachers actually teach science, our model offered more than
the typical “one shot” approach often observed in past professional development efforts. Our workshops incorporated an iterative approach that encouraged participants to reflect on practices already learned while they adapted them to classroom realities.

**Strand 1: Risk and Protective Factors**

In order to develop a relevant professional development program for francophone teachers in the minority language context, the identification of their specific needs was deemed a priority. Bronfenbrenner’s bio-ecological model was used as a means to conceptualize the interplay of various factors that have an impact on the teaching of science. These factors could be deemed risk or protective factors according to their effect on individual teachers. Lewthwaite (2006) has suggested the following: Risk factors are personal attribute factors or processes in the individual’s environment (e.g., low science-teaching efficacy, discouraging comments from colleagues) that contribute to negative trajectories in development. Protective factors are the “engine” processes possessed by an individual (e.g., positive self-concept) or in an individual’s environment (e.g., a committed family member) that contribute to positive outcomes and consequence in personal development (p. 333).

Bronfenbrenner suggests that an individual’s development (in this case, the science teacher’s) is influenced by a system of factors, both personal and environmental in nature. These are illustrated in Figure 4 on the following page.
1. **Individual—Personal Attribute Factors:** teacher interest and motivation to teach science; professional science knowledge including knowledge of learners, strategies for teaching science, content knowledge, contextual knowledge, and strategies for teaching science to learners with less-developed French-language abilities

2. **Microsystem Factors:** collegial support among staff in contributing to teacher development in science; student interest in science and language development capabilities; physical resource availability and appropriate French-language science resource materials; language backgrounds of students

3. **Mesosystem Factors:** school-wide priority placed upon science by the school reflected in teacher timetabling and resource allocation; hiring policies and actions

4. **Exosystem Factors:** community aspirations for the school especially in terms of curriculum priorities; community support provided for teachers in their teaching of science; financial decision making at the school board level and its influence on funding availability

5. **Macrosystem Factors:** provincial government curriculum policy decisions; resource material development at provincial level; professional development support within school
Our study showed that in many cases, several factors influencing science program delivery in francophone minority settings tended to be more risk-oriented than protective in nature (Lewthwaite, Stoeber, & Renaud, 2007a). While there are personal factors, such as content and contextual knowledge, negatively influencing the teachers of science, environmental factors, such as the lack of materials and professional development opportunities, may also work against teachers and their teaching of science. Although the factors are listed as isolated spheres, interactions occur among these spheres, for instance, in terms of how environmental factors have influenced (usually negatively) the teacher personal attribute factors. For example, the low priority typically placed on science as a curriculum area by the school and community in comparison to the emphasis placed on French-language acquisition or the teaching of mathematics influences teacher decisions and their motivation towards the teaching of science. More importantly, student French-language abilities hinder teachers’ ability to teach science effectively. Furthermore, the illustration does not suggest that the macrosystem factors which are most removed from the central individual sphere have the least influence on science program delivery. These factors influence teacher needs just as much as other factors found in the spheres closer to the centre.

Teacher profiles were developed based on the above factors in order to establish a relevant professional development program for meeting their expressed needs. The needs identified through analysis of the data included the following:

- issues related to work in the laboratory, including techniques and suitable experiments
- lessons and activities linking theory with these experiments
- resources for teaching about “science, technology, society, and environment”
- resources available in the French language
- the “big ideas” in each science curriculum cluster
- strategies for sharing knowledge in the science classroom
- the integration of available technology tools in the classroom
- supplementary activities that match curricular outcomes

Rivard and Cormier (2008) reviewed the literature on minority language instructional contexts and on the challenges confronting teachers working in these environments. They identified some of the risk factors that can impede student success in science. In addition to those already described, the literature suggests that francophones historically

- have tended to undervalue their language, culture, and schools
- have been plagued by poor literacy levels
- have a history of underachievement in academic settings
- have had less contact with the literate aspects of the minority language
- have often experienced a linguistic mismatch between the home and the school
Rivard and Cormier (2008) also argued that a strong social identity may be among the most resilient or protective factors for assimilation by the anglo-dominant culture (Landry, 2003). Moreover, as most francophone students identify themselves as bilingual, compensatory strategies in the school and classroom may be required (Landry, Deveau, & Allard, 2006). Rivard and Cormier (2008) concluded that minority-language instruction must expand “literacy experiences using authentic materials while scaffolding discourse acquisition” in the science classroom (p. 31).

An evaluation instrument focused specifically on the challenges to science teachers in minority-language settings was also developed and used iteratively throughout the professional development program to assess its effectiveness. This instrument was validated by the science teachers working within the target school division (Lewthwaite, Stoeber, & Renaud, 2007b).

**Strand 2: Meeting Teacher Needs**

The use of technological tools as a support or protective factor for maintaining and enhancing the effectiveness of the professional development strategy was an important aspect of our research. One research project that emerged from this initiative was project PEER (*Petites écoles en réseau*) in which small rural schools were linked together using Internet technologies in order to explore scientific principles and concepts within a social constructivist framework. This project, an offshoot of the larger CRYSTAL program, was conceived because of the dual problems of teacher retention in small rural francophone schools and of very small class sizes within these.

The creation of a virtual learning community was especially important in this context as it

- specifically addressed the needs of small, rural schools
- gave teachers the opportunity to teach in their area of expertise and promoted the sharing of expertise
- enhanced science programs and curriculum delivery
- enriched the learning environment of students by facilitating group learning and access to experts and mentors
- allowed teacher and students to explore their respective roles
- suggested a possible strategy and model for the teaching of science, as well as other subjects, in small rural schools
The model proposed for the PEER project involved using the expertise and strengths of individual teachers to provide an optimal learning environment through a blended approach.

Blended Collaborative Learning [BCL] actively encourages the modern form of communities of practice and permits dispersed individuals to contribute and gain from this kind of group involvement. Pedagogy and facilitation is the core of BCL. By embedding human interaction in learning programmes, the online educator exploits the human need for socialization to aid learning. (Prendergast, 2004, p. 2)

The goal of this project was thus to support teachers in their instructional role and not to replace them through the implementation of distance education courses.

The model involved identifying a “principal” teacher who was knowledgeable about the subject matter, for instance, the science unit or cluster on electricity. In collaboration with partners from the local university, the provincial education department, and the school division, this teacher worked with other teachers and students in a blended collaborative learning environment to study the scientific concepts underlying the understanding of the nature of electricity. The principal teacher could change throughout the teaching of a science cluster according to the strengths and interests of the teachers participating in the project, thereby creating a sort of virtual team teaching environment. Our challenge was to create professional development opportunities that took into account the technological and pedagogical aspects of teaching in this blended environment. This pilot project has furnished us with qualitative data in the form of both teacher and student questionnaires, as well as transcriptions from individual teacher interviews and focus group sessions. Copies of Internet communications with teachers and students have also been collected for analysis.

A second related research project involved using Internet technologies to link scientists and experts with students and teachers within an authentic experimental context using a prototype “microcompostor” to study the importance of composting and its effects on biodiversity and the nitrogen and carbon cycles. The objectives of this particular study were

- to determine how Internet technologies could be used by teachers to encourage the organization and conceptualizations of students with regard to composting and sustainable development
- to determine how teachers could use these technologies to evaluate student understanding of scientific principles related to the above topics
- to identify useful Internet technologies that could be used in professional development projects for improving the scientific understanding of teachers for the above topics
Different Internet technologies were used to link teachers, students, and scientists both in synchronous (real time) and asynchronous modalities. One of these included a course management system called Moodle, which is a free, open-source software package to help educators create effective online learning communities. The Moodle environment provides teachers and students with opportunities for interacting with others using asynchronous tools such as discussion forums, wikis, and blogs. In the project, two Moodle platforms were constructed: one for teachers and the other for students. The Internet videoconferencing tool Elluminate is a synchronous web-casting software in which students meet virtually for regularly scheduled classes, group projects, or other planned sessions. It lends itself well to the blended learning approach and allows for possibilities such as guest presenters, student group project meetings, online tutorial/lab sessions, peer-based tutoring, exam review, virtual office hours, and mentoring. Real-time discussions with students can be supported with PowerPoint slides, websites, whiteboard markup capability and shared applications. Elluminate can also be used as a communication tool for research collaboration and meetings as a means to enhancing and supporting professional development efforts. The scientist met with teachers and students at a specified time to answer questions about composting and sustainable development. Moreover, meetings among the participants themselves were also held using this technology.

