Constraints and Contributors Towards the Use of Computer Simulations in Manitoba Chemistry Classrooms: Content is Still King

by

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Abstract

Manitoba Education Citizenship and Youth (MECY) recently redesigned Grade 11 and 12 Chemistry curricula in an effort to be responsive to new developments in chemistry education research. In order to support the teaching of the microscopic level of chemistry, the new curricula encourage the use of technology and computer simulations into specific outcomes to aid meaning making of abstract chemistry concepts by students. This study identifies constraints and contributing factors to the use of computer simulations to facilitate student meaning making in chemistry. A questionnaire survey and case study approach informed by Urie Bronfenbrenner's bio-ecological model was used to identify factors. The results of this survey show the chemistry teaching inventory of teachers has become more diversified. Although teachers are using technology as differentiated instruction, their pedagogical use of technology is primarily for content dissemination rather than utilizing the technology to assist students in a deep understanding of chemistry ideas.

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Chapter I – Introduction

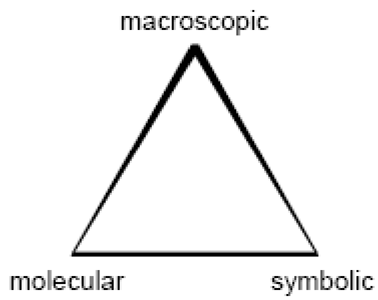
1.1 Context of the Problem

There is a certain mystique that surrounds the field of chemistry. From medieval times, chemists (or at that time, alchemists) have been seen as people who were able to control the natural world through some unexplained ability or magic. In the past, these seemingly magical acts were largely accepted by the society of the time to be self-explanatory because they were reflected in the experiences of that society. Although apparently self-explanatory, often the explanations were scientifically incorrect. In today's chemistry classrooms students continue to enter with prior and often misconceived knowledge of the world around them. This prior knowledge forms for many students powerful conceptual models that may, or may not, contain alternative conceptions according to our current understanding of chemistry (Gabel, 1999). Many student misconceptions have been identified by researchers (for example: Sanger and Greenbowe, 1997) and chemistry educators are taking steps to deal with these identified student preconceptions in various ways. With this identification of areas where misconceptions occur, educators are now adapting their teaching styles along with changing curricula in an attempt to counter these pre-existing student conceptual frameworks.

Teachers are often encouraged to use these preconceptions to engage students. Many of these misconceptions that relate to topics within the Manitoba Chemistry curriculum have been documented (Sanger and Greenbowe, 1997; Sewell, 2002). While it can be engaging for students to make use of prior knowledge, research has shown that when it comes to evaluating and assessing the learning that has taken place, often times the preconceptions that students originally identify often remain as their response (Tasker, 1981). Thus, even though teachers may perceive they have taught well, students chemistry alternative conceptions have remained unchanged (Tasker, 1981). The assessment of changes to student preconceptions also shows that while some students are able to respond appropriately when the assessment of a topic takes place in the same setting as it was taught, the majority of students will rely on their preconceptions when assessed outside of the learning or classroom environment (Gabel, 1999).

Many of the misconceptions that take place in student learning have been identified, yet “as researchers we have solved almost none of the reported problems in Chemistry teaching” (Johnstone, 2000, p. 10). Learning in Chemistry is often seen as difficult due to the high ‘density’ of chemistry concepts that are presented to learners (Gabel, 1999). That is, not only is there much to be learned, but also what is to be learned is complex. To help understand the difficulties that students were experiencing in the learning of Chemistry Johnstone (1991) identified Three Levels of Chemistry Learning, the microscopic, the macroscopic and the representational or symbolic (Figure 1).

Figure 1: Johnstone's Level's of Chemistry Learning



According to Johnstone (1991) in order for students to generate meaning in chemistry, students must be exposed to and make meaning of all three modes of chemistry representation. If students are to generate meaning for a conceptually difficult concept such as the relationship between pressure and temperature when matter is a gaseous state they would need to be exposed to: (1) macroscopic lab-based exercises such as observing the expansion and contraction of a balloon when exposed to room temperature and a lower, outside temperature; (2) why these changes take place by showing visual representations possibly through computer-based simulations or models of what is happening at the molecular level as the space between gas particles changes; and (3) a symbolic representation and algebraic formula that describes the changes that take place.

Over the past decade, the use of computer simulations has been shown to aid in the meaning making of students in terms of their understanding of the microscopic or particulate level of chemistry. Williamson and Abraham (1995) found that students had a better understanding of the particulate nature of matter when using computer simulations as compared to the meaning making that was derived when the same material was taught using still diagrams. Computer simulations are used to create models of microscopic situations so that students can visualize and make meaning from the visual representation. If the computer simulations can be used so that they are constructive, reflective and authentic, there is a greater opportunity for meaning making to occur (Jonassen, Peck & Wilson, 1999). With the influx of computers into the classroom over the past 20 years, educators currently have an opportunity to infuse computer simulations that model and simulate molecular activity into the Chemistry classroom. This infusion of computer simulations can build on student preconceptions, challenge their alternative conceptions and help create new theoretical working models for students to use as a framework for exploring the world around them. This meaning making can be accomplished in a variety of ways. One way is to make use of models in chemistry, including the use of computer animations to create a simplification of the microscopic sense of chemistry (Boohan, 2002). Creating this simplification of a previously unseen event allows the learner to make predictions and to create explanations of the phenomena at the microscopic level. This explanation of events at the microscopic level can then be used to help explain the learner’s observations that took place at the macroscopic level, which can then be worked with at the symbolic level (Gilbert, 2005). Thus, the opening up of the microscopic world can facilitate the connections between the three levels of chemistry (Johnstone, 1991). Computer simulations also allow students the opportunity to have conversations with each other, and with teachers to help them create meaning (Wegerif & Dawes, 2004). This combination of conventional instruction combined with the use of ICT and simulations provides a beneficial impact on student learning (Lowe, 2001).

Despite these progressive moves and the efforts of a long-term and sustained professional development initiative among three cohorts of chemistry teachers, Manitoba chemistry teachers are not regularly using computer simulations in the Chemistry classroom as a teaching technique despite the fact that they have been given considerable exposure to how simulations can be used for teaching chemistry (Lewthwaite, in press). This study serves to gain an understanding as to what the constraints and contributing factors to the uptake of computer simulations are among Manitoba Chemistry classrooms.

1.2 Purpose of the Study

This study is concerned with exploring chemistry teachers' attitudes and perceptions toward computer simulation use in chemistry teaching, especially at the microscopic level of representation. There is a body of research emphasizing how the connection between the particulate nature of chemistry and the macroscopic and symbolic levels of chemistry can be strengthened through the use of computer-based simulations and animations (for example, Jonassen, Peck & Wilson, 1999, Boohan, 2002). The CRYSTAL chemistry professional development sessions built upon these claims and the suggestions of the Grade 11 and 12 Chemistry curriculum directives for the use of ICT to teach chemistry.

CRYSTAL chemistry sought to improve the teaching of chemistry and, among other things, highlighted the connections between computer simulations and the microscopic mode of representation. These directed professional development sessions ran over a five-year period in which teachers have had the opportunity to examine the 2006 and 2007 Chemistry curricula published by the Province of Manitoba. The model used to govern the professional development was based on Professional Learning Communities, or PLC's. This model allowed teachers the ability to guide their own professional development while allowing for reflection and discourse among participants.

During this professional development teachers were allowed to experiment with demonstrations and laboratories that looked at the macroscopic level of understanding. There also was emphasis on how these macroscopic experiences could be explained at the molecular level. There was also a distinct emphasis on the microscopic level of chemistry and the understanding of the learner's preconceptions in regards to various topics in chemistry. After the third year of the five year project, participant teachers were surveyed (Lewthwaite, in press) and it was found that the use of computer based simulations was consistently ranked near the bottom of teaching strategies in terms of the frequency of use in participants' chemistry classrooms.

This study is designed to identify how teachers are using computer simulations in chemistry classrooms and what the constraints and contributors are to the implementation of computer simulations in the chemistry classroom. The changes that have taken place over the past five years in both computer technology and the Chemistry curriculum in Manitoba have created an opportunity for educators to re-evaluate their teaching and classroom practices. The changes have also brought forward an opportunity for students to explore areas of chemistry that were previously only generally observable at the macroscopic level. This study is in response to these changes and attempts to develop an understanding of the processes influencing the uptake of computer modeling and simulations in the chemistry classroom.

The overarching theme of this study deals with attitudes and perceptions of chemistry teachers. It also deals with how these same teachers have, or have not, changed their methods of practice in teaching chemistry in light of computer technology resources that are currently available in the classroom. For this study three research questions have been developed:

a) What are Manitoba Grade 11 and 12 chemistry teachers' current teaching practices, and how is this teaching inventory currently used?

b) What factors do teachers perceive as constraints or contributors to the use of the new educational technologies or ICT, in particular computer based models and simulations, to support student learning in chemistry?

c) What perceived effect has the use of ICT and computer simulations had on meaning making by chemistry students in the classroom?

1.3 Significance of the Study

There has been a great deal of research in the areas of student alternative conceptions in Chemistry. Yet, according to Gabel (1999) "nine out of ten instructors are not aware of these misconceptions or do not utilize ways to counteract them in instruction." (p. 552). In order to overcome this lack of knowledge and to assist teachers in their ability to teach for better conceptual understanding, the CRYSTAL project was developed as a professional development opportunity. Of particular emphasis in the project was the emphasis placed on using new educational technologies, especially computer simulations, to support students in their learning. This study is important to gain an understanding into why or why not teachers are using computer simulations in chemistry classrooms. The constraints or contributing factors are important to identify in order to best foster the use of computer simulations as a best teaching practice in the microscopic mode of chemistry. It is also important to identify why and how teachers are making use of computer simulations and models in order to create meaningful learning experiences for students.

1.4 Scope of the Study and Generalizability of the Results

This study will be used to identify the constraints and contributors to the use of computer simulations in specific classroom situations. The focus will be on those teachers currently involved in the CRYSTAL initiative and will provide understanding of issues associated with ICT use for this group of teachers specifically. Because of the amount of professional support these teachers have received for the inclusion of ICT in their classrooms, it is unlikely that the results will be generalizable to teachers who are trying to implement ICT where limited support is available. The results may not be generalizable to all school situations as the teachers involved are from a specific subset of chemistry teachers from within the province of Manitoba. The data may also alert School District or Division staff to various constraints or contributors that makes the implementation of computer simulations either untenable or accessible within specific classroom, school and divisional environments. This study may also provide some research-based support for further professional development in terms of computer-based learning use in chemistry and other curriculum areas.

1.5 Limitations of the Study

Using qualitative research for this study has inherent limitations in terms of generalizability. The number of participants may put a limitation on how wide the scope of findings can be presented. This may also be the case due to the highly specialized group of individual teachers who are the subject of the study. The small pool of participants who will participate in this study all have a specialized background in that they all teach Chemistry and all are participants in CRYSTAL chemistry professional development sessions. While the backgrounds that the participants have may be similar the results may be applicable to other areas of technology integration in education, specifically in areas of science where there are microscopic or particulate levels of understanding that need to be integrated with a macroscopic and symbolic understanding.

1.6 Organization of the Thesis

The thesis is organized into five chapters. Chapter I describes the research problem, study rationale, the specific research questions and the significance of the study. The second chapter, Chapter II reviews the literature. The history of the Chemistry curriculum in Manitoba and teaching pedagogy, the rationale behind the use of technology to aid in student learning, and the levels of factors that can effect teacher decision making are all reviewed extensively. In Chapter III the research methods are described and the participants that were involved in the study are introduced. The analysis of the data takes place in Chapter IV. Chapter V completes the thesis with discussion and recommendations.

Chapter II – Literature Review

2.1 Introduction

The purpose of this chapter is to review the literature pertaining to the context of the study, the constraints and contributing factors in the use of computer simulations during the teaching of chemistry. The literature review is divided into seven sections. In section 2.2 the review will begin with an investigation into how students create meaning in chemistry. The shift in pedagogy within the chemistry classroom with reference to current research in chemistry education is explored in Section 2.3. The themes and orientations of the current Grade 11 and 12 Chemistry curricula in Manitoba are explored in section 2.4. The section also highlights the advocacy in the current curricula for the use of computer technology in the chemistry classroom. After looking at the Manitoba curricula, research concerning how computer simulations effect student meaning creation is explored in section 2.5. The orientations towards technology and the choices to use computer simulations in chemistry are discussed in Section 2.6. The factors influencing computer simulations and curriculum implementation are discussed against the backdrop of Urie Bronfenbrenner's bio-ecological model (1979). This includes the individual teacher and environmental constraints and contributors to student use of technology in terms of teacher interest and motivation, available infrastructure, including capital costs and access, and professional development and training of teachers. The chapter concludes with a summary of the literature review in section 2.7 and provides the foundation for the research questions and the methodology to be outlined in Chapter III.

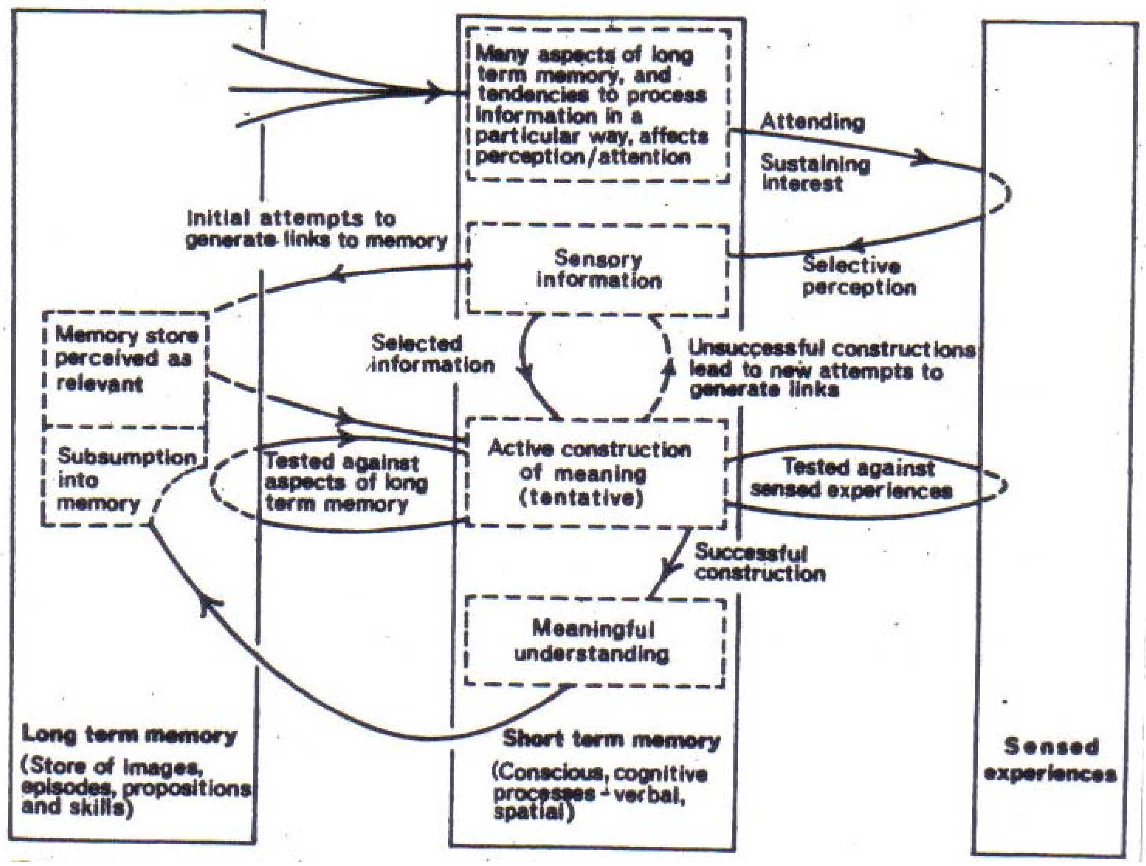
2.2.1 Meaning Making in Chemistry

From the time we are born we begin making observations about the world around us. These observations guide us in developing our understanding of the world and all the phenomena that are contained within this world. Due to the nature of these observations, we are often forced to observe macroscopic events and are left to make assumptions about what has triggered the event to happen. It is these assumptions that lead to student preconceptions in chemistry. These preconceptions are maintained today due to the similar experiences that students are exposed to during their informal education. Chemistry educators are attempting to expose these preconceptions by studying learning styles and implementing new curricula. The approach of using student preconceptions can engage students in terms of a lesson itself, but upon evaluation the misconception that students originally identified often remains as their response. This finding has been documented by chemistry teachers and researchers in so far as there were considerable discrepancies between teacher assumptions about what the students were thinking and learning as compared to that perceived by an observer (Tasker, 1981). With the influx of technology into the classroom over the past 20 years there is currently an opportunity to integrate computer simulations and modeling into the chemistry classroom to work with student misconceptions. The next sections deal with the current research in regards to how students create meaning in chemistry and then relate this meaning to their pre-existing conceptual frameworks.

2.2.2 Generative Learning Model

Due to the number of preconceptions that are present in students as they enter the chemistry classroom teachers need to understand the ways in which students generate meaning. In 1983 a study by Osborne and Wittrock came up with three major findings in terms of students entering the chemistry classroom. The first finding was that students do enter the classroom with a pre-conceived view of the world around them as it pertains to science. These durable ideas form part of a conceptual structure that make up the students understanding of the world around them. The second major finding was that although students may have been exposed to science teaching their childhood conceptual structure often remained intact despite exposure to new ideas. The third finding was that if a student's conceptual structure was changed by exposure to Science teaching the results may not be predictable in terms of improvement of science understanding. With these findings the question becomes how do we better go about teaching students about science concepts? The Generative Learning Model was the result of this research (Osborne & Wittrock, 1983). The goal of the model is to "take fully into account pupil perceptions and viewpoints and, where appropriate, to attempt to modify or build on, but certainly not ignore, children's ideas" (Osborne, Wittrock, p. 492). Osborne and Wittrock take into account the fact that students have an existing conceptual structure and attempt to tap into this structure to help the student to create and generate meaning.

Figure 2: Generative Learning Model



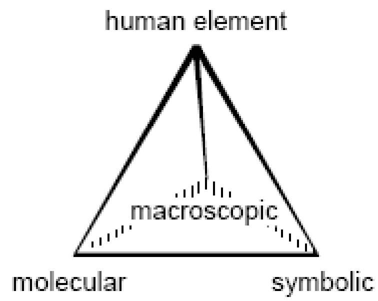
The model attempts to explain how a student's sensed experiences can be used to help the student "actively construct meaning" (Osborne & Wittrock, p. 493) and how students generate a meaningful understanding that can either replace or alter the previous conceptual structure that was in the student's long term memory.

The Generative Learning Model works with student prior knowledge. There are times when this prior knowledge may not be consistent with scientific beliefs. Although it may often be hard to change a student's conceptual structure there are many implications that can be gathered from the Generative Learning Model for teaching science. Motivating students by providing opportunities to be successful can aid in the generation of meaning, as can well structured events that clearly define the various modes of representation in chemistry. Using computer simulations to present visual, organized representations or models can be analyzed by students to help increase understanding in terms of processing of information in chemistry.

2.3 Modes of Representation in Chemistry

Many of the preconceptions that students bring with them into the chemistry classroom have been identified yet, "as researchers we have solved almost none of the reported problems in chemistry teaching" (Johnstone, 2000, p. 10). However, the preconceptions that students hold when studying chemistry are only one piece to a larger puzzle. In order to completely understand what is taking place when students are studying chemistry we must take into account several factors. The first factor is the complex nature of chemistry as an area that affects student learning. The second factor we must also look at is how students process information and student's perception of information (Johnstone, 2000). While subject matter plays a considerable role in chemistry education, the ways in which students generate meaning including the prior experiences of students can take even the most well planned lesson and generate unforeseen consequences. There has been a great deal of research that has taken place studying problem solving and misconceptions in chemistry and the widespread nature of these misconceptions (Gabel, 1999). These misconceptions form barriers in regard to how students interact with the subject matter and the topics within chemistry. According to Johnstone (2000), there are three forms or modes in the subject of chemistry: the macroscopic or tangible side; the sub microscopic or particulate, including the atoms and structures that cannot be seen but only observed; and the representational or symbolic, including the symbols and formula that are often used in chemistry. This triangular view of chemistry has been more recently adapted by Peter Mahaffy (2006) into a tetrahedral model by including a human element which deals with the applications, stories and history of chemistry.

Figure 3: Mahaffy's Tetrahedral Metaphor for Understanding chemistry



Mahaffy's inclusion of the human element emphasizes the importance of the prior knowledge and interaction of students with chemistry as they attempt to create meaning. The inclusion of the human element allows educators to include social and environmental issues currently facing the field of chemistry which will allow for greater societal understanding. By understanding the role chemistry plays in today's society a mental framework can develop for the additional meaning making in chemistry when set against a backdrop of real world experiences.

Chemistry education has a tendency to attempt to present all vertices or areas of chemistry to a student at one time which may overwhelm the learner (Johnstone, 2000). Chemistry teachers also may not have even considered how these dimensions of chemistry may affect student learning (Gabel, 1999). In situations where all modes are introduced simultaneously or where no thought has been given to the modes, the learner may simply maintain their prior thinking about an idea in chemistry and use a more rote approach to the ideas presented. In these situations no meaning has been made for the learners and they simply carry out tasks as needed within the chemistry classroom to ensure good test scores (Gabel, 1999). In order for students to truly learn and understand chemistry there must be an integration of the three levels of chemistry, or else students are left with a “fragmented view of chemistry with many puzzling parts that do not seem to fit together” (Gabel, p. 549).

