DEMYSTIFYING MISCONCEPTIONS IN GRADE 12 ELECTROCHEMISTRY

BY

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ABSTRACT

The purpose of this study was to investigate the effectiveness of a treatment strategy: a laboratory experiment involving model manipulation versus the effectiveness of a teacher-centered approach to teaching and learning for the electrochemistry unit of Grade 12 Chemistry. The subjects were grade 12 students (n = 68) enrolled at two high schools within one urban school division. These students were split into four groups, two control groups and two treatment groups, one of each at both schools. There were also two instructors. All four classes participated in parallel instruction programs with the same notes and laboratory questions. At the end of the teaching sequence, the treatment group worked with a model of an electrochemical cell and an electrolytic cell from which they worked through questions based on their observations and manipulations. Pre-test and post-test data were analyzed by an analysis of variance with repeated measures. Overall, the electrochemical and electrolytic models allowed the students to interact with a secondary strategy assisting them to create a meaningful understanding of the complex topic of electrochemistry in Grade 12 Chemistry. Statistical analysis indicated significant growth over time but there were no significant results for the time by treatment by instructor interaction or for the time by treatment interaction.

Table of Contents

Definitions

This is a list of terms specific to this study:

Distracter: an answer that corresponds to the major misconception for the content area.

Electrochemical cell (also known as galvanic and voltaic cell): an arrangement of electrodes and electrolyte in which a spontaneous redox reaction is used to produce a flow of electrons through an external circuit (Dorin, Demmin, & Gabel, 1990, p. 801)

Electrolysis: "the process that uses electricity to bring about a chemical reaction" (McGraw-Hill, 2005, p. 971).

Electrolytic cell: "an electrochemical cell in which electrolysis occurs" (McGraw-Hill, 2005, p. 972).

Macroscopic level: one of three levels of Chemistry learning as defined by Johnstone (1992). This is the level at which the students can make meaning from directly observed or manipulated phenomena such as demonstrations, lab experiments, or real-life experiences.

Misconceptions or Alternative Conceptions: With respect to this study, are conceptions held by learners that are often scientifically inaccurate. As defined by Sanger and Greenbowe, a misconception is defined as "student conceptual and propositional knowledge that is inconsistent with or different from the commonly accepted scientific consensus" (1997b, p. 378).

Oxidation Number: "the charge assigned to the atom in accordance with [electron loss or gain], involving electronegativities." (Dorin, Demmin, & Gabel, 1990, p. 805).

Oxidation Reaction: Within the scope of a redox reaction "a loss of electrons in an atom or an algebraic increase in its oxidation number" (Dorin, Demmin, & Gabel, 1990, p. 805).

Particulate level: one of three levels of Chemistry learning as defined by Johnstone (2000). Specifically, he stated that this is the level at which "the behavior of substances is interpreted in terms of the unseen molecular level which is then recorded in some representational language and notation" (2000, p. 39). For the purpose of this study, it will refer to all activity of single or small groups of atoms, ions, molecules, and electrons in electrochemical and electrolytic cells.

Preconception: an "existing knowledge base [used] to evaluate new information" (Sanger & Greenbowe, 1997b, p. 378) based on student experience.

STSE: Science-Technology-Society-Environment. An ideological foundation of the Manitoba Chemistry Curriculum that focuses not only on the theoretical aspects regarding Chemistry but also how those theories related to technology, society, and world culture.

Symbolic level: one of three levels of Chemistry learning as defined by Johnstone(1992). This is the abstract theory based learning associated with Chemistry that most commonly includes mathematical calculations, balancing of equations, and writing of formulae.

Redox Reaction: is "an oxidation-reduction reaction" defined by Dorin, Demmin, & Gabel (1990, p. 806).

Reduction Reaction: Within the scope of a redox reaction as "the algebraic decrease in oxidation state or the gain of electrons in a chemical action" (Dorin, Demmin, & Gabel, 1990, p. 806).

Chapter 1 - Introduction

1.1 Context of the Problem

One of the consistent themes evident over the past 40 years in the various Manitoba Chemistry curricula for Senior Years students is the importance of developing student understanding rather than simple knowledge of chemical phenomena. As an example the 1966 Chemistry curricula stated that a main goal was to develop "the understanding of the basic ideas of Chemistry" (Province of Manitoba, 1966, p. 3). Despite this emphasis on developing understanding, the focus of the materials developed to support instruction has been towards a didactic delivery of the curricula with a great focus on textbook work and preparation for post-secondary education. Thus contrary to this admirable intention of affirming the need for developing understanding of chemistry ideas the practical learning support materials that accompany these curricula place a great emphasis on textbook work and algorithmic problem solving. As an example, in the 1970's, there continued to be a great focus on textbook knowledge and problem solving. In fact, the 1972 Manitoba Chemistry curriculum listed at least five different textbooks that were approved for use in classrooms, all of which placed considerable emphasis on abstract Chemistry theory such as atoms and electrons and algorithmic calculations like the algebra of the electron exchange process.

In the 1980s, the focus moved away from a teacher-based model of education to a more student-centered learning model is evidenced in the Manitoba Chemistry curriculum. The curriculum focused on a learning model that emphasized teachers need to explore the students' pre-existing knowledge prior to instruction, and encouraged students to make connections to the real world. Students' were now being encouraged to experience Chemistry and to make the link between what they saw and their theoretical knowledge base. The curriculum advisors recommended that Chemistry instruction should "provide students with a firm grounding in the concepts and processes of chemistry, an understanding of the factors which influence the applications of chemical principles and an opportunity to experience growth in cognitive ability" (Province of Manitoba, 1984, p. 5). In the 1990s, and more recently, there has been a push for students to develop knowledge and understanding through experimentation and teacher facilitation and to make connections to the various public sectors that use Chemistry everyday. The 1998 curriculum document focused not only on how Chemistry impacts the student but also on how it impacts the world and society in which the students live. This was named the "Science-Technology-Society-Environment (STSE)" (http://www.edu.gov.mb.ca/ks4/cur/science/ch40s/main/ch40s.html) aim of the curriculum. Again, despite this progressive inclusion, the focus of the Chemistry support material is on algebraic manipulations, algorithmic representations, with less emphasis on student the discovery and the impact that Chemistry makes to the real world and to students' lives.