Another tool that was explored in the project was the integration of an electronic portfolio, Epearl, a bilingual, web-based electronic portfolio software developed by researchers at the University of Concordia. While the use of portfolios is not a new concept in education, this tool encourages student reflection on personal learning and also promotes self-regulation in learners engaged with these student-centred projects (Meyer, Wade, Pillay, Idan, & Abrami, 2009). The two environments found in this software, the workspace and the portfolio, allow for the display of the finished product, as well as the development and sharing of ideas and classroom tasks throughout the collaborative phase. Epearl also allows for online peer, parent, and teacher feedback on the portfolio and on particular artifacts. This technology was used by teachers to evaluate student understanding and progress with regard to class experiments and research projects. The project is currently in progress and qualitative data in the form of teacher and student questionnaires based on their use of technology, transcriptions from individual teacher interviews, and focus group sessions, as well as Internet communications, are all being collected throughout the project.
Strand 3: Reading and Writing in Science

We also conducted a cross-case study to determine how literacy was enacted in francophone science classrooms (Rivard & Levesque, manuscript submitted for publication). The findings suggested that language-based activities are used infrequently in the science classroom. Most reading is guided by questions while students scan the textbook for answers. Writing involves a few words, short responses, or copying notes, and never includes any extended writing. Talking is predominantly used to engage in conversations with the teacher and rarely with peers for knowledge construction. We concluded that using more language-based activities had the potential to enhance science learning for minority-language students. Teachers also seemed willing to use these if provided with support, both through specially developed support materials and professional development opportunities for enhancing instructional effectiveness.

A follow-up study involved a review of the literature to determine how we might help science teachers improve text comprehension in their students (Rivard & Cormier, in press). The purpose was to develop instructional strategies to promote reading in the science classroom. Our approach has involved evaluating key recommendations in the seminal reports and publications available in the recent literature on reading, but adapting them to the discursive reality of francophone science classrooms. The components of our professional development model for reading include the following:

- supporting metacognitive conversations
- favouring collaboration and discussion
- explicitly teaching text structure
- using a range of authentic texts
- supporting meaningful vocabulary acquisition
- encouraging explicit instruction of comprehension strategies

In our professional development work on literacy in science, we have been collecting teacher and student data using questionnaires that inquire into their beliefs and classroom practices with both reading and texts. This initial data set will serve as a baseline for determining changes as a result of the professional development program. We are currently working on another study on the use of writing in the science classroom.
The Utility of Bronfenbrenner’s Theory and Implications for Minority Language Education

Bronfenbrenner’s model of the ecology of human development suggests that humans do not develop in isolation, but rather in relation to their family and home, the school, the community, and society. Each of these continuously changing and dynamic environments, as well as the interactions among these, is important to an individual’s development. The adaptation of the model for francophone science teachers described earlier depicts the different layers of an individual’s ecosystem that have an impact on his or her development and reveals where interventions for professional development might be implemented, enhanced, or impeded.

The microsystem, the layer closest to teachers, contains the structures with which they have direct contact. The outcomes of professional development specifically target this system and success with regard to the interventions can be measured here. For example, did the professional development targeting teachers have any effect on student interest in science or on language competencies? The second layer, the mesosystem, provides the connection among the elements of the teacher’s microsystem. In project PEER, for example, the impact of the professional development strategy was confirmed by the willingness of school administrators to work together to provide science teachers with time to meet online with students so that they could learn together within a collaborative, socio-constructivist context. The exosystem defines the larger social system in which the teacher does not function directly. The structures in this layer have an impact on the teacher’s development by interacting with some other structure in his or her microsystem. It is hoped that the effects of the professional development provided to teachers could have an impact on this larger social system. The potential of projects, such as the one involving the microcomposter, for example, could lead to more community-based interest in composting and additional support for teachers in teaching other science, technology, society, and environment (STSE) type projects. The macrosystem, which is the outermost layer in the teacher’s environment, can have a cascading influence throughout the interactions among all other layers. For example, if the technology support is not readily available in a school division, even though teachers are willing to appropriate the technology and implement it in their classrooms, then it will not be used. The development of models such as the one developed in PEER can have an impact on materials development at the provincial level for this type of e-learning context, because our findings suggest that it is important and a priority, especially for rural schools.

It is evident that each of the different layers interacts with and affects the professional learning of science teachers. Bronfenbrenner’s theory provides a framework within which to effectively plan for and implement professional development strategies in order to effect changes in teacher practices and support experimentation as strategies are tested at the classroom level. The challenge will be to determine the relationship among the layers as they pertain to a particular group of individuals and the relevance of professional development strategies to the needs of both the individual teacher, as well as to the group.
Research Study 7: The Importance of Local Environment for Promoting Student Engagement in Learning

Janet McVittie and Danette Senterre

Context

The Saskatchewan community in which the study took place was made available by a relationship negotiated with the director of a particular school division. Since working with all school divisions would have presented both opportunities (breadth) and problems (lack of depth), having only one school division and one community actively interested resolved the research dilemma of whether to aim for breadth or depth. The director of the school division set up contacts with school and community leader, so that initial interviews could take place.

Of the 1500 people who live in town, almost all are historically from the area. The population is almost entirely Aboriginal, almost all of these people being Métis, although there are also Cree, Dene, and people with no Aboriginal heritage living either in or near the community. The town has a long and fascinating history, having been influential in the fur trade, and thus has been significant in many histories of European exploration of the continent. Students at the school speak of their community with pride. On the flip side—the community has many traits of other northern communities: high unemployment (although significantly less than nearby communities), low high school graduation rates (although significantly higher than nearby communities), low number of tertiary graduates within the population (lack of employment means that tertiary graduates are unlikely to return to their home community).

Based on interviews with community leaders, teachers, and students, and because of the focus on science and math from the researchers, an integrated Grade 10 science and math program was developed in response to an identified need to engage students in schooling. Grade 10 was chosen because this is the grade in which many students leave school, and so is the grade which has students dropping back in; this decision was based on a community need. The program is based primarily upon the integration of science and mathematics. It is inquiry based linking the inquiry questions to the community. The teachers chose to use inquiry linked to community issues based on their understanding of how best to engage students. Reinforcing their decision, community leaders had suggested the need to integrate the curriculum into the community. Teachers and students suggested students should have more hands-on activities and more outdoor activities. By using inquiry and integrating curriculum into the community, the student requirement for more hands-on activities and the community’s, teachers’, and students’ interests in being outdoors were met. As well, student inquiry activities were connected among the curricula and community needs, so students would have some choice, the choices would be relevant to them and the community, the students could seek answers within the community, and then they could present their learning to the community. For students to remain in Grade 10 and develop their competency in science and
Creating conditions to engage students in their curricular activities requires teacher and school support. Numerous studies of engagement have identified integral factors that must be in place, including autonomy, belonging, competency, and relevancy (O’Connell-Schmaekel, 2008; Schlecty, 2002; Wilms, 2003).

**Applications to Bronfenbrenner’s Bio-ecological Model**

Bronfenbrenner’s model was conceptualized to exemplify how the environment affected human development. On the conceptual level, Bronfenbrenner and Crouter (1983) wrote, “Human development involves a change during the life course in enduring patterns of behavior or perception resulting from the interplay between the evolving biological characteristics of the person and features of the environment in which that person lives” (p. 359). And “Environment encompasses any event or condition outside the organism that is presumed to influence, or be influenced by, the person’s development” (p. 359). Bronfenbrenner’s words pushed us to consider the classroom, where the teachers have attempted to design an engaging curriculum, as an ecosystem. The classroom ecosystem is nested within a larger ecosystem, the school. The school is nested within the larger ecosystem of the community. For the most part, what has been useful for us from Bronfenbrenner’s model is that it has pushed us to look beyond the classroom focus of student engagement to other systems. We looked beyond the microsystem, to the mesosystems and exosystems.

**Mesosystems and Transition Zones**

To examine Bronfenbrenner’s model on a conceptual basis, consider the child* in the classroom. The teacher** can make the classroom and what is learned there as engaging as possible; however, whether the child will take up the challenges offered depends on his or her personal qualities, and how his or her activities intersect with the other activities in the classroom and with the daily transitions among different microsystems. Lastly, what happens in the exosystem is beyond the control of the child for the most part, but affects his or her status within his or her microsystems. As researchers, we noted how the students’ out-of-school social networks (microsystems) are transferred into the school. For example, in one group of students in the integrated Grade 10 program, an influential student decided early that “a Science 10 credit was not going to happen for him this semester.” When he attends, he draws his social network of peers (eight of them in all) into his non-engaged role in the classroom. The out-of-school microsystem of peer social relationships will affect his and his friends’ school success.

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* We choose to name this person not student which would suggest this is his or her only role, but child to indicate someone who attends to the roles played beyond that of a student.