Chemistry classrooms often pride themselves with the use of complex laboratory sections in which students are asked to complete hands-on tasks dealing with phenomenon that have been introduced during lectures. Instructors believe that the practical work can help students make connections between the microscopic and the macro levels of chemistry. This is a false assumption. Johnstone (1991) found that the connection between the two levels is often confused during laboratory work because students make observations at the macroscopic level and it is the expectation of the teacher for the students to interpret these results at the microscopic level. This observation has been confirmed the American Chemical Society’s Conceptual Exams as it has been shown that many high achieving students maintain chemistry misconceptions at the microscopic level despite showing an understanding of chemistry concepts at other levels. Added to this learning dilemma, students in the laboratory are often required to use materials that are unfamiliar to them (Gabel, 1999). Students live in a world where they interact with the macroscopic; even the idea of sodium chloride sounds exotic and unfamiliar when compared to the more common name of salt. This can be especially confusing when the chemical formula of NaCl is introduced. The varying ways of representing the same substance, and the ways in which teachers move between the modes within a single lesson has an impact on student understanding. It is here where the human element referred to by Mahaffy (2006) must be incorporated into the learning of chemistry in order for any learning of chemistry to take place. Student unfamiliarity with the various modes of representation can also have a negative effect on student learning as students are challenged to make the connection between the various levels of chemistry (Gabel).

In order for our students to begin learning and making meaning in chemistry there must be a fundamental shift in the way that chemistry is taught in school (Johnstone, 2000). This shift needs to begin with both a change in curriculum and a change to the teaching system. There are a variety of instructional models that can be used in the teaching of chemistry that deal with the structure of the discipline. Current research in the area of chemistry education (Gilbert, 2005, Gilbert & Treagust, 2008) has shown that Johnstone's model and the adapted Mahaffy version have begun to drive changes in Chemistry curriculum. These two models are reflected in the 2006 and 2007 Manitoba Grade 11 and 12 Chemistry curricula. This was done in an effort to take more theoretical concepts and to present them first at the macroscopic level at which students have a larger stable of prior knowledge. When moving from the macroscopic level several links are created to ensure that all three areas of chemistry are highlighted to ensure a link to students' or societies prior experiences in an effort to help create knowledge that is acceptable to existing structures within students. The new Chemistry curricula also aim to create a discourse among teachers and students about the nature of the subject. The curriculum follows the idea that by orchestrating conversations between teacher and student, or student to student, connections can be made between prior knowledge and newly presented material. When this curricular focus is superimposed over Johnstone triangle of chemistry the goal is to aid students in transferring the data from their "working space" memory to more long-term forms of memory (Johnstone, 2000). There is hope that these changes will bring students back to chemistry and help increase the understanding of those students who are currently enrolled in the subject.

The next section discusses the current state of the Manitoba Curricula and the research on which they are based.

2.4.1 The Manitoba Chemistry Curricula

Over the past forty years Manitoba has developed five major versions of a high school Chemistry curriculum, each being developed as a response to educational issues of importance at the time of each curriculum's development. The curricula have evolved over time to become a guide for teachers to affect their teaching in the classroom. From the 1966 incarnation of the Manitoba Chemistry curriculum to the 2007 version, each curriculum has become more detailed in their approach to the content to be presented, ideas for presentation, and methods for assessment of curricular outcomes. During this time there has also been an increase in reference to technology and the types of technology to be used to support learning as society and education have adapted newly developed computer based technologies.

The treatment of student misconceptions has implications for chemistry teaching in Manitoba. The 2006 and 2007 Manitoba Chemistry curricula publicize the various modes of representation available in chemistry and outcomes are written in a way that requires teachers to focus on a scaffolding approach (MECY, 2007) to bridge the various modes. The incorporation of Mahaffy's and Johnstone's modes of representation allow for the use of technology to help create experiences for students that can be relevant in terms of their previous observations. The new curricula contain instruction ideas that include computer simulations as a possible method for teaching at the various levels of chemistry. These implications of increased use of technology and an awareness of the modes of representation in chemistry represent a significant change to the classroom practices of many experienced educators.

2.4.2 Analysis of the 2006 and 2007 Manitoba Chemistry Curricula

In this section the current Manitoba Chemistry curricula will be analyzed in terms of the guiding conditions that lead to their creation. The analysis will be guided by three central foci. The first focus is the correlation between the curriculum and links to the societal conditions in which the curricula were developed. The second focus is the degree of emphasis placed on the use of technology and the types of technology that are recommended for use in the Manitoba Chemistry Curricula. The third focus involves the inclusion of Johnstone and Mahaffy's modes of representation and their emphasis in the curricula.

Over the past century the educational system and curriculum has remained relatively unchanged. The original work of Ralph Tyler in the area of curriculum theory has been maintained in terms of measurable and observable outcomes. While many schools of curriculum have developed since Tyler, his model of curriculum is still in use today. With the constant of the Tyler curriculum model in place, schools have shown little change in day to day activities in regards to instruction, assessment and evaluation. In the meantime the outside world has undergone a large shift where technologies have come to the forefront as a means by which learning can be promoted. The Manitoba curricula have had an emphasis on Science, Technology, Society and the Environment (STSE) for the past 20 years. This emphasis has emanated from a societal emphasis on STSE issues in both Manitoba and Canada. In 2006 and 2007 the Manitoba Grade 11 and Grade 12 Chemistry curricula were revamped to be more reflective of the research literature on learning theory in Science and Chemistry specifically. This focus on learning theory has incorporated the use of technology into the classroom in an effort to maximize student learning using all available techniques for instruction. However, there is still a strong dichotomy present in schools when it comes to the infusion of technology into teaching. There seems to be little debate about its necessary use, but much emphasis on the general reluctance for its effective use in promoting learning.

The 2007 Chemistry curriculum begins with a statement of broad goals. The main goal that the curriculum focuses on is to increase scientific literacy as a response to the modern world. “Global interdependence; rapid scientific and technological innovation; the need for a sustainable environment, economy, and society; and the pervasiveness of science and technology in daily life reinforce the importance of scientific literacy” (MECY, 2007, p.5). From this beginning, the curriculum develops the focus on understanding chemistry from an ecological viewpoint. This ecological viewpoint and the interdependence of global or macro systems is congruent with the current societal beliefs within Canada.

The interconnectedness between chemistry and the environment is also present in the unifying concepts that are presented in the Chemistry document’s Conceptual Organizer (MECY, 2007, p. 11). The organizer outlines that the foundations for scientific literacy are connected to essential scientific knowledge, the ideas of how science, technology and the environment unite the scientific skills and the nature of science itself. By presenting outcomes in this way, the curriculum encourages students to make connections and meaning between the prior knowledge. As earlier stated, these preconceptions may consist of knowledge of the macroscopic results and the microscopic phenomenon that have not been observed (Gabel, 1999). The Guide to Implementation of the Chemistry curricula refers to the ways in which student populations are changing and their increased reliance on technology (MECY, 2007). There is an emphasis on teaching to the macroscopic, observable world and allowing students to use problem-solving skills to make the necessary connections between the various modes of representation in chemistry.

2.4.3 Manitoba Curricula and Technology

The 2006 and 2007 editions of the Manitoba Chemistry curricula also place an emphasis on students having access to both technology and to a “media-rich environment” (MECY, p. 32). Students are expected to have resource materials available in different formats (book, CD-ROM, Internet) as well as interactive simulations and computer based models in an effort to aid in meaning making and learning. With the wide variety of sources available the curriculum makes recommendations for teachers in a separate annotated bibliography document dealing with the selection of learning resources.

To support the use of computer simulations in chemistry a second document was released in 2006 by the Manitoba government. In an effort to increase computer usage in the classroom an Assessment continuum for ICT (Information and Communication Technology) use in the classroom was released. The original framework was designed for the Kindergarten to Grade 8 levels. This framework was followed with the ICT in the Senior Years curriculum document in 2008. Technology (that is, ICT) is meant to be infused into all curricula rather than being a separate focus in the classroom. As this

Provincial mandate begins to be implemented in schools, many divisions within the province are placing additional expectations on teachers in regards to the amount of usage of computers by students in the classroom. In order to move past simply using technology for data mining, teachers have been introduced to using computer technology to be used for modeling and simulations. These changes represent a societal shift with an emphasis towards the infusion of technology in the classroom.

2.4.4 Modes of Chemistry Representation in the Curricula

The 2006 and 2007 curricula also make reference to Johnstone's levels or modes of Chemical representation. The curricula refine Johnstone's original levels of the macroscopic, microscopic and symbolic and restate them as being the macroscopic or visual, the numeric, the graphical, the particulate and the symbolic mode of representation (MECY, 2007). The ability for students to be fluent in all three modes of representation is emphasized, and teachers are directed to ensure that they incorporate all modes of representation into their teaching practices. The document also goes on to state that it is important for teachers to vary their instructional practices while keeping in touch with the varied modes of chemical representation. The new curricula go one step further by including Mahaffy's tetrahedral arrangement which adds a fourth level to Johnstone's interpretation, the human element. This human element is stated by MECY to be of central importance to the improvement of teaching and learning of chemistry in Manitoba classrooms as students experiencing, thinking and communicating on these four levels (2006). The foundation for implementation can be summed up as a pedagogic document that is meant to ensure chemistry teachers are aware of the changes that have taken place in our understanding of chemistry and the developments we have about how students learn.

2.4.5 Overview of the Curricula

The underlying foundations of the Chemistry curricular document are congruent with research in terms of the levels or modes of chemistry representation. The document also places an emphasis on the use of technology, simulations and modeling in order for students to gain a greater understanding of the microscopic or particulate mode of representation. The means by which technology can be used is made explicit within the curriculum with the listing of web sites that contain either animations or simulations. Many of these simulations focus on the microscopic level of chemistry. It encourages students to have exposure to these three levels and associated concepts. These include observable (macroscopic) concepts, unobservable concepts (microscopic) and algorithmic concepts (symbolic). In order for learning to be effective, students need to make connections between all three levels of chemistry (Johnstone, 2000). Computer simulations and models can be used to help bridge the cognitive gaps between these three levels. In order for this meaning making to take place technology needs to be viewed as an extension of reality to represent and simulate real-world problems, situations and contexts (Boohan, 2002).

Teaching using technology is not an effective strategy in situations where the computer is used as a conveyor of information (Boohan, 2002). In these types of situations the learner often is unable to construct or alter their conceptions of a topic due to the volume of information that technology can present. Students also have difficulties in chemistry due to the abstract nature in which material is often presented. If meaningful learning opportunities are to happen in chemistry when technology is in use, students must have the ability to interact with and manipulate computer-based models.

Allowing students to interact and dialogue can help change student preconceptions (Wegerif, & Dawes, 2004). This interaction works to modify or build on student's preconceptions in an effort to generate new learning (Osborne and Wittrock, 1983). This generative process of learning is important in terms of teaching for conceptual change in chemistry. The Generative Model of Learning and Teaching (Osborne and Wittrock) assists teachers in conceptualizing their teaching as it suggests that learning can be fostered when students have the opportunity to make connections between their preconceptions and newly observed phenomena. The use of simulations that represent molecular activity becomes such an opportunity.

The 2006 and 2007 Manitoba Chemistry curricula seek to change classroom pedagogy by referencing the latest ideas for the teaching of chemistry. It also seeks to infuse technology into the curriculum by embedding content directly into the written outcomes. This multi-pronged approach identifies the needs of learners in the classroom and responds by including techniques for teaching all the modes of chemistry using various types of technology, including computer simulations. The curriculum takes the teaching and learning of chemistry further by incorporating multiple assessment strategies for outcomes. The differentiated instruction ideas and inter-disciplinary approaches create a document that is congruent with current research into meaning making in chemistry and the ways in which computer simulations can enhance this learning.

2.5 Computer representations in the classroom

In order for any type of visual representation to aid in student meaning making the representation or simulation must work to decrease the cognitive load for understanding of a concept (Cook, 2006). Computer simulations allow students to experience interactions with the particulate level of chemistry that can aid in the generation of new ideas that can be linked into their macroscopic understandings of chemistry events. The exposure to a simulation or representation allows for a multimodal approach to concepts that generally cannot be experienced visually. The current Manitoba Chemistry curricula take into account the current understanding of the modes of representation of chemistry and the ways in which students generate meaning. This in turn can help teachers to utilize simulations to foster experiences that aid in student meaning making.

Computer simulations can help students with misconceptions by opening up dialogue both between students and between students and teachers. This concept of “Thinking Together” allows students to explore alternate ideas regarding how things work (Wegerif & Dawes, 2004). It is through this discourse that connections can be made between prior knowledge and the new information.

In the area of chemistry, research has shown that computer animations are most effective in representing concepts where change over time is a major component (Ainsworth & VanLebeke, 2004). When looking at the particulate mode of chemistry animations have also been shown to improve student understanding of chemical processes (Sanger, Brecheisen, & Hynek, 2001; Sanger & Greenbowe, 2000; Yang, Andre & Greenbowe, 2003). This research was conducted as a comparison between static visual representations and animations, and suggests that animations provide a complete model for building mental representations (Mayer & Gallini, 1990).

With the changes that have taken place over the last 20 years in society the infusion of technology into the classroom is becoming an expectation rather than the exception. The next section focuses on the factors that affect decisions around technology infusion.

2.6.1 Factors affecting Technology Infusion

Today the use of ICT in classrooms is influenced by a variety of factors, some pertaining to practical issues such as funding and support and others are less evident such as teacher attitudes and motivation. In all cases the uptake of the use of ICT by teachers, schools, and school divisions is a developmental phenomenon and thus Urie Bronfenbrenner's bio-ecological model (1979) will be used to identify the factors influencing and the relationships influencing ICT uptake. Bronfenbrenner's model allows for an analysis of multi-level factors influencing development. Although Bronfenbrenner organizes these factors into spheres he does suggest that these factors are inter-related.

Teachers are being asked because of provincial policy and social expectation to introduce students to ICT and its learning capability, yet many schools and their divisions have not considered strategic possibilities for supporting ICT inclusion. These competing factors along with others can be placed within the hierarchy of Bronfenbrenner's bio-ecological model (1979). Bronfenbrenner's model looks at the various levels of support that can affect an individual as they grow. These factors include the individual skill set and motivations, as well as the microsystem factors closest to the teacher such as collegial support. As well, mesosytem factors such as school priorities and expectations and macrosystem factors such as government guidelines and curricula all influence ICT infusion into the classroom.

In an effort to combat the issues around technology uptake and use within classrooms, school divisions and districts across North America have created action plans that are meant to increase the reliability and access to technology in the classroom. Many of these programs have looked at providing access to hardware for teachers. This initial phase is important; however there is often a lack of professional development offered in conjunction with the large capital outlay for technology. The professional development factor often is incorporated at a later date after the initial capital outlay for technology (Bereiter and Scardamalia, 2006). In order for all educators to benefit from technology, districts and divisions must concentrate on the pedagogy in technology and on access to technology; otherwise the capital outlay becomes positive only for the companies supplying the technology (Cuban, 2001).

The sections that follow categorize known factors that effect teacher's implementation of ICT in the classroom based on Bronfenbrenner's bio-ecological model.

2.6.2 Technology and the Individual Teacher

The Manitoba Chemistry curriculum has changed five times over the past 40 years. While the goal of each curriculum has been to increase student understanding of chemistry, classroom practice has remained centered around the use of rote learning and pre-planned laboratory experiences (Gabel, 1999). Despite the advocacy for the use of ICT in assisting chemistry meaning making, the pedagogical practices of teachers who have received CRYSTAL professional development, especially in terms of ICT use, have not changed significantly. Inhibitors, constraints and contributors to the teacher use of computer technology have been identified by several studies, most notably those by Cox et al. (1999) and Rosen & Weil (1995). These studies identified the following individual factors as being instrumental as either a constraint or contributor to ICT use: teaching experience with ICT, personal and psychological factors (interest, motivation, and confidence), professional capability in creating more enjoyable lessons and improved lesson quality. These factors as well as other potential factors such as curriculum and technology knowledge and personal and professional priorities may all play a role in the individual's infusion of technology into teaching. The studies indicate that a teacher's motivation, interest and ability to work with ICT are at the heart of a teacher's inclusion of ICT into their classroom.

2.6.3 Microsystem and Mesosystem Factors

The micro and mesosystem will exhibit or alleviate pressure at the classroom and school level on the individual teacher in terms of their uptake of computer technology. The microsystem includes factors such as the collegial support to infuse computer technology into teaching practices as well as encouragement and expectations of infusion from educational administration that teachers may be in ongoing face-to-face contact with. Student response to a teacher's use of technology will influence a teacher's efforts and forms part of the microsystem in the classroom. Teachers have heard many times of how today's students are the 'digital natives' and that as teachers they are immigrants to computers which can have an effect within the classroom environment (Prensky, 2001).

It also includes students' response to a teacher's teaching. The students in the classroom can have a great effect on teaching pedagogy. Many students report dissatisfaction with lecture based teaching practices. Lecture based teaching is a characteristic of a content based classroom (Denessen, 1999). When students are allowed to take on a more inquiry based model through the use of computer simulations, Saar reports increased depth of understanding, increased ownership and investment in learning and higher student engagement in their own learning (2009). So, if a teacher is attempting to move students to a deeper understanding of chemistry ideas through ICT use, students' responses to this action might be positive or negative and, by so doing, influence a teacher's efforts and development towards further ICT infusion.

The mesosystem is defined in our case by the school, primarily its views or beliefs as influenced by school administration and senior teachers. These beliefs may include the school's collective responsiveness to change, school expectations of teachers, and the school's focus or priorities in terms of education. The school environment in which a teacher is placed can have an effect on the use of computer technology in the classroom. The school as an agent of change has been studied by Fullan in terms of educational reform (1991). Fullan found that there has not always been a clear sense of the reasons for changes to take place. This has led to a failure of some programs as teachers have not been given sufficient long-term opportunities to make meaning of the new technologies for themselves (Mumtaz, 2000). A supportive collegial environment and support from divisional sources can also contribute to a teacher's infusion of technology. This can be seen in situations where there is a strong collegial support system in place in terms of the infusion of computer technology into classroom practice (Hennessy and Deaney, 2004).

Cuban (1993) makes assumptions that computer technology has not had the same effect on education as in other aspects of society due to cultural beliefs as to what teaching is and how it should be done. Thus schools may be more apt to take a wait and see approach to computer technology as some may deem it to run contrary to best teaching practices. This negative stereotype indicating that education is slow to incorporate computer technologies may not be accurate. According to Dawes (2001) the perceived teacher resistance to change may simply be a function of the system using its collective knowledge to evaluate the pedagogic possibilities of each individual technological advancement.

These micro and mesosystems also pertain to perpetuating and ongoing support teachers may receive through professional development, especially where a community of learners is established for promoting a particular goal, in this case ICT use. There is a need for teachers to be exposed to ongoing training in order to gain an understanding of the applications of computer technology and its availability for the chemistry classroom (Mumtaz, 2000). All participants in this study have been exposed to ongoing and purposeful professional development within the areas of the 2007 Chemistry curricula through the University of Manitoba CRYSTAL centre. This includes the use of computer models and simulations that are available for use in the Chemistry classroom. In order for professional development to achieve its goals it must be based on four basic premises (Lewthwaite, 2006). The four premises are listed below:

1. Both internal and external research and practical knowledge must be combined to develop a successful program along with specific outcomes and supports must be in place.
2. Teachers are expected to reflect on new content and pedagogy and create meaning in terms of their classroom practice.
3. A collaborative, constructive and ongoing learning environment must be maintained.

4. Teacher leaders need to be developed so that new teaching pedagogy can be propagated within entire communities and not be limited to one specific area.

The CRYSTAL Chemistry program has been designed to follow the four premises. Teachers from each school community are given the opportunity to become teacher leaders. The teachers were given access to currently accepted research in terms of chemistry education with the goal of providing collaborative opportunities to change classroom pedagogy as the teachers became more familiar with the 2006 and 2007 Chemistry curricula. These teacher leaders were given the opportunity to form a collaborative Professional Learning Community (PLC) and this group then commanded more control over the professional development sessions over the course of the project.

2.6.4 Exosystem Factors

Manitoba is a diverse province. There are great differences between urban and rural and again between northern and southern areas. These community based differences create both constraints and contributors to the infusion of technology into the classroom environment.

The community and parental expectations across Manitoba can be diverse. The ability to access computer technology can be substantially different. Major urban centres in Manitoba have similar access to computer equipment and high bandwidth network connections, the same cannot be said for some rural and northern communities. Cuban (2000) would say that this is an effect of the business push of computer technology into schools. The rural and northern areas are not as profitable as more densely populated areas and therefore are not as desirable to deliver technology services. This brings about many implications and logistical problems for teaching in terms of access and community expectations of education. While urban centres may be able to infuse curricular suggested computer simulation ideas, often rural centres do not have the same ability.

2.6.5 Macrosystem Factors

As discussed earlier within this chapter the macrosystem factors within Manitoba tend to be uniform across the province. The newly developed Chemistry curricula are meant to be delivered across the province. They contain specific learning outcomes and examples of strategies teachers might use in their teaching including web-site links specific to the representation of the molecular level. Of particular importance has been the development of over 200 resources by the CRYSTAL initiative posted on the internet that pertain directly to the specific learning outcomes and the three-mode orientation of the curriculum. The explicit nature of the learning outcomes and strategies does not mean that there will not be individual teacher interpretations of outcomes within the document; however the curricula do maintain a standard language and attitude towards the teaching of chemistry.

2.7 Summary of Literature

Over the past 40 years there has been a great deal of research around pedagogy and curriculum development in the sciences. Researchers have identified the various modes of representation in chemistry and have identified ways in which teachers can use these modes to help students generate meaning. Research has also identified ways in which teachers can use student prior knowledge along with experiential learning to generate meaning in chemistry. In response to these claims the new Manitoba Grade 11 and 12 curricula have been developed and implemented over the past four years. Yet, despite organized professional development, experience with technology and computer simulations, and revised curricula that place an increased emphasis on this research, teachers are slow to adopt the revised practices. This may be due to any combination of factors at the individual, micro, meso, macro or exosystem levels according to Bronfenbrenner. The next chapter deals with the method and methodology that seeks to identify the constraints and contributors as to why these technological and teaching practices are being adopted in the classroom but the change in pedagogy from a content centred classroom to a student centred has yet to be adopted.