Typically, Chemistry teaching has focused on abstract and theoretical approaches requiring students to make the leap from observable qualities of chemical phenomena to abstract yet logical balanced chemical equations. As Johnstone stated "[e]verything came in well designed, closed boxes and the exams explore the contents of each box and never asked the pupils to look in two boxes at once" (1991, p. 75). Throughout these years of theoretical teaching pedagogy, there has been a key link that has been absent for the student to be able to make intelligible and meaningful connections between the observable phenomena and the logical algorithms of Chemistry. In other words, Chemistry has been "taught at a macro[scopic] level only, with 'explanation' available on demand" (Johnstone, 1991, p. 82). Johnstone goes on to assert that this missing link is the particulate or molecular level of Chemistry understanding and knowledge. This is the level at which the students can observe and manipulate models of the individual atoms of a compound or work through a model of a system, one macroscopic representation of a molecule at a time.

This study is aimed at emphasizing the importance of the particulate nature of Chemistry teaching with the goal of improving student understanding of otherwise abstract and obscure knowledge. Unlocking the microscopic level may allow students to better understand Chemistry and to facilitate the scaffolding between the macroscopic and symbolic levels of Chemistry understanding (Johnstone, 1991). Many times, students have experiences with the macroscopic levels of Chemistry through such experiences as demonstrations within the class, real-life observed phenomena, and laboratory experiments. Smith, diSessa, and Roschelle (1993) stated "that all learning involves the interpretation of phenomena, situation, and events, including classroom instruction, through the perspective of the learner's existing knowledge" (p. 116). Traditionally, students have been required to make a cognitive leap from their macroscopic experiences to developing intangible and theoretically-based balanced equations or formulae. By bridging the gap between these two levels (that is, the macroscopic and symbolic) with the particulate level, students may be able to make more meaningful connections between their prior experiential knowledge and the theoretical knowledge they will learn.

The particulate level of Chemistry learning can also be very abstract. This is the level at which "the behavior of substances is interpreted in terms of the unseen and molecular and recorded in some representational language and notation" (Johnstone, 2000, p. 39). This can be very challenging not only for the students but also for the teacher. Models, such as molecular model kits and other manipulatives, are one teaching strategy that can assist students to visualize the microscopic phenomena occurring in a chemical reaction. Models can assist students to be active learners and assist students in making meaningful connections to their prior knowledge. As Osborne and Wittrock (1983) stated "the brain is not a passive consumer of information, instead it actively constructs its own interpretations of information, and draws inferences from them" (p. 492). With the use of models, the students may be able to make connections between the observed phenomena at the macroscopic level and the balanced equations learned through a theoretical approach to learning. Therefore, assimilating Johnstone's (1992) and Osborne and Wittrock's claims (1983), when the students need to recall the knowledge regarding the phenomena, not only will they have their macroscopic experience to rely on, but they will also have their particulate knowledge through a tangible representation to assist in the understanding of the particular chemical phenomena at a more abstract and theoretical level.

1.2 Purpose of the Study

This study represents the development of a treatment program designed to improve the understanding of electrochemistry in Grade 12 Chemistry classes within two high schools. Specifically, this study will assess the effectiveness of a treatment strategy: a laboratory experiment involving model manipulation versus the effectiveness of a teacher-centered approach to teaching and learning. A treatment of model manipulation will be administered to two of four groups, one per school, at two different high schools taught by two teachers. In each school, there will be one treatment group and one control group. For this study, three research questions have been developed:

(a) Will there be a difference in understanding of electrolytic and galvanic processes between the experimental treatment and control group students over time such that the students receiving the experimental treatment will be superior to the students receiving the control treatment?

(b) Will there be significant growth difference between the pre- and post- test scores in both the experimental treatment and control groups' students?

(c) Will there be a difference between school/instructor treatment interaction over time

1.3 Significance of the Study

This study is important for the understanding of how students learn Chemistry in a high school situation. There are many learning demands placed on the students enrolled in Chemistry that include learning not only what they see but also what it means in terms of algorithms. Therefore, students should have a method and a means to bridge the cognitive gap between the evidential and the abstract. Being able to manipulate the model, the students will be actively engaged so that they will rely not only on their visual learning strategies but also on their kinesthetic strategies and on their auditory strategies as they will have to listen and learn as part of a small group. As Sanger (2004) stated, "the presentation of simultaneous verbal and visual information should free working memory in the learner that can be used to construct referential connections" (p. 3). By asking the students to think more deeply and to connect what they know to what is actually occurring will allow the students greater success in their study of Chemistry.

In order to assist student learning at the particulate level, the teacher must be responsible for providing the opportunities to allow students to be engaged in investigative activities and to understand the students' preconceived knowledge regarding Chemistry and its topics. Osborne and Wittrock (1985) stated in Ritchie and Volkl that a "teacher need[s] to provide opportunities for students to construct their own knowledge and reflect on their freshly generated views" (2000, p. 83). Understanding and awareness of student's pre-existing knowledge will allow the teacher to help foster meaningful activities and connections so that the students can build upon their pre-existing knowledge bank much like the Generative Model of Learning and Teaching (Osborne & Wittrock, 1983). Therefore, by developing meaningful learning opportunities for the students, the teacher can assist in conceptual change for their students.

Teaching for conceptual change is one of the most important themes in Chemistry education research today (Hewson, Beeth, & Thorley, 1998). Much of the language of chemistry used by the teacher, by the textbooks, and by the media is abstract and foreign to many of the students. In order to bridge the gap between the unknown and the observed phenomena as evidenced by students in secondary Chemistry courses, one must be able to introduce students to the particulate or microscopic level. This molecular level is likely to be closely related to Stinner's (1993) psychological phase of learning where the students begin their Chemistry lessons by experiencing through observations (the evidential phase), making sense of these observations through molecular visualizations at the psychological plane, and consolidating these ideas at the abstract and algorithmic stage (the logical phase) of Chemistry understanding. With the knowledge gained from the particulate or the psychological stage of Chemistry, students will be more equipped to make meaningful connections and to be more successful in Chemistry.