** We focus only on the teacher’s role in the classroom; therefore, we name this person teacher for the role.
Children are members of a variety of Microsystems operating within the school. For example, extracurricular sports are available through the school. Nearly all students who wish to play will earn a spot on the team. As well as the typical southern school sports such as volleyball, basketball, badminton, cross-country running, and track and field, students can also choose to participate in cross-country skiing, outdoor club, canoeing, and marathon canoeing. Once a student graduates from school, she or he can no longer participate in these school-sponsored sports.* Community hockey and curling are available; there are “fun” physical activities for younger children; and many adults (mostly male) hunt and fish. Nonetheless, the bulk of the team sports are only offered through the school. Most of the children, when asked, say they do not attend school because of their friendships; however, they do note they participate in all the extracurricular sports available. Thus, the Microsystems of extracurricular sports and the lack of community recreational leagues affect student attendance. These interactions between Microsystems are part of the mesosystem.

Bronfenbrenner also attended to those times when children moved from one Microsystem to another, such as from elementary school to high school. This is a significant transition in this study. Grades 7 to 12 are all housed in the same building; the transition from Grade 6 in the elementary school to Grade 7 in the high school would be considered significant. However, the geographic change is not as great as the structural change that takes place from Grade 9 to Grade 10. Students in Grades 7, 8, and 9 are with one teacher most of the time, and the children, for the most part, remain in their classroom, more like the elementary school model. In Grade 10, children move from classroom to classroom for different subjects and from teacher to teacher, and with slightly different peers in the subject areas**; perhaps these affect student retention in Grade 10. Another significant aspect of this transition from Grades 9 to 10 is the provincial requirement for official numerical grades at the Grade 10 level. Prior to Grade 10, teachers submit grades to inform families and upcoming teachers rather than for official provincial records. It is possible the pressure of official numerical grades affects the teachers in their relationships with children.

Children move from one Microsystem to another on a daily basis. Bronfenbrenner’s model pushed us to examine the transition zones outside the classroom. This is not the mesosystem the way Bronfenbrenner defined it; however, his model suggested (to us) this transition zone. Perhaps our backgrounds in biology caused us to think of geographic locations on the edges of ecosystems. This led us to think of the daily ritual for entering the school.

* One student in the adult basic education said he wanted to join canoe club the year before, but couldn’t because he was not in school.

** With only 20 to 25 students in each grade, a student’s peers do not vary much by course choice.
In this community, students are bused to school, despite the fact that walking would make the longest walk only about two kilometres. There is one school bus and it makes two trips, bringing students from one end of town, dropping them off in the school parking lot, and then making its second trip around to the other end of town. Sometimes, if there are two bus drivers available, there are two buses, but this is unusual. As long as the weather is fine, children are not allowed in the school until 8:55 a.m. when the first bell rings. Thus, those children getting off the bus on its first trip stay in the parking lot until first bell. The bus, on its second trip, often arrives after the 8:55 bell. Early children stand outside to talk to one another, but the second group are usually late, often up to ten minutes after the second bell. (Teachers have taken to calling the second bus “the late bus.”) The students must pick up late slips in the office, go their lockers and then to class. Teachers, knowing which children should be on the early bus and which the later, know whom to expect after the bell. Knowing is not the issue—classes almost always start ten minutes late, as all must wait for the second bus.

Even more difficult is that the teacher on bus supervision must come in to start class on time for those students who are there, then leave class when the late bus arrives, and then restart class after the late bus has delivered the children. If there is rain, or once the temperature drops below zero, students are allowed to come in to the school and wait in the commons area. When students are allowed to enter the school, they take off their outdoor shoes or boots, and, usually because of reminders from staff, take off their hats or pull down the hoods on their hooded sweatshirts. When the 8:55 a.m. bell rings, they are allowed to leave the commons area, carrying their hats and boots to their lockers where they can put on their indoor shoes and get their books for their first class.

There are good reasons for these rules. The teachers supervise during every break between classes, and all the teachers coach extracurricular activities. They are on duty from 9 a.m. until 6 p.m. with a one hour break for lunch, on almost all week days. As well, if there are tournaments or track meets, the teachers work Friday and Saturday—basically 24 hours of the day. This time before school is a time for them to talk to each other and to psychologically prepare themselves for the day. Some of the teachers spend this time in their classrooms, setting up activities. Nonetheless, to these outsiders (the researchers), the overall message seems unwelcoming to students. One aspect of engagement is a sense of belongingness. Some of the teachers sit in the commons, a pleasant meeting area, but in full view of the children who are outside (as a child, waiting to enter the school, I would be nervous if the teachers weren’t there!). When we, the researchers, arrive after the first bus but before 8:55, teachers come to the door to let us in. We are guests—without keys, but welcomed. We join the teachers, even though we have no need to take our final deep breaths before a long day. But we (more than the teachers) do seem to send the message that the school belongs to the adults, and that children are not even guests.
With winter’s onset, students are admitted to the school immediately on arrival. They stay in the commons area, interacting with one another and in easy good-natured repartee with teachers. From eavesdropping on conversations among teachers, among students, and among teachers and students, it would seem that there is a comfortable, respectful relationship amongst all the staff and students. Rarely does a teacher have to say more than “hood” to have a student take down his or her hood. This has been interesting for us, since we have been doing our research in urban schools prior to this. The students and teachers, despite what surprised us about school entry, are friendly and respectful. Teachers do not talk down to students. Students are polite and respectful to teachers, for the most part.

**Exosystem**

An in-depth examination of the exosystem is beyond the scope of this study. We have limited familiarity with the community and the local culture. We were invited to attend the culture camp,* a three-day event most of the Grade 8 children are invited to participate in (some are excluded for bad behaviour). At culture camp, students had a number of formal and informal activities: they learned to clean and smoke fish, to find rabbit runs, and to set snares in appropriate places; they participated in a sweat; they made bannock and ate their favourite foods; they paddled canoes, going upstream and downstream. When the school van’s sound system was used for playing a CD of fiddling music, the children all participated in jigging. One of the children asked why we were spending time with them in their school. When Janet told her that luck had brought her to this town but that she loved it here, the girl said, “Yeah—it seems everyone wants to live here.” A protective factor for these children is that they have a sense of their history and their culture, and they are proud of it. This might be one reason this community has fewer social problems than other nearby communities.

Two different exosystems affected attendance this year. Attendance is not necessarily an indication of authentic engagement. However, it is difficult for a student to become authentically engaged if she or he is not at school in the first place. Attendance is an issue at this school. This year, unlike other years, the number of students registered in Grade 10 increased throughout September, reaching about 25 percent higher than normal. The weather was fine throughout September. Might students have been affected by this exosystem? Attendance dropped during October, but this was the year of H1N1. Students were encouraged to stay at home if they had influenza-like symptoms. Might the low attendance have been due to this exosystem? When students have missed two weeks of school, it becomes difficult for them to catch up. On the other hand, the weather and H1N1 might not have as much of an effect as whether or not students are willing to complete education for

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* This is one more aspect of the teachers’ lives where they give more than a mere eight-hour day to the children. Two teachers and one teacher associate were with the students for the full three days; another teacher drove out to visit the children on the second day.
the “delayed gratification” of a job after more years of schooling. This would fit with our observations: we have not noticed many students motivated by grades, but more by interest in the subject. In other words, whereas students in urban schools will be ritually engaged, the students here are either authentically engaged or not engaged (Schlecty, 2002).

Another interesting factor from the exosystem is a conflict between the community values and the larger Eurocentric values of the nation. In this community, children are cherished. A girl who at the age of 15 has a baby is not discriminated against in this community the way she would be in southern communities. Is having a baby a risk factor or a protective factor? This will depend on the young mother’s goals. Having a baby certainly makes completing high school on time much more challenging. Having a baby makes going on to post-secondary education even more challenging than completing secondary school. However, having a baby does empower her in ways that cannot be quantified.

Motherhood and extracurricular athletics are protective factors for these students for survival in their community. To do well beyond their community, or to qualify for well-paid work within their community, they require completion of secondary and probably post-secondary education. Because of our interest in Bronfenbrenner’s theory, we will begin to examine the community’s valuing of academics. If the community does not value academics to the same degree that it values sports, this could be a risk factor for the students. They need to acquire education to find interesting and well-paid work. We have heard boys being teased for being “geeks,” but we have not heard them being teased for winning at volleyball.

**Microsystem—The Classroom and Engagement**

Teachers design and implement daily routines for their students. Teachers use curriculum documents to implement curriculum in the classroom. Teachers negotiate their identities and facilitate the students in negotiating their identities. All teachers seek to engage their students authentically in their learning. However, what the teacher does in the way of engagement is affected by the mesosystem, by transition zones, and by the exosystem.