Chapter III Methodology

3.1 Methodology

This thesis focuses on the current ICT teaching practices and the influences on these practices that are used in chemistry classrooms. Research has suggested that using computer models and simulations can help students to gain an understanding at the microscopic or particulate level (Boohan, 2002). Prior research has also stated that when teachers are exposed to professional development that is aligned with research, teachers are more apt to adopt the materials presented (Lewthwaite, 2006). However to this point the directed professional development that has been delivered by the CRYSTAL project from the University of Manitoba has shown that chemistry teachers who have participated, list the use of computer based models and simulations as the 27th teaching strategy out of an inventory of 32 strategies (Lewthwaite, in press) in terms of use in the chemistry classroom. This disconnect between current research and the classroom practice of chemistry teachers led to the development of the research questions of the study which were stated in section 1.2. The research questions represent the purpose of the study, and also influenced the development of the quantitative survey and qualitative interview questions. As stated in section 1.2, the following questions guided the research:

a) What are Manitoba Grade 11 and 12 chemistry teachers' current teaching practices, and how is this teaching inventory currently used?

b) What factors do teachers perceive as constraints or contributors to the use of the new educational technologies or ICT, in particular computer based models and simulations, to support student learning in chemistry?

c) What perceived effect has the use of ICT and computer simulations had on meaning making by chemistry students in the classroom?

These questions were asked to find out what constraints and contributing factors are affecting Manitoba chemistry teachers in their use of computer simulations. In question one the goal is to gain an understanding of current teaching practices of Manitoba chemistry teachers, and to see if their teaching inventory and its use agree with previous research conducted on the CRYTSAL teaching group by Lewthwaite (in press). Once the current teaching inventory and how these techniques are incorporated into everyday classroom teaching are determined, it is important to talk with teachers to identify what factors are affecting chemistry teachers when using computer technology in the classroom. These factors may be at any level of Bronfenbrenner's bio-ecological model (1979). The final question allows teachers to reflect on their personal use of ICT in their classroom. This reflection provided teachers the opportunity to share their stories of student reaction and learning when exposed to ICT and computer simulations. Research has shown that computer technology can help students create meaning in chemistry, however teachers within the CRYSTAL project consistently chose the use computer simulations in the bottom third of their teaching strategies (Lewthwaite, in press). This is particularly important at the particulate level of chemistry and when making connections between the three levels of chemistry as stated by Johnstone (1991) due to the visual nature of ICT and computer simulations.

3.2 Research Design

The design of the study includes both a quantitative and qualitative portion to the research. The initial survey is quantitative in nature in order to determine a broad general aggregated outlook of the CRYSTAL participants. Once the initial data was collected, in-depth interviews took place with a sub-set of respondents. Qualitative research using a case study approach was chosen for this study in an effort to investigate the constraints and contributors to the use of computer technology and simulations in chemistry classrooms. The use of questionnaires, in-depth interviews and classroom-site visits allowed for a more rich description of the types of conversations that take place between teachers and students (Bogdan & Biklen, 2007) than a quantitative approach alone. The questionnaire and interview technique was used with teachers who were implementing the 2007 Manitoba Chemistry curricula and have been regular attendees at the CRYSTAL Chemistry professional development sessions. This process allows for teachers to reflect on their personal use or non-use of technology in the classroom. As teachers reflect on their current use of technology and the factors that have influenced their choices in terms of technology usage, the in-depth interviews allowed teachers an outlet to express their thoughts on their current teaching practices and provided the opportunity to share reflections on their classrooms.

The thought process that goes into the creation of lesson plans for the teaching of chemistry is not something that can be easily found or described through the use of quantitative research. Because meaning creation and learning is unique to each individual, and that the physical and social aspects of education differ greatly around the province of Manitoba despite the uniformity of the curricula in use, the importance of individual discussions to help identify situational constraints and contributors. "To divorce the act, word, or gesture from its context is, for the qualitative researcher, to lose sight of significance" (Bogdan & Biklen, 2007, p.5). Qualitative, in-depth interviews allowed for probing into areas that participants may not have acknowledged to that point in terms of computer usage. This form of questioning also leads to the reasons as to why choices to include or not include technology have been made.

In order to construct meaning in the classroom there are a multitude of social interactions that take place in various contexts. Each and every social interaction that takes place in the classroom is influenced in some way by power (Bogdan & Biklen, 2007). Through the use of the interview technique the study takes into account how the various levels of Bronfenbrenner's bio-ecological model inform classroom decisions that have taken place that in turn affect the generation of meaning by students.

In-depth interviews allow for the probing into teachers perceptions and assumptions about the factors influencing their choices around ICT in the classroom. The interviews also worked to explore the use of computer simulations and how teachers perceive this exposure influences student meaning-making. These relationships would be difficult to express though the use of a survey or the statistical expression of the methods used by chemistry teachers in the classroom.

3.3 Role of the Researcher

I am a high school administrator pursuing my master's degree in curriculum, teaching and learning at the University of Manitoba. As a high school administrator there have been many occasions in which I have seen programs or teaching techniques that have been touted as an answer to promote student learning. These programs often are accompanied with professional development time. While there are success stories in some instances, there are also many times where only a few teachers have taken up the program or technique and within time it is abandoned. The use of computer simulations in chemistry is one technique that can be used to aid in student learning. The use of computers in chemistry to illustrate the microscopic level of chemistry is based in research that has been validated. The CRYSTAL centre at the University of Manitoba has also developed professional development sessions to support the uptake of this technique by chemistry teachers. The Manitoba chemistry curricula have been rewritten to include methodology in the area of computer simulations. Despite these changes to the exosystem and macrosystem (according to Bronfenbrenner's bio-ecological model), the use of computer simulations in chemistry classrooms was ranked 27th out of 32 techniques that were used by chemistry teachers that have been exposed to the new curricula, the professional development and the background research. With a computer technology background and an understanding of the research and professional development, I am hoping to gain an understanding of the constraints and contributors to the uptake of this meaning creation technique.

3.4 Ethical Issues

Prior to accessing potential participants, ethical approval from the Education/Nursing Research Board at the University of Manitoba was obtained. Teachers who have participated in the ongoing CRYSTAL study may not wish to be identified as their approach to curriculum may differ from both the current research into the creation of meaning by students and the newly revamped Chemistry curricula. School Divisions may also not want to be identified as many have begun making large capital expenditures in an effort to increase the access to technology of both staff and students within their divisions. In order to maintain anonymity all identifiable information of school divisions and individual teachers has been changed. Individual participants have been assigned pseudonyms for interview purposes and any information that could clearly be used to identify the school or school division has been omitted.

My role as an administrator within a school division in Manitoba may be perceived as being in a position of power over chemistry teachers, especially within my school division. To avoid this situation participants selected for the study were chosen from across the province of Manitoba. CRYSTAL participants from within my own school were not selected as candidates for the research.

3.5 Identification and Recruitment of Participants

All participants in the spring 2009 CRYSTAL Chemistry education sessions were eligible for recruitment for this study. All participants who were involved with the CRYSTAL professional development forum were made aware of the study. The quantitative survey was made available online for a one month period of time, and 38 CRYSTAL participants chose to complete the online survey out of approximately 50 attendees. The online survey was completed anonymously. The survey contained general questions dealing with the participants teaching background and experience with the CRYSTAL Chemistry program. A section of the survey was based on a previously developed Chemistry Teacher's Inventory (Lewthwaite, 2006) which focuses on common chemistry teaching practices. It then went on to include much more detailed questions about how and why participants are using ICT for chemistry teaching and what is contributing to this use.

Of the 38 participants who chose to complete the online quantitative survey 16 put their name forward to be considered for the qualitative interviews. Of the 16 CRYSTAL participants who put their name forward, six were selected for the in-depth interview process. Of the six selected, four were male and two female. Three participants were selected from the same school division, with two from the same school. These two were selected so that the factors within a school (microsystem) could be documented, and the third participant from the same division allowed for the documentation of any commonly experienced potential school division factors (mesosystem) that may have been present. The remaining three participants were selected from three separate school divisions in order to make comparisons between exosystem and macrosystem factors. All six interviewees were selected from urban areas of Manitoba. The participants provide variety in that all are at varying stages of their career, all are from varying school sizes, from large schools (1000+ students) to smaller schools (below 300 students), and provide perspectives from both genders.

Entry into the various school divisions was controlled by Superintendents who were informed of the research study. Superintendents from the school divisions participating in CRYSTAL gave permission to contact teachers in the 2009 Professional development series. During the initial CRYSTAL sessions all participants were given a brief introduction to the study and their potential role in the study. At that time all CRYSTAL participants were given the opportunity to put their name forward to continue on to the interview process. The chosen six interview participants were asked to sign an informed consent form. There was no deception in this study.

All six chemistry teachers contacted agreed to be part of the study. The interviews and classroom visitations took place between April and June 2009. The following paragraphs describe the participants and the schools in which they work.

Teacher A – Alex

Teacher A, whose pseudonym is Alex, is a Science and Chemistry teacher in a large suburban high school in the western portion of a mid-sized Canadian city. Alex has been teaching for eight years, two years in his current placement and six years in a rural high school. He began teaching General Science after graduation and has been teaching Grade 11 and 12 Chemistry for the past four years. During Alex's time at the rural high school he had worked under term contracts for the first 3 years, and had looked for a position at an urban high school until he applied for his current position.

Alex graduated from a four year Bachelor of Education program with a Major in General Science and Minors in Physics, Chemistry and Math. Alex has been attending CRYTSAL Chemistry professional development sessions over the past three years and has also received some additional training in an internationally developed Chemistry curriculum.

Alex considers himself to be a versatile teacher who has the ability to teach "pretty much anything". During his teaching career Alex has also been involved in coaching team sports at a high level to which he devotes a large amount of time during the season. Although he has done some work with technology through his coaching, he does not consider himself to be a "techie". Alex did not have a great deal of experience with technology during his university course work, but really became self taught after an initial student teaching experience.

Teacher B – Bill

Teacher B, whose pseudonym is Bill, is a Chemistry and Math teacher in a large suburban high school in the north-east quadrant of a mid-sized Canadian city. Bill has been teaching for 30 years. Over the course of his career he has taught mainly in Senior

Years, although he did spend three years teaching Grade 7 Science and Math. Bill also spent a semester teaching Chemistry and Science in New Zealand.

Bill's academic background is mainly in Chemistry and Mathematics, and he graduated from University with a Bachelor of Education degree. During the course of his career Bill has attended "lots and lots and lots of workshops" and coordinated and presented at numerous conferences. Bill has done some Post-Graduate work in the area of Educational Administration.

Bill is a veteran teacher who is at a point in his career that he can pass his knowledge on to the next generation of teachers. Bill often coordinates professional development sessions and attempts to pass on ideas and materials to anyone who asks. The curricular outcomes are paramount for best practice as Bill reflects on his teaching. He believes that the people who wrote the curricula "spent a lot of time thinking about why we should do this, so my assumption, ... is to honour those learning outcomes right from the start." Bill attitude is that a teacher should always be willing to try new ways of instruction as a way to engage students. He sums up his teaching as "Be very deliberate, to have that metacognition on the part of the students."

Teacher C – Carl

Teacher C, whose pseudonym is Carl, is a Chemistry and Physics teacher in a small French high school in the eastern quadrant of a mid-sized Canadian city. Carl has been teaching for eleven years in the same building, and before starting there, he spent two years teaching English in Asia. He graduated with a Bachelor of Science and Bachelor of Education degree. Carl started teaching in the Mathematics department, but due to various personnel moves he began to teach both Chemistry and Physics, and has been doing so for the past eight years.

Carl places great value on his opportunities to participate in professional development. In his current position he is the only Chemistry teacher in the building, and as such he sometimes feels isolated when it comes to his teaching practices. He is open to new ideas and finds that his CRYSTAL cohort has made him “feel at ease enough to say, man, I’m out to lunch on this concept, what should I really be doing?”. Carl has reached a point in his career where he has begun to reflect and change his practice, where he has begun to look at student learning versus simple delivery of the curriculum.

Teacher D – Doug

Teacher D, whose pseudonym id Doug, is a Chemistry, Biology and Science teacher at a large suburban high school in the north-eastern quadrant of a mid-sized Canadian city. Doug has been teaching for 37 years and is nearing retirement. Doug spent the first four years of his career in a Junior High setting, and then moved to a high school. He did not start teaching Chemistry until approximately twenty years ago, due to the way that succession took place at that time. He is in his thirteenth year at his present school which has a mandate that all teachers will teach Grade 9 and 10 Science along with higher level science courses.

Doug views himself as a “jack of all trades”. During his university days Doug majored in Chemistry and earned a Bachelor of Science followed by a Bachelor of Education where he majored in Science and Chemistry education. After his formal education was complete Doug continued to follow his interests by studying areas such as coaching, photography and horticulture. He views this diversity as a positive force in his teaching practice and has taken advantage of the many professional development opportunities to help diversify his practice.

Doug sees his flexibility as the key to his teaching practice. With the many pedagogical changes that have taken place Doug feels he is doing his best to keep up. "Our field has changed, and things are constantly changing, so...I try to at least keep up and to be on the same page as everyone else, if not in the foreground". Doug was excited to share his perspectives on Chemistry and teaching and this enthusiasm is what has kept him teaching all thirty-seven years.

Teacher E – Emma

Teacher E, whose pseudonym is Emma, is a Chemistry teacher at a mid-sized suburban high school in the southern quadrant of a mid-sized Canadian city. Emma has been teaching for 17 years in a high school setting where she began teaching Grade 10 Science and Chemistry. In the current school year Emma is teaching Grade 11 and 12 Chemistry in the afternoons only.

Emma began university entering the Faculty of Science and finished a three year general degree. Once Emma completed her Bachelor of Science, Emma she contemplated doing a post-bac degree so that she could go in to research in Chemistry. However, after meeting with her academic advisor she decided to apply to the Faculty of Education where she completed an Education degree with a double major in Chemistry and Biology. Emma completed her master's degree in Education two years ago. This was done in the area of chemistry education.

Emma has a great deal of background in the field of Chemistry, and has specialized in teaching this area since her graduation. Her teaching revolves around

Johnstone's levels of representation and how the history of Chemistry can be employed to help students make meaning. Her learning style is visual, and as such her lessons contain "visuals, so whether it's drawing pictures or using models" there are many ways that students can interact with lessons.

Teacher F – Fran

Teacher F, whose pseudonym is Fran, is a Chemistry teacher at a smaller high school located just outside of the downtown core of a mid-sized Canadian city. Fran began her teaching career thirteen years ago in another province, and has been teaching in her current position for the past two years. She has worked as a substitute and full time teacher in Grade 10 Science, and Grade 11 and 12 Chemistry.

Fran completed both her four year Bachelor of Science (Chemistry) and her Bachelor of Education degree at a university in her current city. Upon completion of her second degree she chose to leave the province to begin her teaching career. As she has grown in her career she has found that instead of just giving the notes and the theory, she needs to allow students to "see it a little more, whether that is a lab or it's a visual".

Fran is just becoming familiar with the current provincial curricula and as such is open to trying new pedagogical approaches to chemistry. Although Fran feels that she is "computer savvy" her school is just beginning to incorporate technology into their teaching practices. This coincides with her exposure to the CRYSTAL professional development series and as such she has seen her technology use grow and change from when "it started out very much pen and paper".

3.6 Limitations of the Study

There are several limitations to this study. The number of participants, especially in the qualitative interviews is small. The quantitative online survey was completed by thirty-eight people, and only six were chosen for interviews. All participants have been exposed to the CRYSTAL professional development series and as such do not form a representative group of chemistry teachers within the province. The views of Chemistry teachers from outside this sample would have added breadth to the study. The views of students and administrators would have added additional depth to the study and other perspectives to the use of ICT in the chemistry classroom.

Some of the teachers' answers may also reflect beliefs and values of which they may not be aware. The answers may also reflect beliefs and values which they believe the interviewer may want to hear. Despite probing of these answers the teacher may not come to this realization and as such made it impossible to explore the hidden belief. As such the idea of the fossilized teacher identity and what participants believe a Chemistry teacher to be may have an impact on the study. The member checks and follow up discussion may help to address these issues.

Researcher bias may also play a role in this study. As the sole researcher and interviewer, I had to ensure that the study did not become a self-fulfilling prophecy. This is even more apparent in that before becoming an administrator I taught Chemistry and participated alongside some of the participants in the CRYSTAL professional development series. This was minimized through careful analysis and categorization of the data.

The nature of the computer simulations and ICT that CRYSTAL participants were exposed to within the professional development may also be a factor in the educator use of technology in the classroom. CRYSTAL sessions placed an emphasis on simply increasing the amount of computer simulation use within classrooms. There was not a focussed discussion surrounding the pedagogy of computer simulation use. This limitation in the professional development session may reflect on this study's results.

The use of qualitative research from a small pool of participants has inherent limitations in terms of generalizability. The analysis of the data using Bronfenbrenner's model may allow schools or districts the ability to identify the areas which have the greatest effect on teacher infusion of technology in classrooms outside of chemistry.

3.7 Data Collection

The initial survey resulted in data from 38 teachers that was tabulated into spreadsheet data. This data was statistically examined to identify current classroom teaching techniques and teacher attitudes towards computer simulations. It was also used to identify new questions for the interview research protocol. Six participants from this group of respondents to the initial survey were selected.

Semi-structured interviews were then conducted as the main data collection method. This method allowed for probing and exploration of new ideas as the interviews progressed while keeping an overall consistency between interviews. This flexibility allowed for participants to elaborate on areas of chemistry education which they felt were important to them. A copy of the interview schedule can be found in Appendix A.

All interviews lasted for between 60 and 90 minutes. Each interview was recorded using a digital audio recording device which was downloaded onto a computer and transcribed verbatim. Member checks with interviewees were completed and any potentially damaging information were removed from the transcripts. The transcripts were then analyzed, and participants were allowed comment on the analysis to ensure accuracy.

3.8 Data Analysis

This study uses both quantitative and qualitative data. The quantitative data was analyzed graphically and statistically to identify trends and baseline data which helped guide the interview process. Interviews were analyzed using open, axial and selective coding. The coding combined with descriptive field notes provided the themes found in the analysis.

The interview transcripts were examined and sorted using open coding immediately after they were transcribed. The coding categories were based on prior literature and the interview questions. The coding categories included teachers' current ideas on best practice in the classroom, teacher access to technology, factors affecting their technology usage, and technologies impact on student learning. These four categories were selectively coded to illustrate the themes and to make comparisons and contrasts between the data sets. This involved searching the data for quotations and vignettes that illustrated and reflected the emerging themes. The interview data was organized using Microsoft Word files, with a separate document being created for each theme. Quotations for each theme were copied into the document and then analyzed for similarities and differences. In the following chapter the final themes and vignettes that emerged are analyzed.

Chapter IV Data Analysis

4.1 Introduction

This chapter focuses on the analysis of the quantitative data collected from the large group of chemistry educators and the in-depth interview qualitative data collected from the smaller subset focusing on chemistry educator's beliefs and perceptions in regards to the use of computer simulations in the classroom. The study, overall, involved 38 chemistry teachers who responded to the online survey. The six chemistry teachers who were involved in the interview process were selected from this group of 38 and were introduced in the methods chapter. Although the six interview participants each work in different schools and communities, there were commonalities in their perceptions. This chapter will explore some of these commonalities which include their current teaching practices, as well as their vision of best chemistry teaching practices and meaning making for students, and the constraints and contributors that affect their ability to use technology in the classroom based on Bronfenbrenner's bio-ecological model (1979).

4.2.1 Quantitative Survey Data Introduction

The quantitative portion of this survey was completed during the month of March, 2009. All members of the CRYSTAL chemistry professional development series were asked via email to complete the survey they received in March 2009. The presenters of the CRYSTAL professional development sessions that month also reminded participants of the survey. The survey was completed via an online data collection service. All data collected was anonymous in nature and the data was grouped before being analysed to ensure no personally identifying information could be gathered from the data.

4.2.2 Demographic Information and CRYSTAL feedback

There were 38 respondents to the quantitative survey, of which there were 26 males and twelve females. The first six questions in the survey deal with the demographic data of the group.

Table 1: Demographic Data of Qualitative Survey

How many years of teaching experience do you have?		
0 – 4 years	8	21.05%
5 – 10 years	11	28.95%
11 – 15 years	5	13.16%
16 – 20 years	5	13.16%
21 + years	9	23.68%
How many years have you been teaching Chemistry?		
0 – 4 years	13	34.21%
5 – 10 years	14	36.84%
11 – 15 years	4	10.53%
16 – 20 years	2	5.26%
21 + years	5	13.16%

The subjects in the survey were mainly within the first ten years of their teaching career (50% of respondents) with the remaining spread evenly between the remaining categories, with five respondents with over 21 years of teaching experience. This data corresponds with the responses that indicate 72% of respondents have been at their current school for ten years or less. Three teachers have been at their school for more than 21 years. The data shows (Table 1) that the majority of respondents (71%) have taught Chemistry for ten years or less. Seven of the respondents have more than 16 years of experience teaching Chemistry. In terms of academic background 28 of the respondents had either a four year Undergraduate degree or an Undergraduate degree and a two year Education Degree. Only ten of the respondents have completed any Post-Graduate work. Of the group participants, 30 have received some type of professional development training in regards to the use of computer technology in the classroom, not including the CRYSTAL Chemistry sessions.

The next six questions in the survey deal with the respondents' participation and thoughts on the CRYSTAL professional development sessions. The majority of the group, 34, have attended at least one year of the CRYSTAL sessions, with 25 of the respondents having attended for a minimum of two years. The entire group averaged 6.63 CRYSTAL sessions attended as there are 3 sessions per year. The respondents were then asked about which portions of the professional development sessions they found to be most beneficial to their classroom practice. Respondents were allowed to select as many options as they found beneficial.