Success in the unit of Electrochemistry has been hampered by many misconceptions (often referred to as alternative conceptions) that are common to many students. A misconception may be defined in this context as "observed differences between student ideas and corresponding expert concepts" (Smith et. al, 1993, p. 119). Understanding the misconceptions and the preconceptions that the students hold prior to beginning the unit, teachers may be able to better prepare their lessons in order to facilitate student success. The pre- and post-tests used in this study will assess common misconceptions regarding electrolytic cells that have been previously found by Garnett, Garnett, and Treagust (1995) and Sanger and Greenbowe (1997a, 1997b). The misconceptions that have been previously identified include polarity orientation of electrodes and battery terminals, electron movement in an electrolytic cell, purpose of inert electrodes, and the use of standard reduction potentials to determine redox reactions.

1.4 Scope of the Study and Generalizability of the Results

This study will be used to generalize findings to other secondary schools that offer a Grade 12 Chemistry curriculum that contains a unit on Electrochemistry. The results will be in a format and of substance suitable for generalization to similar school divisions that are suburban, predominately middle-class, and with similar student demographics. This study will also allow teachers to better understand how students learn Chemistry especially within the context of electrolysis and galvanic cells. The findings will assist teachers to develop programs that facilitate learning and meaningful conceptual change. By understanding that there are three levels, macroscopic, microscopic, and symbolic, to Chemistry instruction and learning, the results of this study may have implications beyond the unit of electrochemistry to other conceptual areas that could be addressed by focusing on each of the here levels of representation. Knowing the outcomes of this study, teachers may be more inclined to study and implement the particulate level of Chemistry learning and instruction into all areas and units of study in not only Grade 12 Chemistry but also in Grade 11 Chemistry. This study is being carried out a time when the Grade 12 Chemistry Curriculum is being re-written with some emphasis on the microscopic level. This study may provide some research-based support for further restructuring of Chemistry education in Manitoba that will help teachers and curriculum developers to be cognizant of what facilitates success for students in Chemistry, namely the marriage of the three levels of learning and understanding: the microscopic, the macroscopic, and the symbolic.

Chapter 2 – Literature Review

2.1 Introduction

The purpose of this chapter is to review the literature pertaining to the context of the study, the teaching and learning of Chemistry. The literature review is divided into three sections. In section 2.2, the review will begin with an investigation into the themes and orientations of the Chemistry curricula over the past 40 years in Manitoba. The examination is framed by understanding the theoretical premises that have underpinned Manitoba Chemistry education. In other words, what is the purpose of the Chemistry curriculum? Is the emphasis on the development of knowledge for further study or careers or is there focus on developing an understanding of chemistry and its applications to everyday life? A particular emphasis of this historical analysis is focused on examining the importance placed on the development of student understanding in Chemistry, especially in the area of electrochemistry. In section 2.3, the review will examine the implications of the most recent curriculum with respect to the current literature on student conceptual understanding in Chemistry. This section will focus on the definition and identification of student misconceptions in Chemistry with a special focus on the unit of electrochemistry. Finally, in section 2.4 the review will examine recent pedagogical developments in Chemistry that support student conceptual understanding. The recent developments will show the pedagogical shift towards a generative model of conceptual understanding in Chemistry. The chapter concludes with a summary of the literature review in section 2.5 and provides the foundation for the research questions and methodology to be outlined in Chapter 3.

2.2 A Contemporary Approach to Chemistry Curriculum in Manitoba

Curriculum is an educational construct that has various definitions and meanings. Sometimes the word curriculum refers to the outlines teachers are expected to follow in the teaching of a unit and sometimes they refer to the things written and unwritten that guide teachers and schools in the general education of students. In this chapter I use the word curriculum in reference to the former; that is written curricula developed to guide teachers in their teaching. These curricula are evolving written tools that are used by the schools as a method for preparation, presentation and evaluation.

There have been many educational theorists that have studied and contributed to our understanding of the nature of curriculum. Of particular importance is Elliot Eisner (1979) who has assisted curriculum analysts in understanding that curricula are strongly influenced by the social and political milieu in which they are developed. In other words, it is believed that curricula are usually influenced by the socio-political climate in which they are constructed. Eisner holds the view that the Chemistry curricula developed over the past 40 years have been influenced by social and political forces active within the Manitoba climate at the time of the curriculums development. It is not the intent of this chapter to draw causality between the curriculum development in Manitoba and Eisner's work but rather to show an independent correlation between the two. That is to say that it cannot be concluded that Eisner's work did not inform the development of the Manitoba curricula, however, his views about the influence of environmental forces will be evidenced in the curricula. The purpose of this section is to examine the orientations and potential influences of the Chemistry curriculum in Manitoba over the past forty years.

2.2.1 Curriculum Orientations

The purpose of this section is to explore the significant contributions of one theorist who has contributed significantly to the understanding of curricular orientations, that being Elliott Eisner. In general, Eisner suggested that a general curricular goal should be to "foster the development of the student's cognitive processes" (Eisner, 1979, p.50). This idea centers on the student and the student's learning; it agrees with a belief that curriculum should be directed towards those who are actively engaged in the learning process: the students as opposed to teacher centered curricula. More specifically, Eisner proposed five curriculum orientations that underpin various curricula. That is, he suggests that any curriculum will be underpinned by one or more of five curriculum orientations. Again, they are not designed to comply with these orientations; instead they tend to give evidence of these orientations. The first curricular orientation of "Social Adaptation and Social Reconstruction" focuses on the development of individuals who can function in society and serve its purpose. In fact, Eisner states, "the role of the school is to maintain the status quo" (1979, p. 62). This orientation of curriculum is socially and culturally driven and differs according to the many different educational societies one would find in a set area, town or city.

Conversely, Eisner proposed two further orientations: the "Development of Cognitive Processes" (Eisner, 1979, p. 51) and "Curriculum as Technology" (Eisner, 1979, p.67) which focuses on the scientific method as the most effective method of instruction and learning. Within these second and third orientations, there is room for supposition, observation, and theorizing based on theoretical data. For educators, these orientations allow for the development of objectives and the use of those objectives as tools for evaluation.

The development of objectives is taken to the next level within Eisner's "Personal Relevance" (1979, p. 57) fourth orientation of curriculum. The curriculum is developed "in concert with students rather than handed down from the staff of a central office" (Eisner, 1979, p. 57). In this, the curriculum is adapted to the individual student. The student must be given the opportunity to experience the curricula and to connect it with some prior knowledge or experience. It is very individualistic in its delivery, as each student would have his or her own curricula and goals. It is believed that each student has an innate ability to learn and to grow cognitively, and it is up to the teacher to be a "good gardener who cannot change the basic endowment children possess but who can provide the kind of environment that can nurture whatever aptitudes they bring with them" (Eisner, 1979, p. 58).