For the teachers to engage students, they must create a sense of belongingness. The children must both believe they are welcomed into the school and that they have a responsibility to welcome others to the school. A number of the children have gone out of their way to talk to us, to ask us why we are visiting their school, to make us feel welcome. Some of the children definitely feel a sense of belongingness to the school.

There is another aspect of belongingness, though, which is belongingness to the ideas. The children in Grade 10 see us as tutors and as researchers from the university, so, for the most part, they do not show us how they belong to and own their academics. We think they expect that we know the material already. However, we participated in an activity in the adult basic education class. This is school for
those who wish to finish Grade 12 and who are no longer children. One morning, we joined the adults on a field trip to the riparian area near the lake, and collected a variety of living things. In the classroom, we used stereomicroscopes, push pins, scalpels, and petri dishes. We examined the living things as they moved, watched them under the microscope, looked them up on the Internet, and learned together that snails and leeches are hermaphrodites. They excitedly called one another over when they found something interesting, for example, learning that the dead crayfish one young man was dissecting was female—dissection revealed its ovaries. The students owned their learning. This is authentic engagement, and inquiry can inspire this, but the Grade 10 provincial curriculum guide, provincial requirements, and some students’ “too cool for school” attitude mitigate against this.

Relevancy is another aspect of engagement. The teachers created four science units, three of which are integrated with math. All four units are connected to the community, and the learning has the potential to change student lifestyles and perhaps make the community a healthier, happier place. The first unit was linked to chemistry, focusing on health, specifically healthy eating. The students were willing to ask their family members for information; interestingly, however, for the most part, they did not ask health experts for information. When asked about sharing their learning with the community, they suggested spreading the word “like one big rumour.” One of the boys noted that he had told the volleyball team about the importance of nutrition; another talked to his girlfriend about her eating habits. This is the most common way of communicating local events in this community, which is small and tightly knit (although welcoming to newcomers). They did not prepare formal presentations because they did not see this as a way to communicate to others. Relevancy is connected to community, and students believed the health unit was relevant to their community. And they spread the word in their community’s fashion—“like one big rumour.”

Utility of Bronfenbrenner’s Theory and Implications for Education

The most important aspect of Bronfenbrenner’s theory for this study has been its conceptual aspect. We have been pushed to look beyond the classroom microsystem to other microsystems the students participate in. We have also been pushed to examine the transition zones. Transition zones, although not part of Bronfenbrenner’s theory, were suggested to us by his concept of mesosystems. Lastly, we have paid closer attention to the exosystems and how they affect classroom engagement. Just as interactions in an ecosystem are complex, the activities in the classroom microsystem are complex. Although children come into the classroom to play the role of student, they carry with them the values and habits of their exosystem. They also participate in their classroom based on how they are situated in other microsystems—such as playing on the volleyball team or taking care of a baby at home. Children participate in a number of microsystems, and these affect the ways in which they engage in their learning.
Bronfenbrenner’s environmental model of human development has elucidated some of the issues that teachers face in attempting to engage their students authentically. Whether teachers can affect factors in other microsystems or in exosystems remains to be seen. Awareness is a first step. Student academic engagement looks different in different contexts. Sometimes, students have to pretend not to be engaged academically. Some students can show they are engaged because of the roles they have in other microsystems. Perhaps the most significant change that a teacher can make in this school is to help the students recognize that it is cool to do school—that what they learn can contribute to their roles in other microsystems and that what they know from other microsystems can contribute to their school learning.

System D: The Global System

Research Study 8: Sustainability Science—A Systems Approach
*Mona Maxwell, Gordon Robinson, and Amanda Tétrault Freedman*

**Context**

Never before has there been such heightened awareness as presently exists about the deteriorating state of Earth (Hawken, 2007; SengeCambron-McCabe, Lucas, Smith, Dutton, & Kleiner, 2000; Senge, Smith, Kruschwitz, Laur, Schley, 2008) and the associated decline of human well-being (Millennium Ecosystem Assessment, 2005), and the necessity for sustainable global citizenship. Although this awareness is manifested by substantial optimism at the individual level, there are empirical data that create a sense of global pessimism as biophysical systems lose their resilience (Walker & Salt, 2006), thresholds and “tipping points” are surpassed, and system after system is transformed to some alternate less desirable stable state. It is likely that never before has Bronfenbrenner’s (1979) “macrosystem” had such a potentially large impact on the development of young minds in the “microsystem,” as they grapple with the uncertainty of a sustainable future. Although often anxious to participate in positive change, learners remain overwhelmed by the global juggernaut, the trajectory of which seems little changed (Halbroner [1995] as cited in Schriener and Sjøberg, 2005). Despite a plethora of international pressures and agreements it is debatable whether the time for “sustainable development” is evolving to be obsolete rhetoric soon to be replaced by a time for “sustainable retreat” as global thresholds may be close at hand (Lovelock, 2007).

It appears that within the “systems” as defined by Bronfenbrenner (1979), the further one’s interactions move from those of the “microsystem,” the greater the level of pessimism regarding the potential of shifting trajectories toward sustainability (Schriener & Sjøberg, 2005), and the lower the level of confidence in the discipline of science as helpful in achieving that goal. Yet without science, students are less equipped to effectively deal with sustainability issues. The science-sustainability relationship is in need of repair. Despite widespread awareness, only 17 percent of Canadians confess to knowing what sustainability is (although when explained
to them, 82 percent rate sustainability as a high national priority). Thirty-two percent believe that the people they know do not particularly care about related environmental matters (McAllister Opinion Research, 2006).

Applications of Bronfenbrenner’s Bio-ecological Model

If such statistics are to be believed, a call for a much enhanced educational effort would appear clear—a need that is addressed in the work presented here, where a goal has been to examine the interplay between the role of science education within Bronfenbrenner’s (1979) systems and sustainability at the level of the “macrosystem.” Within the mandate of NSERC (Natural Sciences and Engineering Research Council of Canada)-CRYSTAL, two studies were conducted within Manitoba schools (Tétrault, 2008, & Maxwell, 2009), both of which used this context to evaluate the impact of a sustainability-science curriculum on the teaching and learning of mandated science curriculum, affinity for sustainability issues, and inclination towards specific sustainability-related actions. The principal goal of both studies was to increase learners’ critical consciousness of “human-nature” and “science-sustainability” relationships. To provide a level of consistency, sustainability has been defined in both studies in the terms of the four systems conditions for sustainability in the much larger “ecosphere/society” system as recommended by The Natural Step (Robèrt, 2002). Although not directly comparable, reporting the two studies together does permit observations on two interesting aspects: the suitability of Middle Years versus Senior Years for the teaching of sustainability-related science and the appropriateness of integrating sustainability concepts into existing curriculum versus adopting stand-alone sustainability-science curriculum. In both studies, sustainability-specific science curricular resources were created and taught in a number of schools and the outcomes assessed by pre- and post-delivery testing. The Middle Years study compared experimental and control classes, while in the Senior Years study, as no “control classes” existed, curricular resources were delivered in two sites as stand-alone curriculum and in two sites as integrated curriculum.

The Middle Years study (Tétrault, 2008) required the construction of curricular resources addressing sustainability-related issues associated with water, but inclusive of mandated curriculum outcomes. The curriculum was taught to a convenience sample of five Grade 8 classes in three Manitoba schools, and five comparable classes were taught the unaltered mandated “water cluster” curriculum and, as such, served as a control. Essentially, the independent variable was instruction of the developed resources and the dependant variable was increased critical-consciousness (as described above). The intentions of the second study (Maxwell, 2009) sought much the same outcomes, but in Senior Years, by the piloting of specific curriculum resources in five Grade 11 classes in Manitoba schools. Three classes were Chemistry classes (integrated curriculum) while two were Current Topics in Science classes, characterized by being less constrained by mandated learning outcomes of the curriculum and more representative of a “stand-alone” curriculum. Whereas the desired outcomes were essentially the same, the Middle
Years study sought to increase inclination towards specific sustainability-related actions, and the Senior Years study sought to increase the ability for decision making and the development of effective strategies to move organizations towards sustainability.