Table 2: CRYSTAL Benefits to Classroom Practice

Which portions of the CRYSTAL professional development sessions have you found beneficial in your classroom practice? (You may select as many options as you feel have been beneficial)		
Potential student laboratory activities.	34	89.47%
Sharing ideas with other Chemistry teachers.	34	89.47%
Potential teacher laboratory demonstrations.	33	86.84%
Discussions surrounding the three modes of Chemistry.	32	84.21%
Potential student interactive computer simulations.	31	81.58%
Applications of Chemistry to students' everyday life.	21	55.26%
Potential teacher demonstration computer simulations.	14	36.84%
Sharing assessment ideas with other Chemistry teachers.	13	34.21%
Connection between the history of Chemistry and students' learning.	10	26.32%

The results from Table 2 show that the potential to be exposed to laboratory activities along with the ability to share ideas with other chemistry teachers and the discussion surrounding Johnstone's three modes of chemistry were the most beneficial outcomes of CRYSTAL professional development. The outcomes of CRYSTAL that were the least chosen as beneficial were the connection between the history of Chemistry and student learning, as well as sharing assessment ideas with other chemistry teachers and potential teacher demonstrated computer simulations. 34 of the respondents had visited the CRYSTAL web site, and 28 had used some type of resource sourced from the site at least a few times, with five respondents having extensively used resources from the site. Overall the satisfaction with the CRYSTAL sessions (38 respondents) was either very satisfied or satisfied with the professional development that occurred at these sessions.

This demographic data paints a picture of the CRYSTAL professional development group as a younger cohort of teachers either in the beginning stages or entering the mid-stage of their careers. This majority also had done little to no additional training outside of their original Education degree. This lack of additional training may be due to the career stage of the educators, as many of the educators have just begun their teaching careers. The fact that the majority of respondents have undergone some type of technology training may simply be a function of their career stage, as in the last ten years there has been a large uptake of computers in school settings (Cuban, 2001). The experience level of the cohorts may have also contributed to the fact that the perceived most beneficial aspects of CRYSTAL professional development sessions was the exposure to laboratory activities and to discuss ideas in chemistry with other teachers. A more experienced cohort may already have these types of laboratory activities inventoried, and may be more resistant to changing their pedagogical practice than this younger group of educators. In terms of pedagogy, it must be noted that 31 respondents found it beneficial to be exposed to potential interactive computer simulations that could be used independently by students, but only 14 felt that being exposed to computer simulations that can be used as a demonstration for teachers was beneficial. This speaks to the group's overall potential pedagogical view towards the use of simulations as a pedagogical practice. This idea was explored during the qualitative interviews to see how computer simulations are used in the classroom. The career stage of the cohort may also be reflected in terms of the number of respondents who had both visited the CRYSTAL web site and used materials from the site. The younger age of the teachers or the inherent rise in the use of the internet to access materials could contribute to the high use of the

CRYSTAL web site. The demographics of the cohort may also be a factor in the focus on content by teachers. While there is an interest in using computer simulations to give students the opportunity to take more control over their learning there is also a focus on content that makes this pedagogical shift slow or difficult to take place.

4.2.3 Current Teaching Practices

The third section of the survey dealt with the current teaching practices of the respondents. Respondents were asked to respond to a teaching inventory that was first used by Lewthwaite in 2008. They were asked to rank on a five point scale their use of various pedagogical techniques. The most commonly used pedagogical techniques in the chemistry classroom in this survey were students being asked to perform calculations in class, the use of visual images and labs being performed by students. This data appears to agree with the use of the three modes of chemistry for teaching according to Johnstone (1991). The least likely techniques to be used were asking students to make notes from textbooks and students using computer based simulations. This data also agrees with the previous pedagogical inventory that was performed by Lewthwaite in 2008. The data from the inventory was explored in the qualitative interviews in an effort to gain an understanding of why these choices are being consistently made within classrooms.

The next question in the survey asked teachers to reflect on how often certain teaching practices were used with students to generate meaning.

Table 3: Current Teaching Practices that Generate Student Learning

Reflecting on your current teaching practices, how often do you use the following strategies to generate student learning in Chemistry?						
Practice	Almost Always (5 points)	Often (4 points)	Sometimes (3 points)	Rarely (2 points)	Never (1 point)	Average
I talk about the History of Chemistry	0 % 0	26.3 % 10	50.0 % 19	23.7 % 9	0 % 0	3.0
Students are asked to explain what has been demonstrated	13.2 % 5	60.5 % 23	21.1 % 8	5.3 % 2	0 % 0	3.8
I explain how Chemistry topics relate to student lives	5.3 % 2	63.2 % 24	23.7 % 9	2.6 % 1	0 % 0	3.7
Students are required to know what a formula means before they calculate	39.5 % 15	34.2 % 13	23.7 % 9	2.6 % 1	0 % 0	4.1
Students have to explain Chemistry ideas at a molecular level	26.3 % 10	50.0 % 19	15.8 % 6	5.3 % 2	2.6 % 1	3.9
On tests students perform calculations	57.9 % 22	34.2 % 13	7.9 % 3	0 % 0	0 % 0	4.5
Students are expected to explain their results	28.9 % 11	52.6 % 20	18.4 % 7	0 % 0	0 % 0	4.1
I use analogies to get across Chemistry ideas	28.9 % 11	55.3 % 21	15.8 % 6	0 % 0	0 % 0	4.1
I check to see if students grasp ideas before moving on to the next topic	44.7 % 17	44.7 % 17	7.9 % 3	2.6 % 1	0 % 0	4.3
Chemical models are used to help students learn	5.3 % 2	47.4 % 18	39.5 % 15	7.9 % 3	0 % 0	3.5
I assess student learning by tests and lab reports	26.3 % 10	65.8 % 25	7.9 % 3	0 % 0	0 % 0	4.2
I give students lots of examples to help assist students in their learning	44.7 % 17	47.4 % 18	7.9 % 3	0 % 0	0 % 0	4.4
I get students to work together and	44.7 %	39.5 %	15.8 %	0 %	0 %	4.3

help each other on activities and problems	17	15	6	0	0	
I assist students with their work as they request assistance	65.8 % 25	34.2 % 13	0 % 0	0 % 0	0 % 0	4.7
I use everyday examples to communicate Chemistry ideas	21.1 % 8	65.8 % 25	13.2 % 5	0 % 0	0 % 0	4.1
Average %	30.2 %	48.1 %	17.9 %	3.7 %	0.2 %	4.0

Table 3 shows that respondents in general use differentiated instruction in their classrooms. The respondents did identify three methods of instruction as being the most common techniques used within their classrooms. These three options include students being asked to perform calculations on tests as a way to generate student learning, students being assessed through their work on labs and tests, and teachers assisting students when requested. The least likely used methods of instruction were the use of the history of Chemistry and the use of chemical models to help students learn. The overall balanced choices of respondents show a movement towards a more differentiated instructional toolbox yet there maintains a reliance on the symbolic mode of chemistry in terms of assessment and class work. This reliance on a symbolic mode of representation may also explain the lower rate of use for both the use of history and models to help students learn.

4.2.4 Teaching and Technology

The survey then looked at teacher access to technology and its use in the chemistry classroom. All 38 respondents have access to either a desktop or laptop computer along with high speed network access to the internet. 33 respondents also have access to a LCD projector either in their classroom or access to a portable projector. Approximately half of the respondents have access to a Smart Board or equivalent interactive projection device. This access to technology carries over to how the technology is used for pedagogical purposes. There is a direct correlation between the use of computers for teaching purposes and the respondents' access to technology either in or available to their classroom. Respondents unanimously use technology as part of their administrative duties, with 71% of them completing these duties both at school and home. The respondents to the survey are from a wide geographical area, and the above data suggests that educator access to technology and the internet are fairly standard and open to all members of the CRYSTAL professional development cohort.

The next seven questions in the survey dealt with the computer simulations and how they are currently being interpreted and used in chemistry classrooms. 37 respondents have used a computer simulation for teaching purposes in their classroom, however the majority only have used the simulations either infrequently or only a few times. Only seven respondents stated that they frequently used computer simulations in their classroom. The next set of questions queried respondents as to their feelings surrounding how accurately computer simulations represent macroscopic, particulate and symbolic levels. These questions are important to see which type of simulations respondents are using in their classrooms. When simulations are used to explore the symbolic level of chemistry the respondents in the survey felt that computer simulations normally provided an accurate representation of the formulas or math involved. Of the respondents 22 felt that the simulations were often or almost always accurate. When asked about how well computer simulations portrayed the macroscopic level 29 felt that the representations were often or almost always accurate. When working with simulations that portray the particulate level of chemistry, 25 respondents felt that the simulations were often or almost always accurate. When looking at the particulate level all 38 respondents felt that the particulate level is portrayed accurately at least sometimes in simulations. On a five point scale, this data shows that respondents find that computer simulations that show the particulate level are in general the most accurate, followed by simulations that show the macroscopic. The least accurate of the three levels was the symbolic level.

The respondents were then asked questions regarding student interaction with computer simulations. 28 respondents felt that students were engaged by computer simulations either often or almost always. This question leads into how students make meaning using computer simulations. Respondents felt that students were often or sometimes able to create meaning when working with computer simulations. In order to define how students were engaged with computer simulations, respondents were asked to rate how the engagement looked in their classroom. Respondents felt that computer simulations increased student to student dialogue, increased student to teacher dialogue, and increased student understanding. However, the majority of respondents (66.7%) were neutral when asked if computer simulations lead to an increase in student assessment scores.

The final two questions in the survey deal with the factors respondents felt were most important influencing the use of computer simulations in the classroom and which factors influence their choices around computer simulations. These questions seek to find out the group's beliefs in terms of Bronfenbrenner's bio-ecological model and which areas are having the greatest effect on uptake of computer simulations. Respondents felt that several technology factors were equally important in terms of access. The most important factor for respondents was having technology that was loaded with the correct software to ensure a seamless use of technology in their classrooms. The least important aspect was access to materials that would support the simulation. The overall responses show that personal factors have the greatest influence when it comes to the use of computer simulations. Respondents felt that personal motivation, interest and access were the most important factors when choosing to use computer simulations. Support for the respondents from school administration was also an important factor for respondents. Respondents did not feel that the number of teachers using computer simulations in their school had a major effect on their own use, although the professional support from other teachers was deemed to be important. Student reaction to computer simulations also has an effect on the respondent's use of simulations. The support of district or divisional staff and curricular outcomes were not deemed as important as the personal factors affecting respondents' choices.

4.2.5 Summary of Quantitative Data

The respondents to the online survey cover a generally balanced demographic in terms of years in teaching and educational background, although it may be somewhat skewed towards the younger or mid-career teacher. Because the majority of respondents have attended one year or more of the CRYSTAL professional development sessions, it is not out of the expected that nearly all have visited the CRYSTAL website, and the majority are satisfied with the sessions. The teachers surveyed do incorporate a great deal of differentiated instruction and assessment; however most do not use a great deal of information regarding the history of Chemistry or representational models. Access to technology is generally not a problem for any of the respondents, as the majority have a desktop with internet access within their classroom. The data presented shows that respondents have used computer simulations in the past, and that CRYSTAL professional development were a major stimulus to the incorporation of computer simulations being used in the classroom. The respondents also cited that a personal motivation to use computer simulations and technology in the classroom is important as is the support of their colleagues.

4.3.1 Qualitative Interview Introduction

The six teachers involved in the qualitative portion of this study were introduced in the method's chapter. The interviews focused on each teacher's teaching practice, their individual use of computer simulations and the factors that influence their decision to use computer simulations in their classroom. The teachers selected came from various backgrounds, but there remained commonalities in several areas surrounding computer simulations. The six Chemistry teachers will be introduced in a series of vignettes. Each vignette will highlight a critical incident that took place in their teaching career, their past and current chemistry teaching practices and how they have or have not infused technology into these practices. Once the six vignettes have been shared, data from the interviews will be referenced in terms of the similarities and differences that are present in the areas of access to technology, constraints and contributors to technology use according to Bronfenbrenner's bio-ecological model (1979), and the effects that computer simulations and ICT have had on student learning.

4.3.2 Participant Vignettes

The following paragraphs describe the participants and the schools in which they work.

Teacher A – Alex

Teacher A, whose pseudonym is Alex, is a Science and Chemistry teacher in a large suburban high school in the western portion of a mid-sized Canadian city. Alex has been teaching for eight years, two years in his current placement and six years in a rural high school. He began teaching General Science after graduation and has been teaching Grade 11 and 12 Chemistry for the past four years. During Alex's time at the rural high school he had worked under term contracts for the first 3 years, and had looked for a position at an urban high school, which is now his current position.

Alex graduated from a four year Bachelor of Education program with a major in General Science and minors in Physics, Chemistry and Math. Alex has been attending CRYSTAL Chemistry professional development sessions over the past three years and has also received some additional training in an internationally developed Chemistry curriculum.

Alex considers himself to be a versatile teacher who has the ability to teach "pretty much anything". During his teaching career Alex has also been involved in coaching team sports at a high level to which he devotes a large amount of time during the season. Although he has done some work with technology through his coaching, he does not consider himself to be a "techie". Alex did not have a great deal of experience with technology during his university course work, but really became self taught after an initial student teaching experience.

Alex's classroom is a combination of desks and a wet lab, with sinks and gas lines. The room is spacious and appears to seat approximately thirty to thirty-five students. There is a computer in the room along with a DVD player, both of which are connected to a permanently mounted projection system. Alex's experiences with technology are mainly personal. "I didn't take a computer usage, or teacher and technology course, because kind of the reputation going around the school when I was there, was like, you don't need these courses. A lot of it was just kind of, well, I self taught myself a lot." Alex has access to computer technology both in his classroom and within his school. Within the building, he is able to access interactive whiteboards and computer labs. He has also been given access to professional development, but for Alex there was a critical event that took place during his student teaching that began his use of technology in the classroom.

"When I started student teaching, I did my student teaching at (urban high school), and the guys there used quite a bit of technology, and I thought that was awesome. Um, like they used the probes for labs, and um, you know Grade 10 Science they did the little graph match there with the walking and the motion sensor, and, you know, they did a lot. So that's something that I took back to (his next high school placement) when I went out there."

This event is what began Alex's experience with technology. While his pre-service training at the university did not emphasize the use of technology and simulations in the classroom, his cooperating teachers' use of technology and the student reaction to technology was a critical point in his career. The use of computer simulations was reflected for Alex in the engagement of students in the lesson. Students also showed Alex that they could describe the particulate level on assessment after being exposed to the computer simulations. The conversations that followed with Alex's cooperating teacher also solidified the use of computer simulations as a valid teaching technique. He continued to work with computer simulations after this initial placement and during his time in both the rural and urban high schools in which he later taught. It is these micro and mesosystem influences of students and colleagues that have guided Alex's technology interactions. Alex also has a personal motivation to use technology, which he stated throughout the interview. It is this personal motivation that Alex cites in terms of how he learns to use technology. "I'm not an instruction reader, I'm going to go through and figure it out."

Alex has felt that CRYSTAL professional development has greatly affected his teaching, but not in the area of technology. When asked about the most applicable portion of CRYSTAL, Alex responded with "Labs! When I went to the CRYSTAL sessions, the biggest thing was labs and number two was technology, because I wanted to build up my labs, because, I like to make sure we are doing lots of hands on stuff, and, to be able to complement them with technology is key." Alex's access to technology and his willingness to incorporate technology to show the particulate level is evidenced in his teaching practices. The use of a simulation or animation to help students understand microscopic concepts is often used to help introduce a concept in Alex's teaching style. Alex is always willing to share these chemistry simulations, and often does with his students. "I've had several students ask me, like they'll bring a flash drive in and steal a bunch of the animations, so, like I mean they feel that it helps for them. Anytime you can bring it down to the molecular level, because Chemistry is so abstract, um, if you can do that it helps tons." This use of computer simulations and animations "a couple of times a week" has lead Alex to believe that the assessment scores have gone up. Alex reports this through his conversations with his students. "I've asked them quite a bit, and like, do you find these animations are helping and yeah, for sure. I think that is one way you can assess our teaching."

Alex feels that he uses computer simulations often in his class, along with a set program of hands on lab activities. Yet, the "hands on approach" to teaching does not carry over to Alex's impressions of his lessons however, as he feels there is still a strong emphasis on the symbolic level of chemistry. When looking at a regular lesson, Alex begins his teaching with notes on the subject, which is then broken down into the macro and particulate levels. It is in this early stage that Alex uses computer simulations, which can be as often as "a couple of times a week". When asked which level of chemistry his classes spend the majority of their time, his answer is simple. "Most of our time is spent working on problems." When probed as to why this was, Alex answered:

"I don't spend a lot of time at the molecular level. Like I said, animations, a few online labs, things like that, but I have to say that most of the time is spent on the symbolic level and doing problems. I think that's where it needs to be. I think that they need problem solving skills; they need to know how to manipulate formulas, if they are going on with chemistry. If they're not, well, even if they're not, they still need those problem solving skills in everyday life."

This coincides with the area that Alex feels students have the most problems with. "I think that the molecular level does a nice job of complimenting it and the wet labs as well, but they do struggle with those a bit too. But I still think that it's the problem solving that they do struggle with the most." Thus, despite Alex's enthusiasm for using technology and his use of computer simulations in his class, his teaching remains focussed on the math and problem solving skills of students.

Overall Alex is a teacher early in his career who is a supporter of technology in the classroom. He uses computer simulations and animations as an augment to his pedagogy to help students explore the particulate level of chemistry. As well, both computer and hands on labs to help them explore the macroscopic level of chemistry. However the structure of his lessons focus on the symbolic level and problem solving, and as such so does his assessment.

Teacher B – Bill

Teacher B, whose pseudonym is Bill, is a Chemistry and Math teacher in a large suburban high school in the north-east quadrant of a mid-sized Canadian city. Bill has been teaching for 30 years. Over the course of his career he has taught mainly in Senior Years, although he did spend three years teaching Grade 7 Science and Math. Bill also spent a semester teaching Chemistry and Science in New Zealand.

Bill's academic background is mainly in Chemistry and Mathematics, and he graduated from University with a Bachelor of Education degree. During the course of his career Bill has attended "lots and lots and lots of workshops" and coordinated and presented at numerous conferences. Bill has done some Post-Graduate work in the area of Educational Administration.

Bill is a veteran teacher who is at a point in his career that he can pass his knowledge on to the next generation of teachers. Bill often coordinates professional development sessions and attempts to pass on ideas and materials to anyone who asks. The curricular outcomes are paramount for best practice as Bill reflects on his teaching. He believes that the people who wrote the curricula "spent a lot of time thinking about why we should do this, so my assumption ... is to honour those learning outcomes right from the start." Bill's attitude is that a teacher should always be willing to try new ways of instruction as a way to engage students. He sums up his teaching as to "be very deliberate, to have that metacognition on the part of the students."

Bill has been experimenting with technology throughout his career. This began while he was a student in university when he began working as a demonstrator for a "teacher and technology" course. During his first years in the classroom the first computers began to show up in schools. "There were some people that were very keen to try it, and to see what it would apply to, and I sort of held back and said let's see what it does and then at the appropriate times I think I jumped in." Bill also had a second opportunity to embrace computers later in his career as the internet was starting to be brought into schools in 1995. The school he was in was able to get a grant to bring in a bank of computers that were connected to the internet, which increased access for both Bill and his students. "When students are also doing it, and it seems for me that sort of brought me in, because we can work on it together, because there are things that they know...the kids are comfortable with it they help me with it, and I'm okay, I'm good with that." These opportunities were the stimuli for Bill to begin working with technology.

Bill's lesson planning follows a methodical approach. Bill begins with the learning outcomes and plans from there. Bill states that "to honour those learning outcomes right from the start, because you don't really know sometimes, I think that best practices are being willing to try." He attempts to use multiple ways to represent outcomes, and he attempts to "not to rush to the symbolic" as he used to do in the past. His teaching has evolved over time to become very deliberate and to say to students, "we're going to do it five ways. Saying to them afterwards, see how we did it five ways”. Bill scaffolds his lesson, where he gives his students the outcomes he will be covering, and then shows them the macroscopic event that indicates something is happening. This macroscopic demonstration might then be shown as a visual representation of the particulate level, “Maybe an animation to represent it, because the motion is often important”. Bill then “ends up with a symbolic representation along with guided practice”. With the province wide push towards differentiated assessment, Bill is “proud of the fact that I’m doing more descriptive feedback and kids are not having to hand it in for marks, they’re getting hopefully, hopefully it’s extending the learning.”

As part of this multifaceted approach, Bill has access to and uses technology and computers in his lessons. The main reason for Bill’s increase in the use of technology has been both the increase in access to the required technology and the robustness of the network. This “trustworthiness” of the network and the “support of the network” by his IT department have made the choice to use technology more appealing. This has brought Bill to the point that “where I use them regularly. When I teach my course in three hour blocks, and there was always, in every three hour block, an opportunity to use them”. This use of computer simulations is mainly due to Bill’s idea that “most senior years students arrive at the class, and expect that you’ve thought of an appropriate way to teach them. Technology being a big deal is only a big deal to the teachers; it’s not a big deal to students. It’s normal, part of their experience”. When asked about if the technology is helping students make meaning at the particulate level, Bill “hasn’t had the conversations with them. Do I feel they understand it better, ah, not necessarily, and I think that has to do with engagement”. Bill does not always assess how students have interacted with computer simulations, but when it has been assessed it is through the drawing of and labelling of the particulate level.

Bill feels that his problems in Chemistry were always at the symbolic level. It was this area of “struggle with algebraic manipulation” that have affected his current teaching practices. The CRYSTAL professional development sessions and computer simulations have allowed Bill to bring in students and “to help kids understand better”. He sums this up as “it’s just been something that is just part of good practice”.

Teacher C – Carl

Teacher C, whose pseudonym is Carl, is a Chemistry and Physics teacher in a small French high school in the eastern quadrant of a mid-sized Canadian city. Carl has been teaching for eleven years in the same building, and before starting there, he spent two years teaching English in Asia. He graduated with a Bachelor of Science and Bachelor of Education degree. Carl started teaching in the Mathematics department, but due to various personnel moves he began to teach both Chemistry and Physics, and has been doing so for the past eight years.