Finally, the fifth orientation that Eisner identified was "Academic Rationalism" (1979, p. 54) which is a controversial orientation because it states that only the most important subjects be taught in order to "foster intellectual growth" (Eisner, 1979, p. 54). Eisner believes that if a subject or theory is not in the curriculum, then the students will not be given the opportunity to learn it. The major flaw of this orientation is the determination of which subjects are the most important and which ones should be ignored. A question that arises is if the "best" subjects are being taught, do we need the "best" teachers? Basically, this orientation would have us believe "that the basic fields in the arts and sciences are important because they best exemplify and exercise the human's rational abilities" (Eisner, 1979, p. 55). In this, only the best books are read, only the best problems are calculated. This orientation has been criticized as being "culturally parochial" (Eisner, 1994, p. 64) in that Western subject matter should be offered and therefore, many cultures and societies are left out of this orientation in both content and availability of resources.

2.2.2 Orientations of the Manitoba Chemistry Curriculum: A Historical Analysis

In this section, the curriculum orientations proposed by Eisner and how they relate to the grade 12 Chemistry curricula are explored beginning with the 1966 curriculum and through to the present day transition curricula. Specifically, this will be done within the context of the oxidation-reduction and electrolysis units. The analysis will be framed by three central foci. The first focus is the degree of emphasis placed on oxidation-reduction and specifically electrochemistry in the grade 12 Chemistry curricula. The second focus is the independent correlation between the curriculum orientation as outlined by Eisner (1994) and the Manitoba curricula. The third focus is on societal conditions likely to be influencing the Manitoba curricula.

2.2.2a The 1966 Curriculum

In 1966, the Manitoba curriculum document was developed as an aid to new teachers who may have required support in teaching Chemistry. It also offered support to practicing teachers, providing a guideline to follow that addressed the topics to be included in the provincial end-of-year exam. The purpose of the 1966 document was to develop "the understanding of the basic ideas of Chemistry" (Province of Manitoba, 1966, p. 3). The curriculum document did identify that there would be a need for the memorization of some aspects of Chemistry; however, the general consensus was to foster understanding of Chemistry as a subject. The writers of the provincial document suggest that by understanding the content, the students "may be" (1966, p. 3) more apt to do well on the exam rather than if they had to memorize details. This example could fit with Eisner's (1994) "Development of Cognitive Processes", where the students were to be given more opportunities to make meaning and to connect it to their personal experiences.

Throughout the document and in the "Detailed Chapter Outline" (1966, p. 3) section, there are some words that are used numerous times. Such words include "develop an understanding," "ability to show," "develop knowledge," "ability to explain," "show the relationship," "discuss," and "explain" (Province of Manitoba, 1966, p. 3-15). These words and statements show the focus of the curriculum on the understanding of the chemistry content rather than the memorization of the facts and theories. This is closely mirrored by Eisner's (1994) "Development of Cognitive Processes" orientation as the students were encouraged to suppose, observe, and theorize about the content of the Chemistry lessons. The students were given the responsibility to be scientifically literate being able to understand the scientifically relevant terms. There were some areas which called for calculations and rote memorization, but a number of these statements were significantly fewer than those statements that indicated understanding and personal meaning making.

Chemistry understanding is also the focus specifically within the chapter of electrochemistry with ten specific outcomes. The electrochemical and electrolytic learning outcomes began with the words "describe" and "explain" (Province of Manitoba, 1966, p. 12). Again, this demonstrated the same importance later described in Eisner's (1994) "Cognitive Processes" curriculum orientation, which allowed for the development of "the ability to infer, to speculate, to locate and solve problems, to remember, to visualize, to extrapolate" (p. 51). There were specific outcomes described previously in this curriculum document that were directly associated with drawing and calculating but these are not evident in this section of the chapter. Such outcomes include "calculating equilibrium concentrations" (Province of Manitoba, 1966, p.11) and "show how to draw electronic formulae" (1966, p. 6). In comparison with other chapters in this document, the electrochemistry chapter is either one of the shortest in the text or the one that merits a minimum amount of attention in the Chemistry 300 (grade 12) curriculum. Although there are nine teaching hours suggested for this unit, the provincial authors had decided to omit "Balancing by Half Reactions" (1966, p. 2). The teachers might opt not to teach this topic if they chose but it is found on the omissions page, an appendix at the end of the curricular guide, of the curriculum document. There is no statement as to the reasons for omission.

2.2.2b The 1972 Curriculum

Upon revision of the 1966 curriculum in 1972, the Department of Education developed a "teaching guide" for the two high school courses in Chemistry: Chemistry 200 and Chemistry 300. In their words, "this guide is not intended to be prescriptive; student's needs and abilities may require variation in the sequence of the topics and approach used in the development of the course" (Province of Manitoba, 1972, p. 3). The major focus of this document was to tie the curriculum to a variety of textbooks and laboratory activities. Eisner's (1994) orientation of "Curriculum as Technology" is paralleled here with the development of the necessity of laboratory activities (15 in total) to enhance the knowledge and theory taught in conjunction with the curriculum document. However, the scientific method may have been used in the laboratory but there is no mandate as to what should happen with the knowledge developed or what extensions were incorporated with the laboratory data.

In addition to laboratory activities, there is a great amount of theory to be taught in all areas of the two courses within the time allotments specified. In particular, three of the four alternatives for the Chemistry 300 curricula suggest that the Oxidation-Reduction Reactions section take three weeks to complete. In the forth alternative, the document suggests that this section take four weeks to complete. There was no mention or evidence as to the reason for the variance in time frames. Similar to the 1966 curriculum document, "Balancing by Half Reactions" (Province of Manitoba, 1972, p. 13) is listed as optional or it is to be completely omitted. In addition to that omission, the section on "Lead storage battery and Leclanche Cell[s]" (Province of Manitoba, 1972, p.13) is also omitted. Unlike the 1966 curriculum, this curriculum called for calculations based on Faraday's Law. Three of the alternatives did not cover this subject within their textbooks and, therefore, the third alternative textbook by Sienko and Plane was called upon for reference. This served as an example of Eisner's (1994) "Academic Rationalism" orientation where the purpose was to "foster the intellectual growth of the student in those subject matters most worthy of study" (p. 54). Therefore, the curriculum deemed Faraday's Law calculations to be important while other theories such as lead storage cells and balancing half reactions took a secondary roll to be taught only if the teacher opted to. Within the context of Chemistry, the curriculum focused less on the electrochemistry, thus placing less importance on this area as opposed to earlier units.