The success of both studies was dependent on fostering positive human-nature and science-sustainability relationships, such that they might contribute to a critical consciousness (Benard, 1995) in students. Given the broad global context of sustainability, a superficial thought would have been that the studies would fall squarely within Bronfenbrenner’s “macrosystem”—the largest interaction of the learning of science and the achievement of global sustainability. This would be naïve for it would neglect the cascading interactions with and between the subsumed lesser “microsystem,” “mesosystem,” and “exosystem.” Within the microsystem, it was found that although students were indeed invited to develop their critical consciousness in order to address macrosystem issues, both teacher and learner were required to navigate a number of (sometimes predictable) situations:

- the complexity of many sustainability issues (Gayford, 2002; Gayford, 2004; Groves & Pugh, 2002; Hart, 2003; Stapp, Wals, & Stankorb, 1996; Summers, Corney, & Graham, 2003; Summers, Childs, & Corney, 2005)
- a lack of awareness of sustainability issues that could negatively impact necessary critical consciousness—although most Canadian youth are learning about world issues, these largely appear to be traditional topics such as wars and other conflicts that are taught in the context of any history class, and it appears that less attention is being devoted to more contemporary world issues such as global inequities, human rights, the HIV/AIDS pandemic, terrorism, and environmental sustainability (War Child Canada Opinion Poll, 2006)
- a rapidly changing information base
- controversy amongst “experts” (Gayford, 2002; Gayford, 2004; Groves & Pugh, 2002; Hart, 2003; Stap, Wals, & Stankorb, 1996; Summers, Corney, & Graham, 2003; Summers, Childs, & Corney, 2005)
- scarcity of school resources (Elshof, 2005; Summers, Childs, & Corney, 2005)
- variable teacher attributes and motivation (Lewthwaite, 2004)
- disengagement because of a perceived lack of day-to-day relevance (Simmons, 2001)

Of course, in addition to these obstacles, there is the persistence of an inappropriate reductionist pedagogical paradigm where a holistic “systems” approach might be more appropriate—a situation that is made worse when sustainability is spread out over the disciplines and loses its impact (Hart, 2003; Puk, 2003; Summers, Corney, & Graham, 2003).

Given the above, it is quite surprising that individual optimism is an outcome of microsystem interactions. Interactions at the level of the mesosystem are also important, for there can be different belief systems and visions in different schools.
that may either encourage or discourage the delivery of science in the context of sustainability. No matter what the outcome of microsystem interactions, a school vision which promotes sustainability education is critical (Tilbury & Cooke, 2005). Interactions within the exosystem (science teaching and learning) are essentially interactions with public perspectives, and as such have the potential to influence the teaching of science in relation to sustainability issues through the influence of divisional policy.

If one positions both of the studies reported here squarely within Bronfenbrenner’s (1979) bio-ecological model of human development (although it was initially focused on early development), the desired outcomes of both do appear to fall squarely within his macrosystem, in which the desired outcomes would be products of the interaction of the learner and the global lack of sustainability and a poorly developed consciousness of the utility of science in coping with a worsening situation. The experience of both researchers has, however, been that all systems influence the emergent outcome.

Outcomes of the Study

For the Middle Years study, analysis of pre- and post-testing of experimental and control classes indicated that the experimental group showed statistically significant expected outcomes, with the greatest significant difference being the category of “actions related to sustainability.” As anticipated, knowledge of the specific curriculum-mandated learning outcomes on water showed no significant difference between control and experimental classes. (See Table 1.)

| Table 1 | SUMMARY OF MEANS AND STANDARD DEVIATION (SD) FOR PRE- AND POST-TESTS IN CONTROL AND EXPERIMENTAL GROUPINGS FOR EACH SECTION STUDIED (N=111) (TETRAULT, 2008) |
|-----------------|--------------------------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | Affinity for | Affinity for | Knowledge of | Actions Related |
|                 | Science      | Sustainability| Water Systems| to Sustainability|
|                 | Pre-test | Post-test | Pre-test | Post-test | Pre-test | Post-test | Pre-test | Post-test |
| Control (mean)  | 3.57 | 3.39* | 3.69 | 3.46* | .425 | .562 | 2.22 | 2.11** |
| SD               | .62 | .83 | .43 | .81 | .26 | .24 | .71 | .83 |
| Experimental (mean) | 3.55 | 3.65* | 3.73 | 3.72* | .333 | .593 | 2.23 | 2.74** |
| SD               | .47 | .53 | .58 | .56 | .20 | .21 | .76 | .65 |
| Partial Eta Squared | .07 | .06 | .03 | .23 |
For the Senior Years investigation, critical consciousness of the human-nature relationship could be attributed to the curricular intervention, with statistically significant changes in the “recognition of the reality of limits to growth” and “fragility of nature’s balance” (Table 2). This was not the case for the science-sustainability relationship, although it was recognized that a positive outcome would have been more likely if science teaching had been accompanied by a shift away from the reductionist paradigm towards a systems approach. Essentially, encouraging the learner to integrate fragmented content into systemic understanding is an awkward process within the discipline-bound conditions of the secondary school setting, and will thus not likely render science a more “reliable friend” for addressing sustainability issues or equip the learner to deal with modern sustainability issues (Knapp, 2000).

The utilization of the resource did facilitate eliciting from students an impressive variety of realistic strategies to move organizations towards sustainability. Teachers perceived that students’ decision-making processes were enhanced through specific use of the four system conditions of The Natural Step. The perceived effectiveness of strategies involving collective action (Smith-Sebasto & Fortner, 1994) was not enhanced by the curricular resource (Table 2). Students strongly recommended the use of mass media as an effective educational vector in shifting trajectories towards sustainability and it is suggested that there may be a substitution of collective action in the form of rallies and letter writing to a digital form. It follows that the Index of Environmental Action Knowledge and Skill (IEAKS) (Smith-Sebasto & Fortner, 1994) from which the action-taking strategies were derived might be updated to reflect “digital” influences.

As stated, direct comparison of the two studies is not appropriate, but some observations are possible. The Middle Years experiment was successful in that it elicited all intended outcomes without jeopardizing mandated curricular content. The degree of critical consciousness, as defined here, that was elicited in the Senior Years study was substantially less, but the increased capacity for critical decision making and eliciting of strategies for moving toward sustainability was remarkable.
<table>
<thead>
<tr>
<th>Dimension</th>
<th>Wilcoxon Rank Sum Test (Chemistry and Current Topics Classes) p-value</th>
<th>Wilcoxon Signed Rank Test (all students) p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Consciousness of Human-Nature Relation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Possibility of an eco-crisis</td>
<td>0.0452* (Chem)</td>
<td>0.9284</td>
</tr>
<tr>
<td>Fragility of nature's balance</td>
<td>0.2917</td>
<td>0.0646*</td>
</tr>
<tr>
<td>Reality of limits to growth</td>
<td>0.1457</td>
<td>0.0569*</td>
</tr>
<tr>
<td>Rejection of human exemptionalism</td>
<td>0.1686</td>
<td>0.5689</td>
</tr>
<tr>
<td>Anti-anthropocentrism</td>
<td>0.9548</td>
<td>0.7009</td>
</tr>
<tr>
<td>Critical Consciousness of Science-Sustainability Relationship</td>
<td>0.1255</td>
<td>0.0310*</td>
</tr>
<tr>
<td>Perceived Effectiveness of Action-Taking Strategies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Civic Actions</td>
<td>0.8899</td>
<td>0.6877</td>
</tr>
<tr>
<td>Science-based Educational Actions</td>
<td>0.8017</td>
<td>0.5556</td>
</tr>
<tr>
<td>Financial/Legal Actions</td>
<td>0.0679* (CT)</td>
<td>0.7531</td>
</tr>
<tr>
<td>Physical Actions</td>
<td>0.7226</td>
<td>0.8886</td>
</tr>
<tr>
<td>Persuasive Actions</td>
<td>0.7728</td>
<td>0.5583</td>
</tr>
</tbody>
</table>

Note: * p < 0.05
Utility of Bronfenbrenner’s Theory and Implications for Education

A premise of both studies was that the desired outcomes (enhanced human-nature and science-sustainability interactions that were accompanied by learner actions towards sustainability) would be emergent properties of many dynamic interactions (Senge, 1990; Senge, Cambron-McCabe, Lucas, Smith, Dutton, & Kleiner, 2000; Senge, Smith, Kruschwitz, Laur, & Schley, 2008). The process is a “systems model.” This is distinct from the fact the subject matter of the studies (i.e., sustainability and related scientific literacy) is also a holistic “systems model” that is ill-suited to the linearity of a reductionist paradigm. The systems nature of Bronfenbrenner’s work made it a useful (albeit simplistic) guide to thinking, even though it was articulated as a means of understanding interactions of differing scales as they had dynamic impacts on child development. The content of Bronfenbrenner’s work may well not have been entirely appropriate to the studies reported here in that the framework that he presented was useful but the application of a defined set of system interactions in the presence of a continuum of interactions was not useful. Within the microsystem, mesosystem, and exosystem, it can be expected that there reside many positive and negative interactions which can have an impact on the desired outcomes. Within an “ecological” model, this is to be expected and often expressed as negative and positive feedbacks. In both studies reported here, such interactions were recognized by way of comprehensive teacher surveys, but were considered as “risk” or “protective” factors in the vocabulary of Rutter (1987). Defining these interactions as residing within a Bronfenbrenner “system” was not particularly useful, for some interactions could transit from one system to another by way of creative tensions between learners and intrinsic or extrinsic factors. In addition, some factors could reside in more than one system as the boundaries between systems seemed blurred, which is to be expected in any complex systems model.