Carl places great value on his opportunities to participate in professional development. In his current position he is the only Chemistry teacher in the building, and as such he sometimes feels isolated when it comes to his teaching practices. He is open to new ideas and finds that his CRYSTAL cohort has made him “feel at ease enough to say, man, I’m out to lunch on this concept, what should I really be doing?” Carl has reached a point in his career where he has begun to reflect and change his practice, where he has begun to look at student learning versus simple delivery of the curriculum.

Carl starts our interview by saying he considers himself a "bit of a Luddite" in terms of his use of technology, and yet later he states that "I find for myself, technology is relatively easy to figure out". Much like Alex, Carl isn't a person who wants to read a manual. "Just let me sit down with it and I'll probably figure it out pretty quickly." Carl's use of technology in the classroom began when he was introduced to a Smart Board by another teacher in his school. Carl finds that "just having other people there that are willing to try the technology" was the major factor that influenced his uptake of technology. For Carl his teaching practices are always based on the rapport he develops and the relationships that he forms, and his uptake of technology is no exception to this. The technology in his classroom was facilitated by his administrations leadership, as they bent divisional rules to ensure Carl had the equipment he needed. "For a while the division didn't want laptops so we just kind of, just don't say anything, well, she said "this is what needs to happen" and it got done."

Carl sees his use of technology as a way to build relationships with his students. He has seen his teaching change over his career, where originally he "taught a lot more content"; he now likes to be "able to relate the material to the students' lives". As a precursor to making the material more relatable, Carl transferred his teaching technique exclusively to the Smart Board platform. This reflection on his teaching practice took place and Carl "threw everything out and started from scratch. I started rebuilding my notes, adding in more visual stuff, more examples, more applets, more whatever – I'm always working on my notes". This move to the Smart Board has changed his classroom set up as well. "I'm out in front and I've got the desk separate, I've got kind of a hallway, an alley down the middle and I walk and I talk to everybody and I'm next to everybody at one point in the class." The structure stretches into his notes as well. By giving students access to his notes, "the guys who were really disorganized before, it's given them structure". While Carl uses technology everyday in his teaching he does not always use computer simulations, and does feel that a person can't learn without a teacher's guidance.

The structure of the classroom adds an extra level of scaffolding to Carl's lesson planning. Because students have access to the notes beforehand Carl is able to enter into a dialogue with his students and help them to create more meaning. Carl often starts by reviewing the big ticket assessment items that will need to be met at the end of the unit. This often takes the form of a symbolic or algebraic representation of a chemical concept. "I usually have the most difficult problem on the first page, say as we go through, go back and try to do it. If you can do it, you know, let me know, maybe I've got something else for you to do." Carl spends much of his time in the symbolic level and uses student exemplars of responses to help guide his students. "I always have examples of what a student's answer looks like that would be worth so many marks". Carl works to bring in the particulate and macroscopic level through the use of visuals and examples, but admits that "the area that I want to focus on, on the most would be bringing in more labs and demonstrations". Carl still "tends to chose content and I'm really picky about activities" because of the concern if "they really know what's going on there".

Carl enjoys the CRYSTAL professional development series for the professional dialogue that takes place between the participants. "CRYSTAL is the best professional development I've done, because you're with the same people. For me it's the group atmosphere and being around like minded people to bounce ideas off and to see how they do it." Throughout the interview Carl makes reference to teaching as a relationship between the students and teachers. The curriculum and technology aspects of teaching are secondary to the personal approach that Carl takes with his students. For Carl technology "facilitates how I teach my material". "I mean that old idea that we're all going to be replaced by computers, that just isn't practical because you don't, computers aren't empathetic, they have no emotional response or are able to gauge and modify evaluation as you go along." Carl uses technology as a springboard to discussion within his classroom at the particulate level. Carl recalled a time where a Bohr model spectrum computer simulation was used as a visual which engaged the class into a discussion about what was happening at the particulate level. Carl uses computer simulations in his class approximately once a week, although he does use technology to present his lessons every day, but every use of technology comes with a human element. "I have a real tough time believing that learning can take place if someone's not there to guide you with questions for the simulation." Carl does admit that computer simulations have allowed him to "present these things better" in terms of the molecular level, where his teaching generally begins. Despite the work that Carl does in the particulate and macroscopic levels, Carl identifies that the symbolic level is most difficult for students to understand.

Teacher D – Doug

Teacher D, whose pseudonym is Doug, is a Chemistry, Biology and Science teacher at a large suburban high school in the north-eastern quadrant of a mid-sized Canadian city. Doug has been teaching for 37 years and is nearing retirement. Doug spent the first four years of his career in a Junior High setting, and then moved to a high school. He did not start teaching Chemistry until approximately twenty years ago. When

Doug began teaching, teacher assignments were determined by seniority in the school, which meant the higher level courses such as Chemistry were not available to him until he had gained enough seniority and experience. He is in his thirteenth year at his present school which has a mandate that all teachers will teach Grade 9 and 10 Science along with higher level science courses.

Doug views himself as a "jack of all trades". During his university days, Doug majored in Chemistry and earned a Bachelor of Science followed by a Bachelor of Education where he majored in Science and Chemistry education. After his formal education was complete, Doug continued to follow his interests by studying areas such as coaching, photography and horticulture. He views this diversity as a positive force in his teaching practice and has taken advantage of the many professional development opportunities to help diversify his practice.

Doug sees his flexibility as the key to his teaching practice. With the many pedagogical changes that have taken place Doug feels he is doing his best to keep up. "Our field has changed, and things are constantly changing, so...I try to at least keep up and to be on the same page as everyone else, if not in the foreground". Doug was excited to share his perspectives on Chemistry and teaching and this enthusiasm is what has kept him teaching all thirty-seven years.

Doug has had a wealth of experiences over his 37 years of teaching. Doug does not have any formal training with technology, but has been a proponent of its use for many years. "It's been a bit of an uphill struggle because within our division it's always been we wanted to use technology but we (the division) are not going to fund it." Through this struggle Doug has "self-taught" himself to use a number of technological applications. Doug became really involved with technology approximately eight years ago. He was given an opportunity to submit a proposal for computer simulation software, “so I went out and submitted everything under the sun, and nobody else did”. This gave Doug access to “a large variety of things like simulation labs, other online resources and animations”. Since this time Doug’s flexibility has come through and the animations have added to his variety of teaching techniques.

Doug is very aware of student changes and development. He describes himself as being of the Piaget school of thought, and sees his students in various lights. He likes to use very hands on examples and simulations to explore concepts in chemistry both at the particulate and the macroscopic levels. Yet Doug still maintains that “primarily I do a lot of lecture that I supplement with problem assignments”. Doug has seen changes in his teaching focus since he began attending the CRYSTAL professional development series. “At first when Brian started talking about things at the molecular level, my focus and my emphasis wasn’t there at all, mine was very much on problem solving and working on kids to develop problem solving techniques.” This has changed to a point where Doug now incorporates “extremely diverse formats for assessment, including problem situations but there will be diagrammatic types of representations as well”. Doug still does focus on problem solving and the symbolic level because “the unfortunate truth is talk to these guys at the universities and that’s what they want, they want the problem solving skills”. Doug admits that he is better now at identifying “a concept that needs to be developed at the particulate level, but I waver sometimes” but he is attempting to diversify his program.

CRYSTAL has been an important motivator for Doug in terms of reflecting on his teaching. “What’s nice about this group is that we agree to disagree. Everybody has their own personal preferences, but I think we are getting closer to all being on the same page. We are getting closer as a group to doing those kinds of things because when you dialogue with people and have the chance to interact you now can appreciate other people’s point of view.” Through these conversations Doug has become more aware of the three levels of chemistry, but admits that his use of simulations generally occurs “probably a minimum of once a month” which hasn’t changed significantly since CRYSTAL began. What has changed is how Doug presents the simulations, which he feels is more effective, as he has opened up computer animations to students at a molecular level which then begins a dialogue about what represents their observable reality in the chemistry classroom.

Doug is nearing the end of his teaching career. “It’s been kind of nice being part of this evolution and change. I think for the longest time Chemistry education was static, and it stayed that way for 50 years, and we’ve been very, very fortunate to live in a time of unbelievably dynamic change. Everybody talks of education about how kids have changed, and my feeling is that they haven’t”. Doug has infused computer simulations into his teaching, but he is still guided by the premise that in order for students to move on in chemistry, they must have a solid grasp of the symbolic level, and depending on the day he continues to teach at this symbolic level through the use of worksheets and questions. There has been growth in his teaching from the professional development sessions he has attended and the reflection that goes along with the CRYSTAL sessions.

Teacher E – Emma

Teacher E, whose pseudonym is Emma, is a Chemistry teacher at a mid-sized suburban high school in the southern quadrant of a mid-sized Canadian city. Emma has been teaching for 17 years in a high school setting where she began teaching Grade 10 Science and Chemistry. In the current school year Emma is teaching Grade 11 and 12 Chemistry in the afternoons only.

Emma began university entering the Faculty of Science and finished a three year general degree. Once Emma completed her Bachelor of Science, she contemplated doing a post-baccalaureate diploma so that she could go in to research in chemistry. However, after meeting with her academic advisor she decided to apply to the Faculty of Education where she completed an Education degree with a double major in Chemistry and Biology. Emma completed her master's degree in Education two years ago. This was done in the area of Chemistry education.

Emma has a great deal of background in the field of chemistry, and has specialized in teaching this area since her graduation. Her teaching revolves around Johnstone's levels of representation and how the history of Chemistry can be employed to help students make meaning. Her learning style is visual, and as such her lessons contain "visuals, so whether it's drawing pictures or using models" there are many ways that students can interact with lessons.

Emma does not have a lot of experience using technology, and relies on her support network for gaining access to computer simulations and other uses of technology in the classroom. "I don't think that we used a computer at all during my education" states Emma when asked how prepared she felt on leaving University. Her main teaching deals with "lots of examples, analogies, lot of analogies, visuals, so whether it's drawing the pictures, or models" as her post-graduate work does centre on the importance of visuals in her classroom. A portion of Emma's Master of Education degree dealt with Johnstone's three levels of chemistry, and her teaching also incorporates those aspects. For Emma her introduction to computer simulations took place through the CRYSTAL professional development sessions. Emma likes to begin her lessons with a scenario, which can include either a macroscopic or particulate situation, which she asks the students to explain based on their prior knowledge. "Just to see what they know, and then we do a lot of, you have to start off with learning the concepts, so the vocabulary. And then we'll, I'm still a notes and I'll show them a problem, they'll try a problem." There are often "a lot of little demonstration and quick activities, to get them up and moving around, so it might be the computer and the LCD projector. Lots of worksheets, try to review, then the usual test at the end". Emma's assessments have changed over the last few years with the focus on assessment practices within her division. "The unit tests have gone away from more algorithmic testing and memorizing, into more explain, describe, draw, and that's how I know they are understanding, because they can verbalize it or draw it in pictures, instead of just giving me a numerical answer in the end." Emma's thesis work was her defining moment in terms of this change in her teaching. "The first day of chemistry I will sort of talk about those three levels, and I'll give them examples of all three of them. So that's been a big change in how I've been teaching".

Emma has also found that CRYSTAL sessions that provide labs and activities that are presented to be the most valuable in her teaching practice. These sessions have "given me different activities that I can do or activities where I haven't done activities in the past." The sessions have also exposed Emma to how computer simulations can be used in chemistry. “Seeing the different sites and discussing the pros and cons for them. And going through them, so I know that when I open them, I want to look at this, I want to stress this with the students.” These sessions along with the ability to analyse the Chemistry curriculum has really highlighted the three levels of chemistry in Emma’s lessons. This is telling as Emma describes her move from her original teaching style to how her classroom works today.

“It was really hard at first as you tend to teach as you were taught. So, I was taught textbook and problem solving, we didn’t do a lot of labs or activities, so at first it’s really hard, to get myself to even think to draw the molecules, what are they doing, and the students don’t like it at first, but they have become accustomed to it. And I think it’s really valuable. I find the students are able to ask better questions. They seem to catch on a little faster, they almost groan because they know it’s coming, what are the molecules doing, can you draw what’s happening?”

While Emma is very clear about the direction her teaching is evolving, she is aware she cannot completely change all of her materials at once. “Having taught for so many years, I tend to look at the outcome, and if I’ve taught it before I tend to just move the stuff over from my old binder. So I tend not to look at all the resources.” The evolution of her teaching continues in terms of computer simulations being used to reinforce concepts from her lecture.

Emma has used technology in the past to help her students with chemistry material. In the past Emma developed a web site containing updates on what had taken place in the classroom that day. At the time she felt that “a lot of students didn’t use it though”. Emma did find more success through the use of email with her students, “I tell them to email me before their exam, and they will email me their questions". Since attending the CRYSTAL sessions Emma has begun using computer simulations to reinforce concepts. In order to assess this new teaching strategy Emma questioned the students in order to check for understanding, but this has not always gone according to her original plans. While some simulations have worked well, others have limitations. "For some of them the simulation is small on the screen, so it's not as large as you would want it to be. So you're not too sure that they can see what's happening." Other times Emma found that timing really is everything. One site she had planned on using only gives guests a 5 minute window of time to explore the simulations. "I made the mistake of going on before class to make sure that I could get on, and I only had a minute, so you run out of time and you know it would have fit perfectly, but the next day you've gone past that, so it's not as good of a fit." Overall Emma gets the sense that students do enjoy the simulations and "for the most part they like it. I think they do find it valuable". Her use of the simulations in class varies, but is "maybe once every 2 to 3 weeks, and it may only be for five minutes at the start of a class". This is a large increase in usage when compared to the frequency before attending the CRYSTAL sessions, when she did not use them at all.

Emma's classroom has changed over the past few years, and continues to change and evolve over time. This change is a move from the symbolic level to the particulate level. "I think I've gone over more to the microscopic, my students might even say that it's too much, but I know that every time I teach something, I know that there is a diagram that goes with it. And, I think it really helps the students to see that." Emma has made an attempt to represent concepts at all three levels, and actually feels that the students are weakest in the microscopic or particulate area. "They can memorize formulas, and a lot of them you can see their mark goes really high when it's calculation based, but I think, or if you look at multiple choice tests, they tend to do poorer on the multiple choice, so it's the understanding of the concepts."

Teacher F – Fran

Teacher F, whose pseudonym is Fran, is a Chemistry teacher at a smaller high school located just outside of the downtown core of a mid-sized Canadian city. Fran began her teaching career 13 years ago in another province, and has been teaching in her current position for the past two years. She has worked as a substitute and full time teacher in Grade 10 Science, and Grade 11 and 12 Chemistry.

Fran completed both her four year Bachelor of Science (Chemistry) and her Bachelor of Education degree at a university in her current city. Upon completion of her second degree, she chose to leave the province to begin her teaching career. As she has grown in her career she has found that instead of just giving the notes and the theory, she needs to allow students to "see it a little more, whether that is a lab or it's a visual".

Fran is just becoming familiar with the current provincial curricula and, as such, is open to trying new pedagogical approaches to chemistry. Although Fran feels that she is "computer savvy" her school is just beginning to incorporate technology into their teaching practices. This coincides with her exposure to the CRYSTAL professional development series and as such she has seen her technology use grow and change from when "it started out very much pen and paper".

Fran began to see a change in her teaching practices during her time teaching in Alberta. She credited this change to both "evolution but then as technology in our school started to be more available and easier to use then it was a lot simpler to make it happen". Fran began her teaching career much as the other educators did. "It used to be a lot more, you know, here are the notes, here is the worksheet, here is the test kind of thing." Fran has seen her assessments change as well over the course of her career. Although Fran admits "it's probably still fairly traditional... I still do tests and quizzes and that kind of thing" she has begun to branch out to having those informal conversations in the classroom that make up formative assessment. "I do a lot of verbal clarifying making sure that kids can talk to me about it back again."

CRYSTAL sessions have also been a driving force in Fran's teaching since she came back to the province. For Fran CRYSTAL gave her an opportunity to interact with other chemistry teachers in the area. This has helped her reintegrate into the Chemistry curricula as "the Grade 12 curriculum is quite a bit different than Alberta". This is especially important as Fran teaches in a smaller high school. "I don't even have anybody else that's teaching it at the same time." Thus the discussion aspect of CRYSTAL has been important in Fran's growth as a teacher.

"A lot of what I liked and some of this I've learned from CRYSTAL just in the last couple of years is really talking about the sort of the on the lower scale like molecular scale rather than so much on the theoretical scale. For instance like I was doing gas laws with my Grade 11's and can they describe to me what's really happening inside a container when you are talking about Boyle's law or Charles's law or whatever, not just the formula, but can they say that back to me."

Although Fran's teaching is beginning to change, she has found that sometimes it is not so easy to get her students on board. "A lot of them are pretty much type A sequential, I just need the formula, just give me the formula kind of thing, and so it's hard to push them out of that." To push them out of the symbolic level Fran has integrated all levels of chemistry, but due to CRYSTAL's influence she spends more time now in the particulate level. Although this training does take time, Fran has found that "once they start thinking that way, it becomes a lot easier".

Fran has also gained knowledge in the areas of labs and demonstrations from CRYSTAL sessions. Fran sees these materials as being "lot of stuff that we've done that has been like really quick and easy demos or labs, the staff that has been truly effective in conveying a point" that do not require a large amount of set up. Due to Fran's placement in a smaller school she also does not have access to any type of lab technician who would help with lab set up. CRYSTAL has also supplied Fran with access to computer simulations and applets that she has used in her class. In the past Fran became frustrated when searching for computer simulations, "the issue was finding like even just to go into Google and go, you know chemistry applets well holy smoke like there is you can spend days looking for things that were useful". For Fran the biggest advantage of having access to the educators in CRYSTAL "is that somebody has already found it for me, and it links directly to the curriculum". This connection between materials and the curriculum has also helped Fran develop her confidence with the new content.

Of the six teachers interviewed, Fran is the only one who mentioned issues regarding access to technology being a major factor in her lack of use of computer simulations. At the time of the interview Fran did have a desktop computer with internet access in her classroom, but in her school she was required to share a projector. Fran has managed by either bringing students to view things on her monitor, or at times she has brought in the projector, but this brings along with it a new set of problems. “It’s often hard to find the right connections or a cord long enough to allow me to use the projector, so sometimes it’s just easier to have the students at my desk.” Fran also has access to a computer lab but finds this hard to book, and often uses computer simulations for only a few minutes during a class period, which makes booking the lab not practical. “I think I already get technology pretty well, it’s having access to the hardware stuff that allows you to make it easier to do that.” Fran is also aware of the wow factor that can go into the classroom if it relies entirely on technology. “I think the weakness might be to become too reliant on the technology, and forgetting about teaching. You need to fill in the holes in the simulation to ensure you cover what it is you intended to.”

4.3.3 Constraints and Contributors

This section deals with the commonalities of the six interview participants in terms of technology usage and teaching pedagogy. It will touch on the main questions through the course of the interview as well as the influences on pedagogical choices by the participants.

4.3.4 Teaching Pedagogy

The six chemistry teachers interviewed are all at various stages of their career, and teach in different areas in the province. Early in the interview the participants were asked about their best practices in terms of teaching Chemistry. When the teachers were asked about these best teaching practices, they were somewhat guarded in their answers. As the interview progressed they became more open and stated several times that perhaps their best practices may not be their norm for everyday teaching. In general when the interviewees talk about best practices they all make reference to Johnstone’s three levels of chemistry and being sure to include each level in their teaching. What is missing in all the interviews is the lack of Mahaffy's fourth element of chemistry education, the student.

Alex – "Well, you want that deeper level understanding right? First of all I like to be able to actually show them that, using a hands on lab to show the macroscopic aspect of the topic, then I've got some notes to describe what's going on, give them some examples to talk about it. But to really understand what a concept means, I'm going to bring in animations, showing what is happening at the microscopic level. That's the biggest thing with say, equilibrium, is trying to pound away that it's not static, it's always moving. Towards the end we do some notes and calculations."

Bill – "I try to think very carefully about the learning outcomes. But the other part that's embedded in there that's really stuck with me is the multiple ways of representing you know, matter, and the way matter behaves, that's really important to do that. It's probably been said before, but not to rush to the symbolic representation. I think, I used to do some of that, but I think I'm better at it now. Let's take a look at how this thing moves. Now, they need to engage with it for a long time, so it's helping them to understand that so that they will be engaged and try to find a way for themselves to learn it."

Carl – "I think being able to relate the material to the students lives or relate it to something that's a little bit more concrete, lots of examples, lots of analogies, visual. The visual aspect is really important, being able to give students the opportunity to invest themselves in the course."

Doug – “I think if you use a variety of techniques, different kids have different learning styles, different kids are coming – again, depends on the grade level. I do a lot of experiments but primarily I do a lot of lecture. I supplement lecture with problem assignments, having been around for 20 odd years in chemistry you collect things, so I’ve got all kinds of resources to draw on.”

Emma – “Lots of examples, everyday examples, analogies, lots of analogies, visuals. So whether it’s drawing the pictures, or models, I’m visual myself so I need those.”

Fran – “I used to be a lot more, you know, here is the notes, here is the worksheet, here is the test kind of thing, but in the last few years and even before I left Alberta I was starting to try and implement more technology stuff and more different ways of showing chemistry as opposed to just here is the notes, here is the theory, let’s try and see it a little more and whether that meant it’s a lab or whether it’s a, like a computer simulation or whether it’s a PowerPoint or something like that where you can put images in that kind of thing. So, one thing I’ve changed some of that recently. But it started out very much pen and paper.”

The teachers feel that the inclusion of visuals and simulations into teaching help students gain an understanding of the particulate and macroscopic levels of chemistry. As the participants described the best practices it became evident that they have put thought into the three levels of chemistry and how students’ best interact with them. When the participants were asked to discuss what a typical chemistry lesson looks like in their classroom the reliance on the three levels was maintained, but to a lesser degree.