2.2.2c The 1984 Interim Curriculum

Twelve years later in 1984, the Department of Education created an interim document that was based upon much student and teacher-based research that explored the way students were perceived to learn Chemistry. The curriculum writers summarized the design of the new document as an aid to "provide students with a firm grounding in the concepts and processes of chemistry, an understanding of the factors which influence the applications of chemical principles and an opportunity to experience growth in cognitive ability" (Province of Manitoba, 1984, p. 5). This parallels Eisner's Development of Cognitive Processes orientation of curriculum, as the purpose of this 1984 interim document was to foster the growth of student cognition. Again, in comparison to the 1966 document, the 1984 curriculum used words such as "develop," "examine," "explain," and "describe" (Province of Manitoba, 1984, p. 7). However, the 1984 document went one step further and demanded the development of the understanding of Chemistry in the world in such topics as science-technology and the "finiteness in the supply of most raw materials that are now in demand" (Province of Manitoba, 1984, p. 7). It was interesting to note that the number of required laboratory activities had decreased to eight from the fifteen that were in the 1972 document.

Another novel curricular inclusion in the 1984 curriculum document was a section on evaluation. It states different methods through which a student could be evaluated in the course and that this course went past the traditional "paper and pencil testing" (Province of Manitoba, 1984, p. 31). Such methods include observations, reports, projects, and so on. Eisner's (1994) orientation of "Personal Relevance," is exemplified in this curriculum that "emphasizes the primacy of personal meaning" (p. 57) by allowing the students to observe the chemical phenomena and by allowing the teacher to gain insight into this process. This document seemed to be very teacher friendly as it not only goes over some basic chemical nomenclature that is required in the two high school Chemistry courses, it also gives an extensive list of resources and a detailed outline of unit objectives. There were far fewer units required for study than in previous documents, and each unit was not outlined as per a textbook but rather as a set of learning outcomes. There were numerous textbooks and references a teacher could choose from, and they were all listed on a table of resources in the curriculum document (Province of Manitoba, 1984, p. 29-30).

The fifth unit of Chemistry 300 in this document dealt with "Oxidation - Reduction" (Province of Manitoba, 1984, p. 135). In this unit there were nine learning objectives. It is interesting to note that, in this document, the students were now required to draw an electrochemical and an electrolytic cell and label all the parts. This is the first time in the contemporary Chemistry curricula that this specific outcome has been outlined. The curriculum also mentions "a demonstration of a cell by the teacher would be useful in illustrating this objective" (Province of Manitoba, 1984, p. 137). This allows for the differentiated instruction of the Chemistry course permitting students the opportunities to learn in a variety of ways and to make personal references to their prior knowledge. In addition to Eisner's (1994) orientation of "Personal Relevance," the orientation of "Development of Cognitive Processes" is exemplified in this 1984 curriculum document. Demonstrations would allow the students the opportunity "to infer, to speculate, to locate and solve problems, to remember, to visualize" (Eisner, 1994, p. 51). Furthermore, for the first time specifically, spontaneity of a cell reaction is a listed curricular outcome to be covered. In the 1972 document, problem solving involving Faraday's Law continued to be an outcome to be covered within the framework of Chemistry 300 in the 1984 document. For the first time since the omission in the 1966 curriculum document, balancing using half-reactions returned as one of the curricular objectives in the Oxidation-Reduction unit of Chemistry 300 in 1984.

2.2.2d The 1990 Curriculum

In 1990, the Department of Education made the 1984 interim document the active document for use by all Chemistry teachers in Manitoba. In fact, they reprinted the 1984 document with the revision date of 1990 on the cover. There were no differences in the Oxidation-Reduction unit outcomes or teaching suggestions between the interim document and the 1990 active document.

2.2.2e The 1998 Transitional Curriculum

Most recently, an overhaul of the objectives of the Chemistry curriculum is evident in the present working transitional curriculum. The Department of Education had changed the designation of the senior year's courses to new numbers in 1993. The designation for grade 12 Chemistry was no longer Chemistry 300 but rather Chemistry 40S. The "S" indicated that it was a specialized course rather than a general course. In 1998, a new interim or transition curriculum document had been developed with the aims of scientific literacy. This document mirrors two of Eisner's orientations namely Development of Cognitive Processes and Academic Rationalism. With the "S" designation on the course number, it was a goal that students would strive to be scientifically literate members of society, mirroring Eisner's (1994) "Academic Rationalist" orientation. Also, there was much room for intellectual growth and meaning making with this transition document that would assist in the development of the cognitive processes (Eisner, 1994) of the student. As stated in the 1998 transition document:

> "science education should prepare individuals to meet personal needs, to enable them to resolve current societal issues, provide them with an awareness of a wide variety of science and technology careers, and lay the foundation for continued study" (http://www.edu.gov.mb.ca/ks4/cur/science/ch40s/main/ch40s.html).

In an age of increased use of technology, the transition document focuses greatly on the correlation between science, technology, and the world. The curriculum writers developed a "Knowledge/Science-Technology-Society-Environment (STSE)" (http://www.edu.gov.mb.ca/ks4/cur/science/ch40s/main/ch40s.html) curriculum that focused on not only the theoretical aspects regarding Chemistry but also how those theories related to technology, society, and world culture. Therefore, this aspect of the curriculum is closely aligned with Eisner's (1994) "Social Adaptation and Social Reconstruction" orientation. Eisner asserted that "content in the science curriculum is not exclusively to be drawn from the problems with which scientists work but from the individual and social problems for which scientific inquiry has some relevance" (p.65). Therefore, students studying the STSE will acquire not only a curricular understanding of Chemistry but they will also develop a societal awareness that will foster personal growth along with academic success.