If one assumes that the intended outcomes of both studies are the emergent properties of many dynamic interactions (Senge, 1990), there seems little advantage to the strict application of the Bronfenbrenner model, and some other simple systems model (see Meadows, 2008) might be more appropriate.
PART 4: SUMMARY AND RECOMMENDATIONS

Because the theoretical framework for the University of Manitoba’s CRYSTAL work has been premised upon Bronfenbrenner’s bio-ecological theory, we, as authors, have been accorded both the self-appointed opportunity and responsibility to work with the model in our research. In this, our final section, we reflect on our experiences in working with the model.

All research and development projects are essentially “journeys,” maybe even “roadtrips.” Similar to all journeys, there is an intended destination in mind, fellow travellers, and a timeline for the journey to be completed in. Although the destination is important, the journeyed experience, in itself, is often the highlight. There are things to be learned, new relationships and communities to experience, and shared opportunities along the way. There are constraints upon the manner in which the journey unfolds, yet also opportunities to be taken. There are likely to be some definite destinations and requirements along the way, but also some flexibility in what routes are taken—divergences so to speak. All that is experienced cannot be anticipated. We wouldn’t want it to be. There are hidden positive and negative experiences to be encountered along the way, most of which could not be predicted.

Ultimately, along the way and upon completion, the journey is evaluated and reflected upon. In this final section, that is what we do. We reflect upon the journey, paying particular attention to the vehicle we used in our journey—Bronfenbrenner’s bio-ecological model. As a metaphorical description, we have been able to take this model on a test drive. Similar to a test drive with a vehicle, we have been able to test the model’s utility or performance in a variety of contexts, albeit all in education. Of importance to us has been how the model functioned. Was it able to assist in getting to the intended outcome? By using this model, did we have a smoother ride? Did the model operate efficiently? Did it become a means by which energy was not expended without purpose? Most importantly, based upon these experiences, would we recommend the “vehicle” to other travellers?

In this final section, we provide a synthesis of our evaluations pertaining to the utility of the model. The synthesis is framed in sections based upon several themes that have precipitated from our considerations. We conclude the section by making some recommendations to other researchers who seek to use the model as a theoretical framework for informing their research.
The Utility of Bronfenbrenner’s Bio-ecological Theory: A Synthesis of Our Findings

The Value of the Model in Organizing CRYSTAL’s Activity

As illustrated and described on page 12, a practical application of Bronfenbrenner’s bio-ecological model was found in organizing the research activity under four of the systems defined by Bronfenbrenner. Although we have described eight of the projects, there were nine other projects for a total of seventeen. Each system consisted of two to six projects. Each system had clearly identified research goals that captured the focus of the system as a result of the identified common elements of the projects within the system. For example and described earlier, the individual system focused on examining an individual’s view of self and the personal attribute factors that influence an individual’s interaction with and success in science and mathematics. Examples of factors considered in this system were teachers’ and students’ perceptions of their identity and role as teachers and students and their perception of factors influencing their personal success.

Although the projects in each system operated independently, it was envisaged that each project would inform the others through regular information exchange opportunities. As well, it was envisaged that each system would inform the other systems through information exchange. To foster this communication, two researchers within each system were assigned the role of system managers carrying a primary responsibility to see this information exchange implemented. One of these two researchers was also on CRYSTAL’s management team. Because of the geographical distances between projects and researchers, it was anticipated that communication among projects within systems and among systems might be difficult. To support this, some system leaders used electronic forums and guided the discussion among system members, but these were rather limited in their effectiveness. Despite the logic of the organizational framework developed according to a systems framework, the communication network among researchers in each project was only somewhat successful. Communication among projects and systems did occur, but this primarily occurred at the face-to-face events CRYSTAL held. On an annual basis, an open-to-the-public conference was held, and researchers shared their research results. Through public presentations, and, afterwards, the dissemination of papers through the CRYSTAL website and informal conversations, researchers were kept informed of others’ activity.

The establishment of a management team was of greater significance in ensuring communication among projects. Although the regular management team meetings focused on administrative matters, they also ensured that discussion around the central questions among system leaders did occur. In all, the application of a systems model to the organization of CRYSTAL was seen to be a major contributing factor to the overall success of CRYSTAL, especially in terms of its management, and, less so, in the flow of information among projects.
The Value of the Model in Defining Development

A valuable construct in our CRYSTAL initiative’s journey has been Bronfenbrenner’s definition of development. Since our CRYSTAL initiative, overall, has focused on success, several of the projects were challenged by identifying key outcomes that could be used for research purposes as indicators of success. In most projects, we were actually focused on developmental success. Bronfenbrenner’s definition was useful as he describes development as the phenomenon of continuity and change in the bio-psychological characteristics of human beings both as individuals and as groups. The phenomenon extends over the life course through historical time, both past and present. He also describes development as the sustained, progressively more complex interaction with and activity in the immediate environment (Bronfenbrenner, 2005, p. 97). Similar to most social science research, we were looking for empirically based evidence of development in our studies, for example, progress made by students, teachers, and schools in specific areas such as teacher self-efficacy—their perceptions of their confidence to carry out particular tasks. This description of development was used in several studies. As an example, in the Sustainability Science Middle Years study, analysis of pre- and post-testing of experimental and control classes indicated that the experimental group showed statistically significant expected outcomes, with the greatest significant difference being the category of “actions related to sustainability.” Similarly, in the Chemistry Teachers study, researchers were able to monitor chemistry teachers’ development through the use of the Chemistry Teacher Inventory. It gave an indication of teachers’ perceptions of changes in their activity in terms of chemistry teaching strategies used to support student learning. In brief, Bronfenbrenner’s conceptualization of development provided an insightful lens to consider what specific, observable, and measurable changes were to be the focus of the investigation.

The Value of the Model in Identifying Factors Influencing Development

A common theme that is evident in the outcomes of the eight studies presented in this monograph is the utility of Bronfenbrenner’s model in conceptualizing the multi-system factors that influence development. Bronfenbrenner’s nested systems model recognizes that development is influenced by individual and environmental conditions. His model, through this suggestion, assists researchers in being cognizant of the broad and complex nature of influences on developmental change. Researchers are able to use this multi-system lens as a systematic framework for considering what conditions at each level may be influencing development. As an example, within the Francophone Minority study, the researchers were able to use Bronfenbrenner’s model to identify the many impediments to science teacher development within this vulnerable context. Within this study, the preliminary interviews with stakeholders identified a variety of influences upon teacher development. Although many of these were interrelated and, therefore, resident within a variety of Bronfenbrenner’s systems, the researchers were able to use
Bronfenbrenner’s systems-thinking construct as an organizer for identifying influences upon teacher development. We recognize that this “reductionist” model for identifying constraints or contributors to development was not something that Bronfenbrenner endorsed, but we do see that this application has benefit.

The Value of the Model in Conceptualizing a Research Agenda to Foster Development

Following on from the points made above, a further benefit of Bronfenbrenner’s model was its value in conceptualizing the research agenda. If the model was of benefit in identifying influences on development, it was, equally, of benefit in systematically fostering consideration for what mechanisms might be put in place to mitigate these risk factors and maximize supportive factors. Most significantly, most projects focused on assisting project participants in becoming more aware of what could be done at the individual and microsystem level to improve the supportive nature of interactions at these system levels. As an example, in the Teacher Candidates study, collaborating teachers and faculty advisors that promote teacher candidate’s reflection-on-action were identified as important contributors to teacher candidate development. Consequently, the study concentrated on fostering the development of this capacity in collaborating teachers by placing candidates in settings where this characteristic was already being applied and, further, by using mechanisms that might improve this capability in collaborating teachers and faculty advisors. Thus, the model not only assisted in identifying likely contributors or impediments to success, but also assisted in making the research programs more efficient and effective by identifying where effort needed to focus in fostering development.

This inherent value of the model was most obvious in projects where the interactive influences were relatively simplistic, such as the Teacher Candidate study. In this project, the focus was on developing the capability of a collaborating teacher as a supportive member of an individual teacher candidate’s microsystem. The influences upon a teacher candidate’s development are largely influenced by the capabilities of a collaborating teacher. It is this face-to-face interaction that has a significant impact upon a teacher candidate’s development.