Alex – "You know it's pretty heavily based in problems. I give constant quizzes as we go, with a unit test at the end, several labs as we go through, and for every wet lab that we do I've been trying to incorporate an online lab. So that they do both, and I do the online labs generally first, as a bit of a precursor to the wet labs."

Bill – "The students would have a list of the outcomes from the very beginning. I guess we might typically look at some evidence, it's not really an investigation, really it's more of an illustration of the macroscopic properties. Then we might try to visually represent what we think is happening with the particles. Maybe an animation, to represent it, because the motion is often important. And then to end up with a symbolic representation, and then I guess guided practice with problems and then eventually working towards the assessment.

Carl – "I usually start with a review of previous topics." Carl goes on to talk about showing the final symbolic problem type in order to focus them on their learning. "The students have a skeleton of the notes, so when we work on a concept, I'll usually explain it, then I'll usually question them on it, try and question as many people as I can to get as much feedback to build off of that." "For each concept I try to have an analogy of several examples, some images and then some questions to go back at them with, just to test to make sure they fully grasp it." For Carl the relationship and the dialogue that takes place, that is created through his use of technology, drive his lessons.

Doug – "My focus was very much on problem solving and working on kids to develop problem solving skills. I try to stress taking a theory and applying it, more than anything else in the way I do things, and I've gotten more and better at taking things in a molecular level and following through and adding that to the continuum. Lot of worksheets, lot of problem solving skills and that's been my focus since a million years ago."

Emma – "If we are starting a unit we've done lots of scenarios, and those are from CRYSTAL, a lot of the scenarios, can you describe what's happening and why it's happening? Just to see what they what they know. I'm still a notes and I'll show them a problem, they'll try a problem, we'll usually do a lab in there, after we've learned the main concepts."

Fran – "A lot of what I liked and some of this I've learned from CRYSTAL just in the last couple of years is really talking about the sort of the on the lower scale, like molecular scale, rather than so much on the theoretical scale."

In terms of pedagogy and classroom practice, Bill is an exception in terms of his reliance on the outcomes and the curriculum. This comes across later in his interview as he talks about the new Chemistry curricula that have been introduced. "I think what's implied and what sometimes is very obvious is that multiple representations, students should be able to do that." Carl also shows that he has done an in-depth review of the curriculum when he discusses the embedded links within the curriculum and the assessment options that are presented within the documents. This lies in contrast to the other participants in the interviews. All participants noted that they do use the curriculum, or at least they did initially to make review outcomes as compared to past curricula. The more experienced teachers like Doug and Emma did not refer to the curriculum, and even the other teachers noted that the actual document was not integrated into their teaching.

Carl – “It’s not too dissimilar from the old 1983 curriculum, with more details right. I have been working on my notes for years, so I have just kind of modified them, adding in some of the molecular things.”

Doug – “Okay, so we have a curriculum guide and it’s a very good recipe book, but every so often I am going to add a dash of peppers and I’m going to add some salt and some ice cream where I think it’s applicable. The actual truth on that one is I have been teaching that curriculum for twelve years.”

Emma – “Having taught for so many years, I tend to look at the outcome, and if I’ve taught it before I tend to just move the stuff over from my old binder.”

The participants identified the CRYSTAL sessions as being the most influential force in changing their teaching. This professional development series has exposed all the participants to Johnstone’s three levels of chemistry and highlighted the need to expose students to the levels. All participants made mention of the new emphasis on the particulate or molecular level that they have infused into their teaching. Yet the participants still professed through the interview process that their original teaching pedagogy was one that focussed almost exclusively on the symbolic level of chemistry, and that the symbolic level still made up a large portion of their teaching practice.

All six participants maintain a teacher oriented, content centred classroom. Throughout the CRYSTAL professional development sessions they have begun to look at differentiating their instruction, but it is evident that there is still a major focus on the teacher as being the main conduit of information in the classroom. The participants maintain a focus on the content and while there is mention of classroom dialogue, most notably by Carl, it remains a teacher – student conversation versus a true classroom dialogue. Doug specifically notes that lecture is his dominant technique, which according to Denessen is a hallmark of a content oriented classroom (1999). All participants make note that the new Manitoba Chemistry curricula have had little effect on changing their classroom practice despite the student centred approach that is one of the guiding principles of the documents. The planners of the CRYSTAL sessions did attempt to focus on this aspect but due to the Professional Learning Community (PLC) learning environment that evolved among participants, the focus shifted from curriculum to content and differentiated instruction techniques. This focus on content is apparent throughout all six interviews when they are asked about best teaching practices.

Alex – "the biggest thing with equilibrium is trying to pound away with the kids – hey, it's not static, it's always moving"

Bill – "I think that best practices is being willing to try."

Carl – "I taught a lot more content, eight, nine years ago when I started, than I do now. But, as far as teaching goes, like I think being able to relate the material to the students' lives or relate it to something that's a little bit more concrete, that's important."

Doug – "Primarily that I do a lot of lecture, I supplement lecture with problem assignments, having been around for 20 odd years in Chemistry you collect things, so I've got all kinds of resources to draw on."

Emma – "You have to start off learning the concepts, so the vocabulary. And then we'll, I'm still a notes and I'll show them a problem, they'll try a problem, and we'll usually do a lab in there, after we've learned the main concepts."

Fran – "I am starting to implement more technology stuff and more different ways of showing chemistry as opposed to just here is the notes, here is the theory, let's try and see it a little more."

While the presentation and instruction of the material is beginning to become more diversified the teachers maintain their content based classroom environment. These classrooms maintain Denesson's ideas that a teacher centred discourse is created where little true meaning making is taking place among students.

4.3.5 Teaching and Technology

This section deals with the participants' access to technology and it's usage in the classroom. The participants are from four different school divisions however all have a similar access to technology within their buildings.

A factor influencing teacher usage of computer simulations in the classroom is the access to technology. All participants in the interviews have access to some form of technology within their classroom, and the majority did not feel that their access negatively affected their ability to use computer simulations in their teaching.

Alex – "I've got the light source, so whenever I find a good animation or a good video or something like that I'll bring it in. I do all my notes up on PowerPoint, and just kind of change them from year to year. And we're starting to get more and more Smart Boards in the school."

Bill – "There's a computer on every teacher's desk so that's available, there's a projector in every science classroom, or almost every science classroom. Access to the internet. Smart Boards, although we're not quite there yet."

Carl – "I have a Smart Board in my classroom, a projector."

Doug – "Every classroom here has a computer and ours are hooked to the projectors with DVD and VHS units. And of course we have internet access."

Emma – "All the classrooms have LCD projectors, they all have a computer in there, so we've got the DVD player and access to all the online resources."

Fran – "We've got computers in our room right now, and we've got LCD projectors but not in each classroom right now. We've got one on a cart that we can slap around."

The only participant who commented that the access was not there for technology was Fran. This was due to the lack of a projector dedicated to her classroom. All the other participants felt that this type of set up in their classroom gave them access to computer simulations or any other type of internet material that they might want to use and project for their students.

While the participants in the interviews felt their classroom access to technology was adequate or good, they were still not certain that computers throughout the school were being used as productively as possible. Many of the participants felt they could not comment about the school as a whole. Alex's quote sums up the majority opinion of the participants, "In my classroom I probably could be doing a lot more". But Bill raises an interesting point which where he asks not about if technology is used enough but "to me the bigger question is, are they using it for teaching and learning". There was the general thought that sometimes the computers aren't there just for teaching and learning, but for the administration of the school, which is where Bill's comment is derived from. Bill sums it up like this, "If you walk around a school you'll see a teacher in front of a computer fairly regularly now, but in our division schools are starting to do their attendance that way, there is no staff bulletin being printed anymore, there's no student bulletin. The administrative part of our job is a big reason why the computers are there".

The participants were also asked about what has influenced them in their use of computer simulations and technology in the classroom in an effort to understand which spheres of influence have had an effect. These spheres of influence are based on Bronfenbrenner's bio-ecological model (1979). There was a great deal of variation in terms of which areas had the greatest effect on technology use among the participants. There was agreement however that there was not a great push for technology to be infused into classroom teaching outside of the individual teacher, or at least none that could be identified by the participants. This was especially clear at the divisional (mesosystem level) and at the Provincial level (macrosystem level).

When the participants were asked about the driving forces for technology in their schools, nearly all stated that they could not identify any divisional group or person(s). For example Alex states that "I know it's encouraged, but I don't know if there are any specific goals for technology". Most participants felt like Emma in that "Our computers are pretty tightly arranged so I don't know, I don't know. I think that has been a divisional thing like I think that there has been a push for that across the division, and I think that there are probably goals out there, you know, and whether I know the specific ones I don't".

Alex's drive to use computer simulations is drawn from a very individual and microsystem level. During Alex's practicum placement in university he was exposed to a group of teachers who supported his exploration of technology. "The two cooperating teachers I had were really quite into technology, and from seeing them use it, that's when

I started to see the benefits of it." Alex then incorporated technology into his everyday practice. He also states that his students are a key reason for his continued use. "Well, the kids know the technology right, so we need to know our clientele. We need to do what's working best for them." At the mesosystem level Alex does not see any push either from within his school or division. He does see the CRYSTAL sessions as a promoter at the macrosystem level. "

Bill's motivations around the use of ICT are again at the microsystem level. "The two departments that I teach in are the driving force. We have people who come across resources and share them regularly." Bill also cites the support received both at the school and divisional level in terms of the support of the network, and he has had an involvement in the Literacy with ICT at the provincial or macrosystem level. "I think that teachers will use technology when it's appropriate."

Carl began using technology as a pilot program within his school, and as such cites the mesosystem factors of the school responsiveness and willingness to include technology as being the critical factor in his use. He also feels that he is a driving force for technology within his school. "I think it would have to be me, I would say, yeah. I mean, I found the Smart Board, I suggested that we use the money to buy it. I push it everywhere I go." But he did not do it alone. "Yeah, administration pushed to get those, you know for a while the division didn't want laptops so we just kind of, just don't say anything, let's go get what we need to get it done."

Doug found that the mesosystem factors had the most influence on his choice to use technology. This came from his school giving him the opportunity to order whatever he wanted in terms of computer software. Doug also states he "hopes it's the textbook publishers" as he feels the manufacturers need to support the classroom teacher. Doug was unable to identify any divisional push for technology, and is emphatic that there needs to be a macrosystem influence. "There better be. (a province-wide initiative) This province is one of the leaders in bio-technology, and in some ways we have moved forward, but in others we have taken steps back."

Emma was supported by her administration to begin using technology. "We had a Vice-Principal who was working on his Master's in Technology, so he was asking the questions and looking for how we could do things." Divisionally and provincially Emma didn't see any real driving force except for CRYSTAL sessions, which introduced her to computer simulations and animations.

Being new to the province, Fran was not able to identify any driving forces for technology in her division, community or in the province as a whole. CRYSTAL for her was an important factor, but she has also stated that the microsystem factors were most influential for her during her time in Alberta. "I know at my old school in Alberta there was one teacher who was really interested...it took somebody who was really interested in it to really make it happen because otherwise, it was just, it was one more thing for people who weren't interested in it to try and figure out on their own." The supports at the micro and mesosystem levels are what motivated Fran to begin the exploration of technology in her own classroom.

It is important to note that all participants feel that technology helps engage their students in the lesson. This is a somewhat superficial reflection as it looks at computer simulations as a tool for differentiated instruction rather than an opportunity to give students more control over their learning. Carl is quick to state that "I don't believe that anyone can learn from a computer alone". These types of statements surrounding teachers being replaced by computers is a sign of the conflict the interview participants are facing. By maintaining a content centred classroom as a teacher they can control the knowledge and maintain their position and importance in the classroom. This under current is evident in all six interviews and is stated in several different ways. The use of computer simulations in the classroom gives students more of an opportunity to create their own links and meaning which may be a reason as to why they are used infrequently by teachers.

4.3.6 Qualitative Summary

When looking at all six of the interviewed participants, they all have varied classroom environments and teach in varied socio-economic school divisions. They also have a varied background in terms of their experiences with technology. And yet their teaching practices are similar in that they all have made attempts to include Johnstone's three levels of chemistry. The three levels were sighted by all participants in an attempt to ensure meaning making takes place so that a greater understanding of the concepts can take place for students. This similarity may be in part due to all six participants' common professional development experiences at CRYSTAL. What is evident however is the lack of inclusion of Mahaffy's fourth element of chemistry, the human element. This lack of student voice and participation in the classroom is due in part to the content and teacher centred classroom that all participants maintain. The participants' access to technology is not an issue for the majority of the participants. While all participants use the curriculum to ensure they are teaching the correct outcomes once these outcomes are identified the curriculum is generally put away and not used in detail for either the links or activities embedded within the document.

The group uses computer simulations in their teaching to varying degrees from a daily to once every month, but for all the participants the simulations are often used for only a few minutes. The participants are split when it comes to how well students can make meaning from computer simulations. Some feel the amount of pre-teaching required make it daunting, where others feel that once students are exposed to the simulations on a more regular basis they can make meaning through teacher-student and student-student interactions.

The greatest impact on the participants in the interviews has been the CRYSTAL sessions. The CRYSTAL group was set up based on Professional Learning Community (PLC) model which allowed teachers to control and direct their learning. These sessions have introduced them to using computer simulations and animations in the classroom. They have altered their classroom teaching practices to move away from the symbolic level of chemistry to provide students with experiences at the macro and particulate levels of chemistry in an effort to help them make meaning and gain a greater understanding of chemistry. And perhaps most importantly, the CRYSTAL sessions have given the participants the opportunity to dialogue with fellow professionals around curriculum. The sessions have created links between the classroom teachers and university Education and Chemistry professors. The strength of the sessions is shown due to the number of participants who continue to attend session after session.

While CRYSTAL has been successful at differentiating instructional practices in the classroom, there has been relatively little movement to allowing student's more control over their learning and meaning making. The teachers involved in this study all maintained a content centred classroom which lacks student voice and meaningful reflective discourse despite having completed 4 years of involvement in the learning community.

Chapter V Discussion and Recommendations

5.1 Discussion of the Findings

This chapter provides an overview of this study which focuses on the teaching practices of chemistry teachers involved with a chemistry development project in Manitoba supported by the University of Manitoba Centre for Research, Youth, Science Teaching and Learning (CRYSTAL). The summary first discusses the perceived constraints and contributors to the use of computer simulations by CRYSTAL participants to support student learning. The final section of this chapter highlights the implications this research may have for both professional development programs and school, divisional and provincial efforts to support the infusion of technology into the classroom. Recommendations for future research and initiatives complete this discussion.

5.2 Overview of the Study

This study used both a quantitative design which consisted of an online survey as well as a qualitative interview process to reveal the constraints and contributors to the use of computer simulations in chemistry classrooms. Guided by the adapted conceptual frameworks of Johnstone's three levels of chemistry understanding (1991), with the addition of Mahaffy's human element (2006), and Urie Bronfenbrenner's bio-ecological model (1979), data was analyzed to determine the influences on educator use of computer simulations in the classroom. The new Manitoba Chemistry curricula which were developed in 2006 and 2007 draw attention to the importance of a more conceptual understanding of chemistry ideas. This conceptual understanding along with the addition of supporting curricular resources based in technology is meant to encourage ICT and computer simulation use by classroom teachers. The findings from this study identify that teachers rely primarily on teaching methods that emphasize the symbolic level of chemistry. There has been only some change in the teaching pedagogy of chemistry teachers despite changes to the curricula and focused, peer based professional development. Due to teacher emphasis on the symbolic level and teacher centred pedagogy, the use of computer simulations in chemistry teaching is limited. When the qualitative data from participant interviews was looked at in terms of Bronfenbrenner's bio-ecological model, the study finds that the participants identified a variety of individual factors such as their motivation, interest and confidence as the main contributors or inhibitors to the use of computer simulations and ICT in the classroom. This agrees with the research that has been done in the field by Cox et al. (1999) and Rosen & Weil (1995). Teachers also felt that the microsystem factors of collegial support and expectations of administration as a second major contributor to ICT and computer simulation infusion into their teaching.

5.3 Summary of Findings

The findings of this research represented by the quantitative and qualitative data answered three research questions. The first question asks:

> What are the Manitoba Grade 11 and 12 chemistry teachers' current teaching practices and how is this teaching inventory currently used?

In order to determine Manitoba chemistry teachers' current teaching practices the quantitative data from the thirty-eight online respondents was used. This data includes a Chemistry Teaching Inventory, or listing of common teaching practices for chemistry. This quantitative data indicates that the most common teaching practices within the 38 teachers' classrooms involve students performing calculations representing the symbolic level of chemistry; students performing laboratory activities representing the macroscopic level of chemistry; and students copy information notes and as concepts are explained. Conversely, the least practiced strategies of the Chemistry Teaching Inventory include student centred activities such as: students making notes from textbooks, and, central to this study, students using computer based simulations. When examining how these methods of delivery are applied in the classroom, the qualitative data show that teachers have altered their teaching practices only somewhat in terms of Johnstone's three levels of chemistry (1991). Participants in this study spoke of spending more time at the particulate level than they had in the past and more than what would be indicated by their choice of teaching practices. The survey data shows that the participants value all of Johnstone's levels of chemistry. Participants did note that they placed the highest priority on the symbolic level of chemistry when it came to the assessment of their students. Participants in the study did place value on student understanding at the particulate and macroscopic levels of chemistry, but the majority of their teaching and assessment involved symbolic questioning. The Chemistry Teaching Inventory that was edited and used by Lewthwaite (in press) confirms the use of symbolic level teaching strategies as the predominant mode of instruction in the chemistry classroom. The quantitative data indicates that the inclusion of teaching strategies that explore the particulate level of chemistry (such as computer simulations) are in use in many classrooms, even though their use is irregular and uncommon. In order to understand how the particulate level strategies fit into the classroom and curricular materials six of the quantitative survey respondents were interviewed.

The six interview participants' teaching practices mirror the data from the quantitative survey. All six teachers acknowledged an increase in importance of instruction for students in all three levels of chemistry. Yet all six teachers were similar in terms of the use of symbolic teaching practices being identified as a major portion of their teaching inventories. Throughout the interview process it was found that giving attention to the particulate level of chemistry is becoming a regular teaching practice of the individual teachers in order to help students develop meaning at the other two levels of chemistry. As the teachers discussed and described their teaching, they gave indication that there has been a shift in their teaching to more purposely help students generate meaning through the use of models and simulations. This shift has taken place with an emphasis on helping students visualize the particulate level of chemistry as a way to help understand the macroscopic, or observable, level of chemistry. When the participants were asked about their teaching pedagogy, it is apparent that while the symbolic level takes up most of their teaching time, the particulate and macroscopic levels have taken on a greater importance. The rote learning and pre-planned laboratory activities that have dominated chemistry education according to Gabel (1999) has begun to shift with the participants in this study. All six interview participants chose to use computer simulations to help students explore the particulate level.

The participants did indicate that the computer simulations used within their classroom are generally minor portions of their teaching and tend to be used for only small periods of time. Often the simulations are limited in terms of the curricular outcomes that are developed and studied, as most simulations only concentrate on one or two concepts. Participants did indicate that computer simulations are required to have a narrow scope in terms of the outcomes covered in order to best model and showcase that material. This narrow scope may also limit the amount, both in frequency and length of time used in classrooms as the curricular outcome may not be one that is in need of in-depth study as indicated by either the teacher or the curriculum. Symbolic teaching strategies are generally easier to produce by the teacher as many of the curricular outcomes are perceived to have a mathematical component or have a perceived greater application in terms of problem solving for students.

The differentiation of instruction by teachers to include more material at the particulate level has taken place due to several factors which are discussed against Bronfenbrenner's bio-ecological model. What appears to be the most important contributors to ICT use are factors at Bronfenbrenner's individual level; that is, at the teacher level. What is evident from this study is that teachers who are more informed about the value of visualization in learning chemistry are more likely to use it. Several studies have encouraged educators to give consideration to the use of visualization for learning chemistry. The importance of studying the molecular or particulate level of chemistry in order for students to create meaning was first studied by Johnstone (1991). The power of students to making meaning at the molecular level was enhanced by the Williamson and Abraham study (1995) and the Jonassen, Peck & Wilson study (1999) that found computer simulations gave students a greater opportunity to create meaning. The participants in this study agree that computer simulations provide an accurate representation of the particulate level and that students are able to create meaning when using these simulations at both the particulate level, and are able to apply this knowledge to the macroscopic and symbolic levels of chemistry. This study finds that the participants make use of the molecular level in order to introduce concepts for students or to explain observable macroscopic events that students have been exposed to, either within the classroom or throughout their life experience. This usage of the molecular level agrees with Johnstone in terms of providing scaffolding between the three levels of chemistry to create greater meaning making by students.

Participants in the quantitative and qualitative portions of the survey are using a larger inventory of teaching techniques than what typically be the teaching repertoire of chemistry teachers. These techniques are being used to explore Johnstone's three levels of chemistry. While chemistry teaching techniques are being differentiated in the classroom, the way these techniques are being incorporated into the classroom is important to document. The six interview participants all spoke of using a differentiated instructional approach to teaching chemistry and used many of the inventory techniques described above. The classroom environments of the six participants show a teacher centred classroom pedagogy that made use of differentiated teaching techniques that are being used in their classrooms. The participants were asked questions' surrounding what a typical chemistry lesson looks like in their classroom, and the responses showed that there is differentiation in teaching techniques, but the participants continue to maintain their place as the centre of information within the classroom continue to be unable to give students greater control of learning.

The level of student involvement in lessons varies, however the responses of participants are telling in terms of their orientation towards how student learning and meaning making can occur within a classroom. All participants see themselves as the focal point of the classroom. Bill makes mention throughout his interview of how his practice has differentiated in terms of teaching inventory, but he has yet to give ownership of the content to students, and continually draws on the “we” rather than having students complete the work themselves. The idea that students are unable to create meaning on their own is common to all six participants in this study. Carl incorporates a great deal of technology in his classroom through the use of a Smart Board and yet his teaching still remains focussed on content acquisition in his interactions within the classroom. The teacher as the central figure in the classroom is exemplified by quotes such as “I try to have analogies”, (Emma) “I explain”, (Fran) “We discuss”, (Alex) but rarely are students given the opportunity to create linkages between the three levels of chemistry of their own accord.