Within the chapter of Oxidation-Reduction in the 1998 transition document, there are five major units. This unit contains four sub-units that deal with the drawing of electrochemical and electrolytic cells, the description of a variety of cells, calculations involving Faraday's law, and research projects (http://www.edu.gov.mb.ca/ks4/cur/science/ch40s/main/ch40s64.html). This last sub-unit was new and was consistent with the STSE standpoint of this curriculum document especially since it was suggested that the research project be done locally. Following the pattern of the 1972 and 1984 curriculum documents, spontaneity of redox reactions was addressed in an earlier unit of the oxidation-reduction chapter. However, in contrast to the 1972 document, the 1998 transitional document calls for the re-introduction of the lead-storage cell among other types of cells in the last unit of the oxidation-reduction chapter. It is also interesting to note that the suggested teaching time for this unit is at fourteen hours up 50% from the nine hours suggested in the 1966, 1972 and the 1984 curriculum documents. This could allow for more of a focus on mastery and the development of cognitive processes as postulated by Eisner. More time would allow for better teaching practices including activities that will foster intellectual and academic growth.

At the time this thesis was being carried out, the Manitoba Chemistry Grade 12 curriculum was being re-written. It is suggested by curriculum writers that the content of the curriculum will be very similar to that of the 1998 Transitional Curriculum but, potentially, with more emphasis on the student as a learner and the particulate level (George Bush, Senior Curriculum Writer, personal communication).

2.2.3 The Theoretical Underpinning of the Chemistry Curricula in Manitoba

This analysis shows how the curriculum orientations underpinning the Chemistry curricula in Manitoba may be interpreted as being aligned with two of Eisner's suggested orientations; Development of Cognitive Processes and Academic Rationalism orientations of curriculum. Despite these common orientations, there has been evidence of Eisner's Social Reconstruction orientation especially with the adaptation to the changing technology and social aspects of the modern Chemistry curriculum. As the needs of students and society have changed, so have the objectives of the curriculum documents. From the 1966 document that focused on understanding rather than memorizing to the present 1998 transition document that centered on technology, society, and science, the underlying orientation of grade twelve Chemistry has not changed markedly. Despite this consistency, there has been a shift towards technological understanding and scientific literacy from a simple knowledge and comprehension of theories and concepts within the context of Chemistry. As well, much of the content on electrochemistry has remained consistent over the years. However, there is evidence of shifts in the organization and concepts to be covered in a Chemistry course. That is the sequence and content of the course changes. Such topics included balancing using half-reactions, calculations using Faraday's Law, and the discussion of Lead-Storage cells. Although the content of the Chemistry curriculum has not changed markedly, the amount of time expected to be devoted to the topics and the suggested manner in which these topics are addressed suggest that over the past 40 years, shifts in orientations have been evidenced.

2.3 Student Conceptual Understanding within Electrochemistry

The developments over the past forty years in the Chemistry curricula for Manitoba students imply that a strong emphasis has always been placed on enhancing student understanding of chemistry phenomena. This is no surprising since Eisner (1979) states in his Development of Cognitive Processes orientation of curriculum that the intent of curricula commonly is to "foster the development of the student's cognitive processes" (p. 51). Eisner asserts that if this intention were followed, students would have "the ability to infer, to speculate, to locate and solve problems, to remember, to visualize, to extrapolate, and so on" (1979, p. 51). Eisner suggests that a curriculum that emphasizes the development of cognitive processes de-emphasizes the mere acquisition of information and instead, provides the students with the opportunity to use and strengthen the variety of intellectual capacities they possesses (1979, p. 51). Rather than emphasizing the simple dissemination of a body of ideas or information, the emphasis is placed on the development of intellectual power and reasoning (Eisner, 1979, p. 52). The purpose of the next section is to examine what research indicates about student understanding of and reasoning about chemical phenomena, especially within the context of electrochemistry and electrolysis. This will be done in an attempt to identify the major student misconceptions that may act as barriers for promoting student learning and understanding in Chemistry.

2.3.1 What Research Tells Us about Student Conceptions

Students of Chemistry come into our classrooms with many different ideas about how the world works. Many studies confirm that students enter Chemistry classrooms with well-developed but inaccurate conceptions of chemical phenomena. There has been extensive research into how students learn and into the preconceptions students have regarding Chemistry and chemical processes (e.g., Garnett, Garnett, & Hackling, 1995; Sanger and Greenbowe, 1997a; Sanger and Greenbowe, 1997b; Sanger and Greenbowe, 2000; Sewell, 2002). Often, these conceptions that students hold prior to learning

Chemistry, or pre-conceptions, are scientifically inaccurate and are thus referred to as misconceptions or alternative frameworks. Misconceptions are defined as "student conceptual and propositional knowledge that is inconsistent with or different from the commonly accepted scientific consensus" (Sanger & Greenbowe, 1997b, p. 378). These misconceptions are strongly held by the students.

Science, specifically Chemistry, is an area in which students hold a variety of misconceptions. A possible reason for the held-fast misconceptions may lie in the fact that "some student misconceptions are capable of adequately explaining the student's experiences and observations" (Sanger & Greenbowe, 1997b, p. 378). Therefore, the misconceptions about a scientific phenomenon make sense to the students, and they are reluctant to change or adapt their pre-existing knowledge. Student learning can be hindered by these misinformed and inaccurate ideas. The constructivist approach to learning Chemistry postulates that students are "active learners who construct their own knowledge" (Sewell, 2002, p.24) from their existing conceptions regarding the topics in Chemistry. If the students are constructing their knowledge on existing misconceptions, they could build greater misconceptions or alternative frameworks which could hamper their success in the course.

Sanger and Greenbowe state, "students use their existing knowledge base to evaluate new information" (1997b, p. 378). If the new information conflicts with the pre-conceptions, the students will use a variety of cognitive strategies to deal with this dilemma. In learning, students may "delete the pre-existing knowledge, modify the pre-existing knowledge so that it fits the new information, modify the new information so that it fits the old knowledge, [or] reject the new information" (Sewell, 2002, p. 24).

Evidence has shown that in many cases, the choices that the students make lies within these last two strategies.

The next section details the types of misconceptions our students hold regarding Chemistry, specifically, those misconceptions students hold in the conceptual area of electrochemistry and electrolysis.