When development is influenced by a much larger and more complex pattern of factors, the model becomes less valuable in conceptualizing how a developmental research agenda might be put into action. A good example of this exists within the Sustainability Science project. The systems nature of Bronfenbrenner’s work made it a useful, yet, albeit simplistic, guide to thinking, even though it was articulated as a means of understanding interactions of differing scales as they had a dynamic impact on child development. The content of Bronfenbrenner’s work may not be entirely appropriate to studies where the application of a defined set of system interactions is less important than a continuum of interactions or where the degree of influence is of more importance. Within the levels of individual, microsystem, mesosystem, and exosystem, it can be expected that there reside many positive
and negative interactions which can have an impact on the desired outcomes and that these influences differ in magnitude. Within an “ecological” model, this is to be expected and often expressed as negative and positive feedbacks with varying influence. In both Sustainability Science studies, reported interactions were recognized by way of comprehensive teacher surveys, but considered as “risk” or “protective” factors in the vocabulary of Rutter (1987a). Defining these interactions as residing within a Bronfenbrenner “system” was not particularly useful, for some interactions could transit from one system to another by way of creative tensions between learners and intrinsic or extrinsic factors. We would suggest that if a research study is working within a context where development is the emergent property of many dynamic interactions (Senge, 1990), there seems little advantage to the strict application of the Bronfenbrenner model, and some other simple systems model might be more appropriate.

The Inherent Value of Several of the Conceptual Constructs of Bronfenbrenner’s Theory

As evident in the studies present in this monograph, Bronfenbrenner’s bio-ecological model encourages much consideration of what constitutes supportive interactions in fostering development. That is, it goes beyond identifying what might influence development, and, more importantly, assists in considering how and why it influences development. Furthermore, Bronfenbrenner’s theory also assists in considering how an interaction might be added or taken away or improved to foster development and, especially, how a face-to-face interaction between a developing individual and an agent within his or her environment might be changed. We emphasize here that although Bronfenbrenner’s multi-system model has value in identifying the resources that influence development, it is likely of most value in assisting consideration of how the resource might be used. Inherent within this idea is the emphasis Bronfenbrenner places on proximal processes, those interactions nearest to the individual that have the greatest influence on the individual.

Three studies in particular emphasize this idea. In the Mathematics Pre-service study the anxiety of perceived confidence of pre-service mathematics teachers are recognized as areas of concern, as potential risk factors, that would work against success as a teacher of mathematics. In order to address these concerns, mechanisms that maximize protective factors have been achieved by the provision of focused mathematics instruction in a supportive environment—as exemplified by the creation of the Mathematics for Teaching course. At the heart of the protective factors is the development of specialized mathematical learning opportunities for teachers, founded on principles of social constructivism. It is within the face-to-face interactions that occur within constructive learning environments that strong growth in conceptual understanding and associated belief changes in mathematics occur.
Similarly, in the Effective Teaching Profile developed in response to what Middle Years Inuit students say about their learning, what is quite apparent is the primacy of positive personal interactions in classrooms. Students affirm the importance of caring, connected, and consistent teachers in influencing their educational success. As both of these studies progress, they work to understand, exactly, what social and interactive processes contribute the most significantly to student success. How can the resources provided by the microsystem best be used to foster an individual’s development? These two studies presented here give evidence that the most valuable aspect of Bronfenbrenner’s model is in its insight into the nature of positive interactive patterns that influence development, especially at the face-to-face level.

Finally, with the Minority Language study, the online environment is used as a means to foster a blended community of learning despite the geographical distance among teachers within the francophone minority. Blended Collaborative Learning (BCL) actively encourages the modern form of communities of practice and permits dispersed individuals to contribute to and gain from this kind of group involvement. Pedagogy and facilitation is the core of BCL. By embedding human interaction in learning programs, the online educator exploits the human need for socialization to aid learning.

Bronfenbrenner identifies other constructs that are significant for those working in educational development. As presented in the Integrating Whiteboard Technology study, ecological transitions need to be identified and considered when supporting teachers in their development. As well, in the Teacher Candidates study, Bronfenbrenner’s construct pertaining to role identification is important. In this study, the researchers focused on assisting collaborating teachers and teacher candidates in identifying what specific actions were likely to influence their development. Particular role stances were likely to influence their development and, in turn, effort was made to maximize those role stances and manifest interactive behaviours that positively influence teacher candidate development.

**Recommendations**

Overall, the studies presented here provide evidence that Bronfenbrenner’s bio-ecological model has considerable utility in fostering educational development. Its primary benefits are seen in its application to conceptualizing research and development programs in the initiating and evaluating phases of the research agenda. It assists planners and researchers in identifying what outcomes might be anticipated as indicators of development and what factors might influence developmental success. This prompts initial discussion about what mechanisms might be implemented to foster development. For projects that require a systems approach in the initial conceptualization of the project, the bio-ecological model has considerable utility. If the influences on the development project are complex and interactive, the model is believed to have less utility and for this reason needs to be used in conjunction with other models that capture the dynamics of
these interactions. The model’s greatest utility is in emphasizing that educational change is likely to best result at the proximal—the face-to-face interaction—level. Developmental projects that fail to place emphasis and priority on improving the quality of personal contacts and interactions are likely to have limited, sustained influence. For this reason, Bronfenbrenner’s bio-ecological model is of considerable value in helping to improve the quality of the proximal interactions associated with the individuals and groups associated with the development project. It emphasizes the quality of interactions and the manner in which these interactions can be improved.

We see two important efforts requiring attention in the use of Bronfenbrenner’s model in education:

- Because development is typically associated with multi-system influences, we suggest that future educational development projects seek to quantitatively ascertain the influence and degree of multi-system factors on educational development, both at the individual and group level. At the heart of such studies will be determining causal influences on development.

- Because the face-to-face interactions are of such significance in influencing development, we suggest that future educational development projects seek to qualitatively determine the nature of the processes associated with individual and group development. At the heart of such research is determining through listening to participant voice the nature of the processes having an impact upon an individual’s development.
References


Tétrault, A. (2008). *We are all downstream: Teaching middle years science from a sustainability perspective*. (M.Ed. thesis). University of Manitoba, Winnipeg, MB.


### Appendix A: Chemistry Teacher Inventory

**Chemistry Teacher Inventory (CTI)**

**Grade:** __________

There are 33 items in this questionnaire pertaining to strategies or actions used in the teaching of chemistry. They are statements to be considered in the context of one chemistry class in which you work. Think about how well the statements describe your teaching of chemistry in this class. If you teach more than one class and you believe your teaching is different in this other setting you might consider completing a further CTI for this other setting.

Indicate your answers on the score sheet by circling:
- N if you *never* use this strategy in your teaching of chemistry
- R if you *rarely* use this strategy in your teaching of chemistry
- S if you *sometimes* use this strategy in your teaching of chemistry
- O if you *often* use this strategy in your teaching of chemistry
- A if you *almost always* use this strategy in your teaching of chemistry

If you change your mind about a response, cross out the old answer and circle the new choice.

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Students copy notes from overheads without explanations.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>2.</td>
<td>I perform chemical demonstrations.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>3.</td>
<td>Visual images are used to clarify chemistry ideas.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>4.</td>
<td>Students plan investigations and then carry out the investigations.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>5.</td>
<td>Computer-based simulations are used to clarify chemistry ideas.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>6.</td>
<td>I explain how chemistry topics relate to students’ lives.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>7.</td>
<td>I talk about the historical development of chemistry ideas.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>8.</td>
<td>Students carry out prescribed or set labs.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>9.</td>
<td>Students do laboratory formal write-ups.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>10.</td>
<td>Students are provided with pre-written notes and they are discussed.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>11.</td>
<td>Students are asked to explain what has been demonstrated.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>12.</td>
<td>Students perform calculations.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>13.</td>
<td>Students use manipulatives to help understand what is happening at the molecular level.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>14.</td>
<td>Students are required to know what a formula means before they calculate.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>15.</td>
<td>Students have to explain chemistry ideas at the molecular level.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>16.</td>
<td>I use a variety of strategies to get across chemistry ideas.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>17.</td>
<td>On tests students perform calculations.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>18.</td>
<td>Students make notes from textbooks.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>19.</td>
<td>Students are assigned problems from texts.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>20.</td>
<td>Students work together on tasks.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>21.</td>
<td>Students are expected to explain their results by discussing with their group.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>22.</td>
<td>I use analogies or role plays to get across chemistry ideas.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>23.</td>
<td>I check to see if students grasp ideas before moving on to the next topic.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>24.</td>
<td>I refer to the history of chemistry applications in my teaching.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>25.</td>
<td>Chemical models are used to help students to learn.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>26.</td>
<td>Mini-labs/short experiments are performed by students.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>27.</td>
<td>I assess student learning by tests.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>28.</td>
<td>I give students lots of examples to assist them in their learning.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>29.</td>
<td>I get students to work together and help each other on activities and problems.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>30.</td>
<td>I assist students with their work as they request assistance.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>31.</td>
<td>I use everyday examples to communicate chemistry ideas.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>32.</td>
<td>I explain ideas as students copy notes.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
<tr>
<td>33.</td>
<td>I assess student learning of student experimental activities.</td>
<td>N</td>
<td>R</td>
<td>S</td>
<td>O</td>
<td>A +0 -</td>
</tr>
</tbody>
</table>