The teaching technique of using computer simulations in the classroom is one area in which the classroom can become more student centred. All the interview participants use computer simulations at least part of the time in their teaching. All handle the use of computer simulations in a similar way in that they generally present the material to the class as a whole and allow for feedback from the group. Emma states “If we are starting a new unit we’ll do lots of simulations and scenarios, and I ask “can you describe what’s going on?” which gives students a chance to describe in their own terms what is happening.” It is during this time that students are given a forum to voice their prior knowledge and make connections between the three levels of chemistry. Emma’s comments were the exception rather than the rule. Teachers have begun to use this strategy, however Carl feels strongly that he “isn’t going to be replaced by a computer” and that the students “need the interaction with a teacher to create meaning”.

The strength of using computer simulations to show the particulate level of chemistry is acknowledged by the participants however this teaching technique is not often used in the classroom, and makes up a small portion of classroom time. The majority of classroom time is spent with traditional teaching practices where the teacher lecturing or explaining concepts or the students working on symbolic level problems and assignments. While ICT and computer simulations have, as Carl asserted, “brought me amongst the kids instead of being in front of them or above them”, the students are still not given the opportunity to take ownership of their learning. Teachers have maintained their control over the content and see themselves as the “Sage on the Stage” despite differentiating their teaching inventories including the use of ICT to support student learning.

This type of classroom is an example of what Denessen refers to as a content centred approach as opposed to a student centred approach to teaching (1999). In the content centred classroom teachers focus on the discipline and include goals that are concerned with career development and a focus on the product. The six interview participants in this study all state their reasoning behind spending a majority of their time at the symbolic level of chemistry is due to the perceived student need to have symbolic level skills in order to be prepared for university. Doug sums this up by stating “I would love to spend more time looking at computer simulations, but for the students going on in chemistry, they need to have the mathematical skills to continue”. In order for the student voice to have greater influence in the classroom there needs to be a restructuring in a teachers’ identity (Denessen, 1999). The content centred classroom by nature also dismisses the varied learning styles of the students and again focuses on differentiating the ways in which material can be delivered to students.

While this more teacher-directed, content-based instruction may have been required in the past, teaching today need not be practiced in this way. There is little evidence from this study that significant shifts have occurred in teachers' pedagogy. Instead this study suggests that the shift in teaching practices is simply, as Martinez suggests simply a changing of the "tools, as well as this paradigm of teaching that taught students that learning occurs when they look toward the front of the classroom, listen and follow the teacher" (p. 73, 2010). This study did not show any significant change in terms of giving students a greater presence in their own classrooms, especially in changing the discourse of classrooms whereby the use of simulations is used to stimulate active discussion likely necessary to lead to deeper conceptualization of chemistry phenomena.

The second research question asks:

> What factors do teachers perceive as constraints or contributors to the use of the new educational technologies or ICT, in particular computer based models and simulations, as to support student learning in chemistry?

The shift by teachers to include more material at the particulate level has taken place due to several factors which are discussed against Bronfenbrenner's bio-ecological model. There has been very little research done in the area to identify which factors have influenced teachers to incorporate computer simulations in their classrooms. Bereiter and Scardamalia (2006) have looked at the implementation waves of ICT in the classroom from a systematic standpoint, including the professional development aspect that is incorporated after initial implementation. Cuban (2001) has studied the exosystem factors that affect technology uptake within the school system. This study examines the individual participants' responses regarding the factors affecting their own implementation. All participants have been regular attendees of the CRYSTAL professional development sessions and as such have a common microsystem experience for encouraging the use of simulation software in chemistry.

With a common microsystem experience for the participants, at an individual level the participants in this study identified that there was a critical event in their teaching experience, usually not attributed to the CRYSTAL teacher development that first exposed them to the use of ICT and computer simulations in the classroom. For the participants, this event did not take place during their formal university education, but rather during their time in the classroom as either a pre-service or in-service teacher. The critical event varied according to participants but generally involved an experience where a cooperating teacher or colleague introduced the participant to the technology and the potential ramifications of such technology in delivering science content with little consideration of whether such use was supporting student learning. Thus, this event was not seen as a way to change teaching pedagogy, but rather as adding a new tool, or as a way to differentiate instruction. Despite this limited shift in pedagogy, teacher's individual beliefs about the influence of ICT use on student learning was clearly a prime influence on teachers' use of ICT in their classrooms.

While this initial event may have triggered an initial interest in using computer simulations and belief that ICT use was beneficial, the participants in this survey continued to implement ICT mainly due to individual factors such as their own motivation and the perception that the use of computer simulations creates a more engaging classroom environment for students. The use of computer simulations is considered to be another way to differentiate teaching strategies. Through differentiated teaching all participants indicated that they felt the technology improved their lesson quality and student engagement. This aspect of improved engagement was not formally studied in this research project or documented by the participants, but was a generalized perception they associated with students when using computer simulations.

The microsystem level in terms of the implementation of ICT in the classroom includes factors such as peer support and support to infuse ICT from administration within the classroom. The microsystem also includes the student reaction to the use of ICT in the classroom. The participants in this study identified these microsystem factors as being a major influence in their use of ICT. All teachers were able to identify other teachers and peers that have used technology in the past or supported their own use within the classroom. For those participants who did not identify a peer as a significant influence to their implementation of ICT, they did point to an administrator in their school who supported their infusion of technology. This support at the microsystem level agrees with Hennessy and Deaney (2004) who showed strong collegial support is necessary for the infusion of ICT in the classroom. Teachers are also turning to social media to make informal Professional Learning Communities (PLC) to share ideas (Martinez, 2010). While ICT may not be the focus of these socially networked PLCs, technology is being used to facilitate this sharing of information and adds to the collegial support network of teachers. This use of a PLC is especially important for teachers who are working in specialized areas such as Chemistry.

This study also explored the effect school culture has on the implementation of computer simulations in the chemistry classroom. The participants in the study did not specifically state that the school's focus and goals in the area of technology effected their uptake of computer simulations. They did make reference to the existence of provincial, divisional and school goals for the implementation of technology. The participants often were not able to specifically identify these goals, however they did make note that school and divisional support was important to ensure that access to ICT was at a level necessary for implementation. The level of ICT required for implementation to take place within a school included reliable access to hardware and a reliable network through which to connect to the internet, supporting views made by Cuban (2000). As an example, Bill was very clear that the use of ICT would not happen without "knowing that when you go to use the technology it will work as you want it to".

The greatest factor at the environmental level that influenced participants in this study appears to be the CRYSTAL professional development workshop series. All participants found that this long-term professional development opportunity created an atmosphere of trust between participants that allowed for the sharing of teaching strategies and the differentiation of instruction including the exposure to ICT and computer-based simulations. The professional development in itself appears to have served as a microsystem supportive factor influencing teachers' views on the ICT use, and, to a lesser extent, their actual use of ICT. Of the online survey respondents surveyed, 94% felt that the CRYSTAL sessions were satisfying or extremely satisfying in terms of professional development. These responses are mirrored by the six interview participants who all felt that the cohort of educators allowed them to feel comfortable enough to explore and share aspects of chemistry education within the group. In terms of the sharing and differentiation of the Chemistry Teaching Inventory among participants the CRYSTAL sessions have been a success. This success of the CRYSTAL group is in part due to the way in which it was assembled. Following Lewthwaite's basic premises of professional development (2006), the group has become an ongoing and successful professional development opportunity for chemistry teachers. It was set up on the model of a PLC so that the teachers could be in control of their own learning and explore those pedagogies most beneficial to them as teachers. At this stage, the group has yet to propagate itself outside of the realm of chemistry so that the new teaching pedagogies that were developed for chemistry teachers can be shared with all teaching subjects, especially in the Grade 9 and 10 Science areas.

Community and parental expectations vary across the province in which this study took place. The respondents to the online survey came from a variety of communities and locations throughout the province. These respondents stated that access to both computers and networks is not a problem for them in terms of the implementation of ICT into their classroom. This result is noteworthy because usually a lack of ICT uptake is attributed to this perception. As Cuban (2000) stated, rural and remote areas lack of ICT use is typically attributed to access to technology. In this study it would appear these issues have been resolved or mitigated. This may be due in part to the funding of education at a provincial level, which would help to alleviate the variances between rural and urban and remote and populated areas. Although school division control the flow of these provincial grant monies for education, most areas have invested in technology and ICT. Only one interview participant felt that access was an impediment to her use of ICT, but it did not completely curtail her use of computer simulations and ICT as a part of her teaching practice. The community or parental influence forms a second exosystem factor. The interview participants dismissed this aspect as simply being expected by parents and students. This may be due to the infusion of technology within our society and the school itself. This study has found that within the area studied the exosystem factors do not exert influence as either a constraint or contributor to ICT use in the classroom. Simply put, ICT use in Manitoba in senior high schools appears to no longer be about equipment, facilities and use. It now is about teacher beliefs as a result of exposure to ICT use. This study would suggest that teachers are also now believers of ICT use and now require exposure to how it can be used effectively to facilitate student learning through a deeper understanding of what the learning process and what students and research are saying about effective ICT pedagogy for learning, something that was potentially underdeveloped in the CRYSTAL professional development.

The provincial curricula in Chemistry were revised in 2006 and 2007. As such the learning outcomes are universal across the province. The new curricula also recommended certain activities for chemistry teachers to perform as they implemented these curricula. The interview participants did make mention of these outside factors but they did not identify them as causing any change in their instructional practices or teaching pedagogy. The curricula changes have had little to no effect on the teaching practices of the participants in the study of their own accord. What has caused changes at the exosystem level is the ability to dialogue with other chemistry teachers at CRYSTAL sessions, where the new curricula and appropriate pedagogies were introduced and studied.

The third research question asks:

> What perceived effect has the use of ICT and computer simulations had on meaning making by chemistry students in the classroom?

The quantitative portion of this study found that the majority of respondents (37 out of 38) have used a computer simulation in their teaching. Of those that have used a computer simulation, the majority also believe that they portray the microscopic and macroscopic world accurately. In terms of the effect computer simulations have had on student learning and meaning making the respondents to the survey feel that the use of simulations increases the dialogue between students, and between students and the teacher, as well as increasing student understanding of a concept. Despite these positive comments, the survey respondents did not feel that the use of computer simulations has lead to an increase in the assessment scores of students.

The interview participants were asked similar questions in terms of the usage of computer simulations and student meaning making within the classroom. All six of the participants indicated that they have used computer simulations within their classroom. And all six noted that student engagement increased when these simulations are used. The participants were also asked about how computer simulations affect student meaning making. The participants stated that engagement is increased, and a better understanding of content occurs. The participants also stated that their assessments of student learning are generally at the symbolic level of chemistry, which may explain why there has been no increase in student assessment scores. The microscopic and macroscopic concepts that simulations best depict are often not part of current general chemistry assessment. Assessment emphasis continues to be at the symbolic level. The participants also stated that they have not had the conversations with students that would be necessary to evaluate the meaning making that is taking place. This again points to the lack of a differentiated assessment techniques currently in use by chemistry teachers. It is likely that if there was a required move to assessment practices that addressed the molecular dimension of chemistry, ICT use would likely increase and be used more effectively to assist student learning. It is well known that assessment can drive pedagogy and possibly explicit focus on assessment on a deeper conceptual understanding of conceptual chemistry would encourage ICT use in a more meaningful way. In the mean time, ICT used to support student understanding in Chemistry is a teacher's choice. Little drives teachers to support students in their understanding of the molecular nature of chemistry. In this study, what appear to be motivating teachers' efforts to do so, albeit in a minor way, are their own beliefs about 'good' chemistry teaching which has certainly been influenced by the long-term professional development.

This summary of the findings has addressed the three research questions and provided some indication as to how computers simulations are used as a part of best teaching practices and the factors that are currently affecting teacher uptake of technology in the classroom. The next section will highlight some implications the research has for current practice.

5.4 Implications

This study explores a small group of Manitoba Chemistry educators and their experiences with computer simulations and their efforts to support meaning making for their students. The research has implications for educators seeking to infuse computers simulations in classroom pedagogy. The study also has implications for professional development practices within education and the implementation of provincial initiatives such as curriculum documents.

This study has shown that there are many factors that affect the uptake of computer simulations and ICT within the classroom. While there are many individual factors that effect the changing of pedagogy for teachers, there is a clear indication of the importance of how professional development should implemented within the educational community. This study confirms Lewthwaite's 2006 premise that in order for professional development to achieve its goals of changing teaching pedagogy it must allow for the following:

1. Both internal and external research and practical knowledge must be combined to develop a successful program along with specific outcomes and supports must be in place.
2. Teachers must be expected to reflect on new content and pedagogy and create meaning in terms of their classroom practice.
3. A collaborative, constructive and ongoing learning environment must be maintained.
4. Teacher leaders need to be developed so that new teaching pedagogy can be propagated within entire communities and not be limited to one specific area.

The teachers within this study indicated that the professional dialogue between experts and the time to reflect on and share their own experiences in the classroom over a long term has allowed the professional development to be successful within the cohort.

The importance of the relationship and trust that is established over a long term professional development is what enabled the teachers within this study to begin to have dialogue surrounding change. This type of dialogue has been shown to be an important component of the PLC model for professional development (Manouchehri, 2002).

When future professional development is planned for, from the school level up to the provincial level, the planning must include a long term cohort in which to contain the professional development sessions. When professional development is not sustained over a long period of time or done in a single session the professional dialogue that is necessary for change does not take place.

This study also found that the teachers within the cohort were unable to identify provincial and divisional staff that supported technology. The participants were not being asked for the name of a specific person but if they could name a division or government position or leader who is championing the use of technology within the province. The six interview participants did state that they felt the CRYSTAL professional development sessions both exposed them to computer simulations and was a driving force for the inclusion of technology in the classroom. Yet, in order for any change of pedagogy to occur within the classroom the provincial education authority must recognize that the release of documents and new curricula will not lead to change on its own accord. In order for pedagogical change to occur new curricula must be accompanied by professional development as described within this survey and by Lewthwaite (2006).

The CRYSTAL professional development series of workshops played a major role in the re-culturing of the educators involved in the survey. The series was planned by the Manitoba Chemistry curriculum writer along with support from the local University and other Manitoba High School educators. These educators have a background in best practices in terms of adolescent learning; however the majority do not have a background in adult learning pedagogy. As the CRYSTAL series developed over a period of three years (which is the time at which this study occurred), a Professional Learning Community (PLC) model was employed so that the educators involved could give more control to those who were participating in the professional development series. The organizers of the CRYSTAL sessions chose the PLC method so as to align the professional development with the current adult learning literature. The re-culturing of educators and the school as a whole is a topic that has been discussed by Liberman (1995) and Darling-Hammond (2005). Liberman speaks of creating new roles and structures for teachers as well as creating a "culture of inquiry, where in professional learning is expected, sought after, and an ongoing part of teaching and school life" (p. 593). This shared ownership of the professional development was evident in the formation of the PLC and in terms of determining discussion topics including the ways in which the group shared the information with teachers outside the group. CRYSTAL members were given a responsibility to share information with teachers outside the group through other professional development conferences such as the Special Area Group conferences held annually in Manitoba.

All CRYSTAL participants were engaged in a multiple year Professional Learning Community. The purpose of this community was on the surface to introduce the new Manitoba Chemistry curriculum, but also to help differentiate chemistry teaching inventories and to introduce educators to Mahaffy's tetrahedral model of chemistry. This study shows that a majority of Chemistry teachers have differentiated their teaching and have begun using computer simulations and technology to approach Johnstone's particulate level of chemistry. These changes mirror the intent of the CRYSTAL program.

The Manitoba Chemistry curricula also have the goal of creating chemistry classrooms that are student centred. The six participants interviewed continue to maintain a teacher centred classroom despite access to professional development and the new curricular requirements. While this outcome was not explicitly stated, why did this change not occur? According to Manouchehri the peer discourse, observations and feedback that are a part of CRYSTAL do have an impact on teacher development (2002). There are many possible reasons for why a significant change in pedagogy did not occur. In other words, although changes have occurred there have not been radical changes in teachers' views of teaching and learning. They continue to hold strong content- oriented views of their role as teachers. Jackson has stated that teachers justify their teaching based on their feelings rather than on reflection on their practice and are content with simple explanations in terms of pedagogy (1968).

The answer to these questions may come from adult learning theory. When looking at adult learning theory Mezirow's Phases of Meaning in Transformational Learning (1981) may provide a means to analyze how the CRYSTAL sessions affected the participants.

Table 4: Mezirow's Phases of Meaning in Transformational Learning

Phases
1. A disorienting dilemma.
2. Self-examination with feelings of shame, fear, guilt or anger.
3. A critical assessment of assumptions.
4. Recognition that one's discontent and the process of transformation are shared.
5. Exploration of options for new roles, relationships and actions.
6. Planning a course of action.
7. Acquiring knowledge and skills for implementing ones plans.
8. Provisional trying of new roles.
9. Building self-confidence and competence in new roles and relationships.
10. Reintegration into one's life on the basis of conditions dictated by one's new perspective.

For the teachers in the CRYSTAL sessions to undergo change in their teaching pedagogy Mezirow's phases of meaning need to be followed to some extent (Mezirow, 2002). While coordinators of the CRYSTAL sessions created a PLC for participants to interact and take ownership of their professional development, was there an initial disorienting dilemma to begin a transformation in pedagogy? As stated by the six interview participants in this study many simply continued their teaching practice as they had always done, and looked upon the CRYSTAL sessions as a method for differentiating their instruction, not for changing their approach to teaching. While CRYSTAL did present participants with an opportunity to dialogue and CRYSTAL created discourse in terms of instructional techniques, the participants did not identify a dilemma that would spark a change in their teaching beliefs.

5.5 Recommendations

Research on the uptake of technology by classroom teachers has been analyzed throughout the past thirty years, but the majority of this research has centred on post-secondary student learning. The secondary setting has its own unique characteristics in terms of funding and clientele that make up the microsystem. There has also been research into the factors that affect the individual educators reasoning behind the choice to use ICT within the classroom (Mumtaz, 2000). While these studies have shown factors that have been replicated within this study, more research needs to be done on how professional development can be used to alter teaching practices in the classroom.

This study has contributed to the research literature by explaining why and how chemistry teachers have begun to infuse computer simulations into their classrooms. The analysis I provided needs to be supported or refuted by a more extensive study of chemistry teachers and their beliefs about teaching and can be expanded to other teachers who are implementing computer simulations into their teaching. Such a study is needed in order to see the impact of each level of Bronfenbrenner's model in terms of both individual motivations and the impact of external influences such as long-term professional development. I would be interested to see if the use of computer simulations in the classroom would have been used to the same extent as in this study without the guided and purposeful professional development that all participants in this study were a part of, namely the CRYSTAL series. This alternate situation could serve as a control group to identify the true impact of a cohort within a professional development setting.

Research into the type of dilemma that may spark pedagogical change within chemistry teachers is an area where further study is required. Specifically, what factors can cause epochal changes in teachers' beliefs about teaching? What processes can be used to cause shifts in teachers' orientations to a true learner-centred pedagogy based upon a constructivist orientation? Without a disorientating dilemma to spark the will in teachers to make a change, very little will change in current pedagogy that is content-oriented. Changes in assessment practices in Chemistry are likely to bring about change, but unlikely to occur in Manitoba where there is little requirement for changed assessment practices in Chemistry at the school, divisional or provincial level. The inclusion of the student voice, a microsystem factor in terms of the classroom teacher might well be the spark to begin a change in pedagogy. "Today's child is bewildered when he enters the 19^{th} – Century environment that still characterizes the educational establishment where information is scarce but ordered and structured by fragmented, classified patterns, subjects and schedules" (McLuhan, 1967). Adding the student's perspective on learning can provide powerful insight into the current reality that teachers are not the only source of information in the classroom. Martinez states "teachers need to be expert guides, facilitators, and navigators of knowledge acquisition, analysis and application" (p. 73, 2010). Allowing student voice and student feedback to become part of a teacher's reflections and personal growth will provide mutual benefit allowing for change to occur in pedagogy. This often unwarranted voice will give students a new experience with education and in turn give them more control over the classroom. While students have not always been used effectively for feedback, Cook-Sather have identified that students are able to assume the position of authorities on learning and teaching as accorded the opportunity (2002). Student feedback can lead to a pedagogical shift from a teacher centred to a student centred classroom and in turn change learning from content based practice to an analysis of data and an application of knowledge and concepts.

A second source of a dilemma that may spark reflection on teaching pedagogy may be outside involvement within education. According to Fullan, this involvement may take the shape of any of five external forces: parents and community, technology, corporate connections, government policy or the wider teaching profession (2000). Each of these forces may present teachers with a dilemma to spark a change, and technology may be the choice if we are to look at moving from a teacher centred classroom to a student centred one. While technology gives students access to information, Fullan and Martinez (2010) agree that because of this new access to factual information, teachers must become experts not in content, but in pedagogical design.

When looking at the responses of participants within this study they all maintained a clear idea of what they felt was effective teaching and what makes a Chemistry teacher. This fossilized teacher identity is what teachers base their teaching on and what they believe chemistry teaching to be. This identity is not based on research, chemistry or curriculum. This fossilized knowledge is difficult to change and can mirror the student knowledge of chemistry as students enter the classroom. A future area for research would be to look specifically at the fossilized teacher identity and the types of disorienting dilemma that may result in a change in this identity.

The six interview participants all see technology as engaging students in lessons. Computer simulations provide the opportunity to both engage students but also to allow them more control over their own meaning making. Ensuring that implementation efforts are evaluated through student response to the usefulness of these efforts to improve their learning would be a natural way to provide feedback to teachers in terms of student meaning making and provide the positive feedback necessary to create pedagogical change.