2.3.2 Misconceptions in Electrochemistry and Electrolysis

It has been found that students find the unit of electrochemistry difficult to learn as evidenced by the many misconceptions the students possess in this area (Brandt, Elen, Hellemans, Heerman, Couwenberg, Volckaert, & Morisse, 2001; Özkaya, 2002; Sanger & Greenbowe, 1997a). There may be a variety of reasons for the inherent misconceptions that the students enter Chemistry with, but one idea might be linked to the discrepancy between theory taught and the textbook language. Alternatively, Brandt suggested "the incoherent use of definitions and symbols in electricity sections of physics courses" (2001, p. 1304) could be a cause for the problematic misconceptions in Chemistry. Also, there may be a lack of referencing and connection to all three levels of representations in Chemistry (Johnstone, 1991). Johnstone asserts that in order for students to be successful in Chemistry, their knowledge must span these three levels - the macroscopic, the symbolic, and the particulate levels. Johnstone (1991) suggests that problematic misconceptions for students in Chemistry may arise from the emphasis on the symbolic level rather than the particulate and macroscopic levels.

In reference to the electrochemistry concept of Chemistry courses, Brandt writes that "real life experiments are seldom done in ordinary teaching because of the micro scale of these phenomena" (2001, p. 1304). Without the ability to experience and to visualize the chemical phenomena of electrochemistry at the particulate level, students are not given the opportunity to form or revise their conceptions regarding this unit. Instead, they enter and potentially leave the course with misconceptions regarding electrochemistry because they have missed the opportunity to "modify the pre-existing knowledge so that it fits the new information" (Sewell, 2002, p. 24). With their misconceptions clouding their potential learning success, Chemistry students may conclude that electrochemistry was indeed one of the most difficult to learn in Chemistry.

There are several common themes associated with the misconceptions that students possess for the unit of electrochemistry. These major groupings of misconceptions revolve around the five major themes - electron flow, orientation of electrodes, purpose of a voltmeter/potentiometer, use of the activity series, and the use of inert electrodes (Garnett et al., 1995, Özkaya, 2002, Sanger and Greenbowe, 1997b). The remainder of this section will look specifically at the misconceptions of electrochemical and electrolytic cells identified by three renowned Chemistry education research groups. The overview will also suggest the reasons for the origins of these misconceptions.

2.3.2a – Özkaya's Misconceptions

Özkaya (2002) has contributed significantly to the research of misconceptions in electrochemistry. He found that there were nine unique misconceptions in electrochemistry. Specifically, he found that there were misconceptions held with respect to electron flow, the use and purpose of the voltmeter in galvanic cells, and evidence of electrochemical equilibria. Özkaya (2002) found that students believed that electrons flow from areas of high cell potential to areas of low cell potential. He identified that this misconception may have had roots in previously evidenced chemical phenomena. As an example, students are likely to have experienced that heat moves from a place of high temperature to a place of low temperature and that "mass transport occurs from a region of high concentration to a region of lower concentration" (Özkaya, 2002, p. 736). The students are likely to have developed this reasoning with ideas regarding heat and mass transport and therefore, they have made a cognitive leap to electrons in terms of electrolytic cells. Unfortunately, this leap is scientifically misinformed and the students have formed a seemingly logical misconception regarding electrochemical cells.

The next major misconception that Özkaya identified was that of the purpose of a voltmeter. He indicated that almost half of the students he surveyed believed that the voltmeter could be used to measure the electromotive force of an electrochemical cell. Even though the students used a potentiometer in a practical activity, they still retained the misconception equating the voltmeter to the potentiometer (Özkaya, 2002). Özkaya stated, "most of the university chemistry textbooks used by the subjects do not explain this difference. Moreover, these textbooks generally use the term "voltmeter" when discussing electric circuits related to the galvanic cell" (2002, p. 736). This could account for the false statement of the purpose of the voltmeter associated with high school Chemistry students. This evidence raises the importance of correct terminology not only on the part of the teacher but also on the part of the textbooks employed in promoting learning in Chemistry classes.

The final major misconception identified by Özkaya was that of the idea of electrochemical equilibrium. Students in senior Chemistry are exposed to numerous equilibria throughout their course, two of which are chemical equilibria and electrochemical equilibria. In fact, Özkaya (2002) found that more than half of the students in his study believed that there were no connections between chemical and electrochemical equlibria. Again, Özkaya points to the textbook and their interpretations of half reactions written with a single arrow on the standard reduction potential charts of the textbooks as a potential source of learning difficulty. Also, he suggests that teachers may contribute to these problems as well as they too often believed that there were no differences between chemical and electrochemical equilibria. Therefore, with two possible sources of misinformation with the two types of equilibria, students maintain their misconceptions and in fact strengthen them. Özkaya summarized his statements with the statement, "the origins of the learning difficulties were attributed mainly to failure to acquire adequate conceptual knowledge about electrochemistry, and to the insufficient explanation of the relevant concepts in textbooks" (2002, p. 738).

2.3.2b – Sanger and Greenbowe's Misconceptions

Sanger and Greenbowe (1997) have also done extensive work in this area of chemistry and have produced research based on the teaching of electrochemical and electrolytic cells. One major student misconception that Sanger and Greenbowe identified pertains to electron flow through a cell. They found that many students believe that the electrons flow from "anode to the cathode along the wire and are then released into the electrolyte at the cathode, traveling through the electrolyte solution" (Sanger & Greenbowe, 1997a, p. 820). They identify that a possible reason for the misconception may lie in the ambiguity of the language in their textbooks. Chemistry textbooks contain scientific terminology that may confuse the students and therefore, cause misconceptions to form or to persevere.

Although considerable research conducted on students' conceptions of electrochemical cells, the research emphasis has been primarily on galvanic cells rather than electrolytic cells. With specific reference to electrolytic cells, Sanger and Greenbowe (1997) identified numerous misconceptions held by students in their study. Namely, they found that many students did not believe that a reaction would occur if they were to use inert electrodes. Through interviewing the students in their study, Sanger and Greenbowe found that students believed that, in order to get the desired chemical products, electrodes must also be made of the corresponding metal. In their interview, students were asked why they believed they could not get an aluminium ion as a product. Students often responded, "because Al isn't one of the electrodes" (Sanger and Greenbowe, 1997b, p. 390).

Continuing with the theme of electrodes in electrolytic cells, Sanger and Greenbowe (1997) found that some students believed that identical electrodes would cause identical reactions when attached to the battery. The researchers found that the students made generalizations regarding the electrolytic cells and that since both electrodes were identical, there would be no reason to differentiate between the half reactions that occurred at each electrode. Through interviews, Sanger and Greenbowe found that the students were associating electronegativity with the electrodes and "one's not going to be more electropositive and one's not going to be more electronegative than the other one because they are both the same" (1997b, p. 390); therefore, the orientation of the electrodes and their reactions would be the same as well.