Thanks for completing this questionnaire.
## Appendix B: Chemistry Teacher Inventory—Pre- and Post-CRYSTAL Data

<table>
<thead>
<tr>
<th>Teacher Behaviour/Classroom Characteristic</th>
<th>A: 2006 Mean (Rank)</th>
<th>B: 2008 Gr. 11 Mean (Rank)</th>
<th>C: 2008 Gr. 12 Mean (Rank)</th>
<th>Statistical Comparisons A:B:C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Students copy notes without explanation.</td>
<td>1.52 (32)</td>
<td>1.07 (33)</td>
<td>1.43 (33)</td>
<td>A&gt;B=C, A=B</td>
</tr>
<tr>
<td>2. I perform chemical demonstrations.</td>
<td>2.87 (24)</td>
<td>3.72 (16)</td>
<td>3.00 (27)</td>
<td>A&gt;B&gt;C, A=C</td>
</tr>
<tr>
<td>3. Visual images are used to clarify chemistry ideas.</td>
<td>2.24 (28)</td>
<td>3.63 (17)</td>
<td>4.00 (12)</td>
<td>A&gt;B=C</td>
</tr>
<tr>
<td>4. Students plan investigations and then carry out the investigation.</td>
<td>2.31 (27)</td>
<td>2.30 (31)</td>
<td>2.39 (31)</td>
<td>A=B&gt;C</td>
</tr>
<tr>
<td>5. Computer-based simulations are used to clarify chemistry ideas.</td>
<td>2.60 (26)</td>
<td>2.64 (28)</td>
<td>3.07 (25)</td>
<td>A=B&gt;C</td>
</tr>
<tr>
<td>6. I explain how chemistry topics relate to students’ lives today.</td>
<td>3.62 (14)</td>
<td>3.79 (15)</td>
<td>3.96 (15)</td>
<td>A&gt;B&lt;C</td>
</tr>
<tr>
<td>7. I talk about the history of chemistry applications.</td>
<td>2.10 (31)</td>
<td>2.91 (27)</td>
<td>3.50 (21)</td>
<td>A&gt;B=C</td>
</tr>
<tr>
<td>8. Students carry out prescribed or set labs.</td>
<td>3.83 (10)</td>
<td>3.84 (14)</td>
<td>4.15 (10)</td>
<td>A=B=C</td>
</tr>
<tr>
<td>9. Students do laboratory write-ups.</td>
<td>3.42 (16)</td>
<td>3.41 (21)</td>
<td>3.91 (16)</td>
<td>A=B&gt;C</td>
</tr>
<tr>
<td>10. Students are taught with pre-written notes.</td>
<td>3.02 (20)</td>
<td>2.93 (26)</td>
<td>3.02 (26)</td>
<td>A=B=C</td>
</tr>
<tr>
<td>11. Students are asked to explain what has been demonstrated.</td>
<td>3.10 (19)</td>
<td>3.60 (19)</td>
<td>3.72 (18)</td>
<td>A=B&gt;C</td>
</tr>
<tr>
<td>12. Students perform calculations in class.</td>
<td>4.52 (3)</td>
<td>4.15 (5)</td>
<td>4.37 (4)</td>
<td>A&gt;B=C, A&gt;C</td>
</tr>
<tr>
<td>13. Students use manipulatives to help understand what is happening at the molecular level.</td>
<td>1.24 (33)</td>
<td>2.93 (25)</td>
<td>2.71 (29)</td>
<td>A&lt;B&gt;C, A&lt;C</td>
</tr>
<tr>
<td>14. Students are taught what a formula means before they calculate.</td>
<td>3.24 (18)</td>
<td>4.13 (6)</td>
<td>4.13 (11)</td>
<td>A=B=C</td>
</tr>
<tr>
<td>15. Students have to explain chemistry ideas at the molecular level.</td>
<td>2.89 (23)</td>
<td>3.85 (13)</td>
<td>4.00 (13)</td>
<td>A&lt;B&gt;C</td>
</tr>
<tr>
<td>16. I use a variety of strategies to get across chemistry ideas.</td>
<td>3.85 (9)</td>
<td>3.85 (12)</td>
<td>4.00 (14)</td>
<td>A=B=C</td>
</tr>
<tr>
<td>17. On tests students perform calculations.</td>
<td>4.56 (2)</td>
<td>4.13 (11)</td>
<td>4.54 (2)</td>
<td>A&gt;B=C, A=C</td>
</tr>
<tr>
<td>18. Students make notes from textbooks.</td>
<td>2.68 (25)</td>
<td>2.28 (32)</td>
<td>2.22 (32)</td>
<td>A&gt;B=C</td>
</tr>
<tr>
<td>19. Students are assigned problems from texts.</td>
<td>3.35 (17)</td>
<td>3.19 (24)</td>
<td>2.89 (28)</td>
<td>A&gt;B=C</td>
</tr>
<tr>
<td>20. Students work together on tasks.</td>
<td>3.82 (11)</td>
<td>3.61 (18)</td>
<td>4.20 (8)</td>
<td>A&gt;B=C, A&lt;C</td>
</tr>
<tr>
<td>21. Students are expected to explain their results by discussing with their group.</td>
<td>3.01 (21)</td>
<td>3.28 (22)</td>
<td>3.28 (24)</td>
<td>A&lt;B=C</td>
</tr>
<tr>
<td>22. I use analogies or role plays to get across chemistry ideas.</td>
<td>3.52 (15)</td>
<td>3.58 (20)</td>
<td>3.54 (20)</td>
<td>A=B=C</td>
</tr>
<tr>
<td>23. I check to see if students grasp ideas before moving on to the next topic.</td>
<td>4.01 (8)</td>
<td>3.94 (9)</td>
<td>4.37 (5)</td>
<td>A=B=C</td>
</tr>
<tr>
<td>24. I refer to the history of the development of chemistry ideas in my teaching.</td>
<td>2.17 (29)</td>
<td>2.51 (29)</td>
<td>3.33 (22)</td>
<td>A&lt;B&lt;C</td>
</tr>
<tr>
<td>25. Chemical models are used to help students to learn.</td>
<td>3.00 (22)</td>
<td>3.24 (23)</td>
<td>3.33 (23)</td>
<td>A&lt;B=C</td>
</tr>
<tr>
<td>26. Student-directed labs are performed by students.</td>
<td>4.02 (7)</td>
<td>4.22 (3)</td>
<td>4.17 (9)</td>
<td>A&lt;B=C</td>
</tr>
<tr>
<td>27. I assess student learning by tests and lab reports.</td>
<td>4.40 (4)</td>
<td>4.21 (4)</td>
<td>4.43 (3)</td>
<td>A&gt;B=C, A=B</td>
</tr>
<tr>
<td>28. I give students lots of examples to assist them in their learning.</td>
<td>4.30 (5)</td>
<td>4.34 (2)</td>
<td>4.28 (6)</td>
<td>A=B=C</td>
</tr>
<tr>
<td>29. I get students to work together and help each other on activities and problems.</td>
<td>4.05 (6)</td>
<td>4.04 (8)</td>
<td>4.28 (7)</td>
<td>A=B=C</td>
</tr>
<tr>
<td>30. I assist students with their work as they request assistance.</td>
<td>4.85 (1)</td>
<td>4.72 (1)</td>
<td>4.33 (1)</td>
<td>A&gt;B=C, A=C</td>
</tr>
<tr>
<td>31. I use everyday examples to communicate chemistry ideas.</td>
<td>3.77 (12)</td>
<td>4.06 (7)</td>
<td>3.80 (17)</td>
<td>A&gt;B=C, A=C</td>
</tr>
<tr>
<td>32. I explain ideas as students copy notes.</td>
<td>3.74 (13)</td>
<td>3.88 (10)</td>
<td>3.72 (19)</td>
<td>A&gt;B=C, A=C</td>
</tr>
<tr>
<td>33. I assess student learning by formal lab reports.</td>
<td>2.12 (30)</td>
<td>2.32 (30)</td>
<td>2.40 (30)</td>
<td>A&lt;B=C</td>
</tr>
</tbody>
</table>