While answering the research questions it should be noted that this study looked at the experiences of a small group of chemistry educators within Manitoba. This small number of educators limits the study in terms of generalizability of the results.

5.6 Summary

The teaching inventory of chemistry teachers in Manitoba has begun to change, albeit not in major way, in order to encompass Johnstone's three levels of chemistry. As part of this change, the use of computer simulations to explore the three levels, and in particular the particulate level, has begun to be used in the classroom. Currently the actual class time of usage is low. However, this does not mean that they are not being used appropriately within the classroom. There remains an emphasis by teachers on the symbolic level. This is due to the longstanding belief that chemistry teachers must be masters of content within the classroom. This purpose of chemistry education is a guiding factor that influences the teaching practices that are implemented. It is important to note that allowing teachers the opportunity to explore, reflect, and understand new teaching practices will open the possibility for the uptake of new pedagogy. Monitoring the meaning making by students that takes place after a change to student centred activities will legitimize the initial change. This in turn gives feedback to educators and strengthens their beliefs in the new teaching practices and pedagogy. Using this model of implementation will allow teachers to take an active research role in terms of their own teaching practices and allows for continual improvement and reflection on their teaching practices. In order for this model to occur within the current educational community there must be an initial dilemma that will cause educators to reflect on their current teacher centred pedagogy. Until teachers are confronted by an initial dilemma, the will to change their teaching practice will not occur. There are several potential sources for this dilemma, but it is important to note that external factors such as supportive curricula and directed professional development with collegial support are also required for the change to occur. Without reasons for teachers to reflect on their current pedagogy and meaning making by students it will continue to be the minority of educators that instigate a change in their teaching pedagogy.

Epilogue

In coming to the end of this study I would like to respond to my thesis in terms of my personal teaching career and my current role as a high school administrator. The use of computer simulations has been something that I have been both been exposed to and promoted as a chemistry teacher. As I look at the teachers in this study and reflect on my own career I see several similarities in terms of how I identified myself as a Chemistry teacher. The idea the content is most important remains part of a teachers fossilized identity, and without taking the time to reflect and delve into the idea of teaching chemistry, it is easy to maintain. The increased amount of differentiated instruction techniques as documented by the Chemistry Teacher Inventory is encouraging in that there is now awareness that all modes of chemistry need to be represented. However it is the missing component of Mahaffy's tetrahedral model, the human element, which can truly effect change in pedagogy. With this in mind as an administrator the human interactions within a school can be a factor of change and have become my focus throughout this study. In planning for professional development opportunities for my staff I keep in mind the power that giving ownership over to Professional Learning Communities can have, and the discourse that can result within these communities. As an administrator I can also have an effect on these communities by working with the participants rather than using a top down approach, which has been shown in this study to have little effect on the day to day operations of the classroom. It is within this area that I would like to perform further study to gain a better understanding of the factors that work to transform pedagogy and how leaders can affect this change.

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Appendix A

Online Survey Questions

CRYSTAL Chemistry Survey

Page One - General Teaching Information

1.) What is your gender?

( ) Male

( ) Female

2.) How many years of teaching experience do you have?

( ) 0-4

( ) 5-10

( ) 11-15

( ) 16-20

( ) 21+

3.) How many years have you been teaching at your current school?

( ) 0-4

( ) 5-10

( ) 11-15

( ) 16-20

( ) 21+

4.) How many years have you been teaching Chemistry?

( ) 0-4

( ) 5-10

( ) 11-15

( ) 16-20

( ) 21+

5.) What is the highest level of education you have completed?

( ) Teaching certificate

( ) 4 year Bachelor of Education

( ) Undergraduate Degree and After Degree Education

( ) Post-Baccalaureate Diploma/Certificate

( ) Master's Degree

( ) Doctorate

6.) Have you ever received professional development in the area of computer technology use in your classroom?

( ) Yes

( ) No

Please continue onto Page 2 of the survey where you will answer questions dealing with your involvement with the CRYSTAL Chemistry professional development sessions.

Page Two - CRYSTAL Chemistry Information

7.) How many years of CRYSTAL Chemistry sessions have you attended?

( ) 0

( ) 1

( ) 2

( ) 3

8.) How many CRYSTAL sessions have you attended over your involvement with the program?

( ) 10-12

( ) 7-9

( ) 4-6

( ) 0-3

9.) Which portions of the CRYSTAL professional development sessions have you found beneficial in your classroom practice? (You may select as many options as you feel have been beneficial.)

[ ] Ways in which to represent the molecular level.

[ ] Student laboratory activities.

[ ] Teacher demonstrations.

[ ] Teacher demonstrated computer simulations.

[ ] Student interactive computer simulations.

[ ] Sharing ideas with other Chemistry teachers.

[ ] Sharing assessment strategies with other Chemistry teachers.

[ ] Applications of Chemistry to students' everyday life.

[ ] Connection between the history of Chemistry and students' learning.

10.) Have you ever visited the CRYSTAL website?

( ) Yes

( ) No

11.) To what degree have you used resources (laboratory activities, links to computer simulations, assessment strategies) from the CRYSTAL website in your classroom?

( ) Extensively

( ) A few times

( ) Once

( ) Never

12.) How satisfied overall have you been with the CRYSTAL Chemistry professional development sessions?

( ) Very Satisfied

( ) Satisfied

( ) Neutral

( ) Dissatisfied

( ) Very Dissatisfied

( ) Not Applicable

Please continue on to Page 3 of the survey where you will be asked questions dealing with your classroom teaching practices.

Page Three - Chemistry Teacher Inventory

13.) Thinking about your Chemistry teaching practices, how often do you use the following strategies in your classroom?

	Almost always	**Often**	**Sometimes**	**Rarely**	**Never**
Students copy notes from overheads	( )	( )	( )	( )	( )
I perform chemical demonstrations	( )	( )	( )	( )	( )
Visual images are used	( )	( )	( )	( )	( )
Students plan and carry out investigations	( )	( )	( )	( )	( )
Students use	( )	( )	( )	( )	( )

computer based simulations					
Students carry out prescribed or set labs	( )	( )	( )	( )	( )
Students do formal lab write ups	( )	( )	( )	( )	( )
Students perform calculations	( )	( )	( )	( )	( )
Students use manipulatives	( )	( )	( )	( )	( )
I use a variety of strategies in the class	( )	( )	( )	( )	( )
Labs are performed by students	( )	( )	( )	( )	( )
I explain ideas as students copy notes	( )	( )	( )	( )	( )
Students make notes from textbooks	( )	( )	( )	( )	( )
Students are assigned problems from texts	( )	( )	( )	( )	( )
Students work together on tasks	( )	( )	( )	( )	( )

Please continue on to the next page where you will be asked questions regarding your teaching pedagogy in Chemistry.

Page Four - Teaching Pedagogy

14.) Reflecting on your current teaching practices, how often do you use the following strategies to generate student learning in Chemistry?

	Almost Always	Often	Sometimes	Rarely	Never
I talk about the history of chemistry	( )	( )	( )	( )	( )
Students are asked to explain what has been demonstrated	( )	( )	( )	( )	( )
I explain how Chemistry topics relate to student lives	( )	( )	( )	( )	( )
Students are required to know what a formula means before they calculate	( )	( )	( )	( )	( )
Students have to explain Chemistry ideas at a molecular level	( )	( )	( )	( )	( )
On tests students perform calculations	( )	( )	( )	( )	( )
Students are expected to explain their results	( )	( )	( )	( )	( )
I use analogies to get across Chemistry	( )	( )	( )	( )	( )

ideas					
I check to see if students grasp ideas before moving on to the next topic	( )	( )	( )	( )	( )
Chemical models are used to help students learn	( )	( )	( )	( )	( )
I assess student learning by tests and lab reports	( )	( )	( )	( )	( )
I give students lots of examples to help assist them in their learning	( )	( )	( )	( )	( )
I get students to work together and help each other on activities and problems	( )	( )	( )	( )	( )
I assist students with their work as they request assistance	( )	( )	( )	( )	( )
I use everyday examples to communicate Chemistry ideas	( )	( )	( )	( )	( )

Please continue on to the next page of the survey which deals with your access and use of computer technology.

Page 5 - Technology Access and Usage

15.) What types of computer technology do you have access to within your teaching environment? Choose the answer which BEST describes your situation.

	Currently in my classroom	Available to my classroom	Available within my school	Not Available
A desktop computer	( )	( )	( )	( )
A laptop computer	( )	( )	( )	( )
A LCD projector for computer content	( )	( )	( )	( )
Network access to the internet	( )	( )	( )	( )
A SMART Board or equivalent interactive device	( )	( )	( )	( )
A bank of 2-10 computers for student use	( )	( )	( )	( )
A desktop computer lab (11 to 30 desktops)	( )	( )	( )	( )
A laptop mobile unit (11 to 30 laptops)	( )	( )	( )	( )

16.) How often do you access/use the following types of technology for teaching purposes?

	Almost Always	Often	Sometimes	Rarely	Never
A desktop computer	( )	( )	( )	( )	( )
A laptop computer	( )	( )	( )	( )	( )
A LCD projector for computer content	( )	( )	( )	( )	( )
Network access to the internet	( )	( )	( )	( )	( )
A SMART Board or equivalent interactive device	( )	( )	( )	( )	( )
A bank of 2-10 computers for student use	( )	( )	( )	( )	( )
A desktop computer lab (11 to 30 desktops)	( )	( )	( )	( )	( )
A laptop mobile unit (11 to 30 laptops)	( )	( )	( )	( )	( )

17.) Do you use a computer as part of your administrative duties as a teacher? (This would include things like communicating with parents, taking attendance, use of a grade book, etc.)

( ) Yes - but only at school.

( ) Yes - at school and at home.

( ) No - I do not use a computer for my administrative teaching duties.

Please continue on to the next page of the survey that deals with the use of computer simulations in Chemistry.

Page Six - Computer Simulation Use

18.) Have you ever used a computer simulation during your teaching of Chemistry?

( ) Yes

( ) No

19.) If you have used computer simulations in your classroom, how frequently have you used them?

( ) Frequently

( ) Often

( ) Infrequently

( ) Never

20.) Do you feel that computer simulations provide an accurate representation of Chemistry at the macroscopic (observable) level?

( ) Almost always

( ) Often

( ) Sometimes

( ) Rarely

( ) Never

( ) Not Applicable

21.) If computer simulations can engage students, how does this engagement look in your classroom?

	Satisfied	**Neutral**	**Unsatisfied**	**Not Applicable**
Increase in student - student dialogue	( )	( )	( )	( )
Increase in student - teacher dialogue	( )	( )	( )	( )
Increase in student understanding	( )	( )	( )	( )
Increase in student assessment scores	( )	( )	( )	( )

22.) Do you feel that computer simulations provide an accurate representation of Chemistry at the symbolic level?

( ) Almost always

( ) Often

( ) Sometimes

( ) Rarely

( ) Never

( ) Not Applicable

23.) Do you feel that computer simulations provide an accurate representation of Chemistry at the particulate or microscopic level?

( ) Almost always

( ) Often

( ) Sometimes

( ) Rarely

( ) Never

( ) Not Applicable

24.) Do you feel that computer simulations engage students in Chemistry?

( ) Almost always

( ) Often

( ) Sometimes

( ) Rarely

( ) Never

( ) Not Applicable

25.) Do you feel that students are able to generate meaning when working with a computer simulation?

( ) Almost always

( ) Often

( ) Sometimes

( ) Rarely

( ) Never

( ) Not Applicable

26.) Which factors do you feel are most important when you/if you were to use computer simulations in your classroom?

	Very Important	Important	Neutral	Less important	Not important
Access to computers	( )	( )	( )	( )	( )
Access to LCD data projectors	( )	( )	( )	( )	( )
Ease of access to computer simulation	( )	( )	( )	( )	( )
Computers loaded with required browser plug-ins (latest version of Shockwave, Java, etc.)	( )	( )	( )	( )	( )
Ease of student use when working with the	( )	( )	( )	( )	( )

simulation					
Representation of the three modes or levels within the simulation	( )	( )	( )	( )	( )
Accurateness of the representation within the simulation	( )	( )	( )	( )	( )
Access to support materials that parallel the simulation	( )	( )	( )	( )	( )
Degree of complexity of the simulation	( )	( )	( )	( )	( )

27.) How influential are each of the following factors in terms of your integration of computer simulations in your classroom?

	Very positve influence	**Positive Influence**	**Neutral**	**Negative influence**	**Very negative influence**	**Not Applicable**
Personal motivation to use computers	( )	( )	( )	( )	( )	( )
Personal interest in new technologies	( )	( )	( )	( )	( )	( )
Personal skill with computers/new technologies	( )	( )	( )	( )	( )	( )
Personal access to computers	( )	( )	( )	( )	( )	( )
Personal time to experiment with computer simulations	( )	( )	( )	( )	( )	( )
Personal access to professional development with computer simulations	( )	( )	( )	( )	( )	( )

Number of teachers in your school using computer simulations	( )	( )	( )	( )	( )	( )
Professional support from other teachers in terms of computer use	( )	( )	( )	( )	( )	( )
Student response to prior use of computers	( )	( )	( )	( )	( )	( )
Support from school administration to infuse computers into teaching	( )	( )	( )	( )	( )	( )
Support from district/divisional staff to infuse computers into teaching	( )	( )	( )	( )	( )	( )
Curricular outcomes including references to computer simulations	( )	( )	( )	( )	( )	( )

Thank You!

Thank you for taking our survey.

Appendix B

Letter of Intent School Division Superintendent
Letter of consent, School Division Superintendent (on institutional letterhead)

Free and Informed Consent

Project Title: Constraints and Contributors towards the use Computer Simulations in the Chemistry Classroom

Researcher: Brian Straub, Master of Education student at the University of Manitoba

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what teachers who participate from your division can expect. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Brian Straub, a graduate student in the Faculty of Education from the University of Manitoba in Winnipeg, is conducting this study. The purpose of this research is to identify constraints and contributing factors to the uptake of computer simulations in the Chemistry classroom.

You will be asked to consent to allowing the researcher to recruit teachers within your school division. Participating teachers will be asked to complete an online or pen and paper survey as well as consenting to a personal interview. The survey will take approximately 30 minutes to complete. The interviews should take approximately 120 minutes. The time and location of the interview will be determined by mutual convenience, and will not take place on school division property so as to maintain the confidentiality of participants among colleagues. The interview will be audio recorded and transcribed verbatim. Participants will be allowed to review the transcript and make any changes you deem necessary. The digital audio will then be destroyed. All data will be destroyed seven years from the date of completion of the study. There are no risks involved in this study. Benefits include the opportunity for teachers to receive feedback about the study results, and a greater understanding about factors affecting computer usage and the effect of computer usage on pedagogy. The study's results will be presented at education conferences. The study or parts of the study such as specific case studies will also be submitted to science educator journals.

Please understand that you, as superintendent, are free to withdraw consent and discontinue access to school division personnel who are participating in this study at any time without prejudice or consequence by contacting the principal researcher. Please be assured that your confidentiality will be maintained at all times. At no time will your name, the school or school division's identity or any closely identifying information be included in any documents generated from this study. All information received from teacher participants will be kept in an area to which only the researcher involved in this study will have access. The informed consent sheet containing your name will not be kept with the data, avoiding the possibility of connecting your name to any information that you have provided. All data will be destroyed seven years from the date of completion of the study. You have the opportunity to request a copy of the summary of the study's result.

If you are interested in allowing teachers to participate in this study, please read the following statement and sign and date it. One copy is yours to keep.

I _________________ agree to allow teachers within my school division to participate in this study. I understand that participation is voluntary and that I may withdraw permission to interview teachers in the study at any time by simply telling one of the researchers. I have read and understood the above description of the study. I understand that my privacy will be safeguarded as explained above. I understand that if I have any questions or concerns, I may contact the researcher and/or ENREB.

Your signature on this form indicates that you have understood to your satisfaction the information regarding your schools participation in the research project and agree to allow teachers within your division to be interviewed. In no way does this waive your legal rights nor release the researchers or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

Researcher: Brian Straub, 204-XXX-XXXX
Thesis Advisor: Dr. Brian Lewthwaite, 204-474-9061

This research has been approved by the ENREB. **If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Secretariat at 474-7122, or e-mail margaret_bowman@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.**

____

Participant's Signature Date

____

Researcher's Signature Date

I would like to receive a summary report of the findings:

_____ _____
Yes No

Please mail a summary report of the findings at:

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Appendix C

Letter of Intent School Principal
Letter of consent, School Principal (on institutional letterhead)

Free and Informed Consent

Project Title: Constraints and Contributors towards the use Computer Simulations in the Chemistry Classroom

Researcher: Brian Straub, Master of Education student at the University of Manitoba

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Brian Straub, a graduate student in the Faculty of Education from the University of Manitoba in Winnipeg, is conducting this study. The purpose of this research is to identify constraints and contributing factors to the uptake of computer simulations in the Chemistry classroom.

You will be asked to consent to allowing the researcher to recruit teachers from within your school. Participating teachers will be asked to complete an online or pen and paper survey as well as consenting to a personal interview. The survey will take approximately 30 minutes to complete. The interviews should take approximately 120 minutes. The time and location of the interview will be determined by mutual convenience, and will not take place on school division property so as to maintain the confidentiality of participants among colleagues. The interview will be audio recorded and transcribed verbatim. Participants will be allowed to review the transcript and make any changes you deem necessary. The digital audio will then be destroyed. There are no risks involved in this study. Benefits include the opportunity for teachers to receive feedback about the study results, and a greater understanding about factors affecting computer usage and the effect of computer usage on pedagogy. The study's results will be presented at education conferences. The study or parts of the study such as specific case studies will also be submitted to science educator journals.

Please understand that you, as principal, are free to withdraw consent and discontinue access to school division personnel who are participating in this study at any time without prejudice or consequence by contacting the principal researcher. Please be assured that your confidentiality will be maintained at all times. At no time will your name, the school or school division's identity or any closely identifying information be included in any documents generated from this study. All information received from teacher participants will be kept in an area to which only the researcher involved in this study will have access. The informed consent sheet containing your name will not be kept with the data, avoiding the possibility of connecting your name to any information that you have provided. All data will be destroyed seven years from the date of completion of the study. You have the opportunity to request a copy of the summary of the study's result.

If you are interested in allowing teachers to participate in this study, please read the following statement and sign and date it. One copy is yours to keep.

I __________________ agree to allow teachers within my school to participate in this study. I understand that participation is voluntary and that I may withdraw permission to interview teachers in the study at any time by simply telling one of the researchers. I have read and understood the above description of the study. I understand that my privacy will be safeguarded as explained above. I understand that if I have any questions or concerns, I may contact the researcher and/or ENREB.

Your signature on this form indicates that you have understood to your satisfaction the information regarding your schools participation in the research project and agree to allow teachers within your division to be interviewed. In no way does this waive your legal rights nor release the researchers or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

Researcher: Brian Straub, 204-XXX-XXXX
Thesis Advisor: Dr. Brian Lewthwaite, 204-474-9061

This research has been approved by the ENREB. **If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Secretariat at 474-7122, or e-mail margaret_bowman@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.**

____
Participant's Signature Date

____
Researcher's Signature Date

I would like to receive a summary report of the findings:

_____ _____
Yes No

Please mail a summary report of the findings at:

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____

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Appendix D

Letter of Intent Interview Participants

Letter of consent, interview participants (on institutional letterhead)

Free and Informed Consent

Project Title: Constraints and Contributors towards the use Computer Simulations in the Chemistry Classroom

Researcher: Brian Straub, Master of Education student at the University of Manitoba

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Brian Straub, a graduate student in the Faculty of Education from the University of Manitoba in Winnipeg, is conducting this study. The purpose of this research is to identify constraints and contributing factors to the uptake of computer simulations in the Chemistry classroom.

You will be asked to consent to completing an online or pen and paper survey as well as consenting to a personal interview. The survey will take approximately 30 minutes to complete. The interviews should take approximately 120 minutes. The time and location of the interview will be determined by mutual convenience, and will not take place on school division property so as to maintain the confidentiality of participants among colleagues. The interview will be audio recorded and transcribed verbatim. Participants will be allowed to review the transcript and make any changes you deem necessary. The digital audio will then be destroyed. There are no risks involved in this study. Benefits include the opportunity for teachers to receive feedback about the study results, and a greater understanding about factors affecting computer usage and the effect of computer usage on pedagogy. The study's results will be presented at education conferences. The study or parts of the study such as specific case studies will also be submitted to science educator journals.

Please understand that you are free to withdraw your consent and discontinue your participation in this study at any time without prejudice or consequence by contacting the principal researcher. Please be assured that your confidentiality will be maintained at all times. At no time will your name or any closely identifying information be included in any documents generated from this study. You may choose a pseudonym for yourself if you like. All information received from you will be kept in an area to which only the researcher involved in this study will have access. The informed consent sheet containing your name will not be kept with the data, avoiding the possibility of connecting your name to any information that you have given. All data will be destroyed seven years from the date of completion of the study. You have the opportunity to request a copy of the summary of the study's result.

If you are interested in participating in this study, please read the following statement and sign and date it. One copy is yours to keep.

I __________________ agree to participate in this study. I understand that participation is voluntary and that I may withdraw from the study at any time by simply telling one of the researchers. I have read and understood the above description of the study. I understand that my privacy will be safeguarded as explained above. I understand that if I have any questions or concerns, I may contact the researcher and/or ENREB.

Your signature on this form indicates that you have understood to your satisfaction the information regarding your schools participation in the research project and agree to allow teachers within your division to be interviewed. In no way does this waive your legal rights nor release the researchers or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

Researcher: Brian Straub, 204-XXX-XXXX
Thesis Advisor: Dr. Brian Lewthwaite, 204-474-9061

This research has been approved by the ENREB. **If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Secretariat at 474-7122, or e-mail margaret_bowman@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.**

____
Participant's Signature   Date

____
Researcher and/or Delegate's Signature   Date

I would like to receive a summary report of the findings:

_____   _____
Yes   No

Please mail a summary report of the findings at:

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