Finally, Sanger and Greenbowe (1997) identified that the use of the activity series in electrolytic cells to predict the half reactions led to another set of misconceptions.

There were two misconceptions that were evident; the first involved students who believed that water was unreactive, the second occurred when there were more than two possible half-reactions. Sanger and Greenbowe found that students thought that water was unreactive even though they found through interviews that the students recognized that water could dissociate into hydrogen and hydroxide ions. The researchers highlighted one statement made by an interviewee that, "water will not enter into the equation." They state that this comment could result in this misconception because the students have made generalizations from their previous experiences with water. Sanger and Greenbowe state that due to the use of aqueous solutions in which water is taken for granted, "water is always around and its presence is ignored when performing acid-base, electrochemical (galvanic), and equilibrium calculations" (1997b, p. 391).

The other misconception regarding the use of the activity series as a predictive tool was the inability of the students to consider more than two potential half reactions. When faced with the possibility that there would be more than two half reactions in an electrolytic cell, Sanger and Greenbowe (1997) found the students would not do the problem or they would randomly assign half reactions without consulting the activity series. Although Sanger and Greenbowe based much of their research on the research done by Garnett and Treagust (1992), they were able to identify some major misconceptions that students held and, thus, propose reasons as to how and why the students develop these misconceptions about electrochemistry and electrolytic cells.

2.3.2c – Garnett, Garnett, and Hackling's Misconceptions

Further research on electrolytic cells has been carried out by Garnett, Garnett, and Hackling (1995). Consistent with the findings of Sanger and Greenbowe, Garnett et al.

(1995) found that students held many different misconceptions regarding the location of electrons in electrochemical and electrolytic cells. Garnett et al. found that student misconceptions about electron placement had one thing in common; the electrons were always identified as being in the electrolytic solution. How the electrons traveled to and from the solution is where Garnett et al. found the misconceptions among students to differ. Some students believed that the electrons were "carried by an ion" (Garnett et al., 1995, p. 84) where as other students believed that the electrons were moved by being "attracted alternately from one ion to another" (Garnett et al., 1995, p.84). Garnett et al. identified that a possible reason for this misconception is that the students assumed that the free, unattached electrons had to move about the entire system in order for a current to be achieved. Furthermore, Garnett et al. suggested that the terminology used in high school Chemistry courses might cloud the understanding of the students. Specifically, they state "electricity and electric current should be defined as the flow of electrons in metals and the flow of positive and negative ions in solutions or melts" (1995, p. 85). However, two approved grade 12 textbooks define electric current as the "net movement of electrical charge; often the flow of electrons in a circuit," the "flow of electrons through the external circuit" (McGraw-Hill Ryerson, 2004), and "the rate of flow of charge past a point" (Nelson, 2003). Definition of electric current as per Garnett et al. may allow the students to break away from the misunderstanding that electric current is simply the flow of electrons throughout the entire system.

Congruent with the research done by Sanger and Greenbowe, Garnett et al. found that the students believed that "no reactions will occur at the surface of inert electrodes" (1995, p. 84). The researchers postulated that a reason for this misconception was that the students were being too literal-minded and translated the meaning for inert as inactive and an area where no reaction could occur. Yet again, this misconception may have something to do with the semantics of high school chemistry language in both the lessons and the textbooks.

The third major misconception that Garnett et al. identified pertains to the labelling of the two electrodes. Some students believed that the polarity of the battery did not determine the attachment of the anode and cathode. The students merely thought that you could attach the anode and the cathode to whichever pole of the battery they wanted to. In identifying the electrodes as either cathode or anode, Garnett et al. found that the students believed that the electrolytic cell was simply the reverse of an electrochemical cell. Again, Garnett et al. thought that the students were over generalizing and over simplifying the electrochemical and electrolytic processes.

The major theme found in Garnett et al.'s research on electrochemical and electrolytic cells was that the students tended to over simplify chemical processes. Although students may be able to express their understanding of the Chemistry occurring at the symbolic level, their actual reasoning for what is occurring at the particulate level is very poorly developed.

2.3.3 Implications for Teaching and Learning

The research into student misconceptions in electrochemistry and electrolysis identifies two major reasons for the formation of misconceptions. They are the use of ambiguous language on the part of both the teacher and the textbook and the oversimplification of chemical theory and phenomena by the students. As Garnett et al. state, "research reviewed suggests that many of the alternative conceptions held by students result from curriculum decisions, various pedagogical practices, imprecise use of language, and the abstract and symbolic nature of much of the subject matter of chemistry" (1995, p. 87). Therefore, it follows that many of the high school students formed misconceptions specifically regarding electron transfer, purpose of the voltmeter, orientations of the electrodes, and the use of the activity series in the prediction of half reactions in the unit of electrochemistry.

With the assistance of research in Chemistry education, teachers now have an idea of some of the misconceptions that the students may form or hold during the instruction of this unit. Sewell states, "it is vital that teachers take existing student knowledge into account" (2002, p. 27) especially when there are many opportunities for the misconceptions to form, namely with the scientific and at times confusing language used in the electrochemistry and electrolysis unit.

This has implications for Manitoba Chemistry teachers. The Manitoba Chemistry transition curriculum document requires students to gain an understanding of electrochemistry and electrolysis through the use of diagrams and descriptions (1998). Clearly, an emphasis is placed on understanding the processes associated with electrochemistry. Despite this intent, the electrochemistry concepts can be marred by ill-informed misconceptions that hinder student learning and growth. Teachers need to be aware of common misconceptions associated with electrochemistry. This is important because as the unit progresses, the students will be required to apply their electrochemical and electrolytic cell knowledge to real-life phenomena such as Hall's process, fuel cells for space exploration, and corrosion of metals and its prevention (Province of Manitoba, 1998). Therefore, the teachers must make an attempt to fully understand the preconceptions that their students hold prior to the commencement of this unit. Also, the teachers must use consistent terminology in their lessons with the textbook to describe electrolytic and electrochemical phenomena. By doing this, the teachers will have a good beginning to a unit that not only the students find difficult. As Audrey Sewell assured, "being aware of what the wrong beliefs are is the next step in attempting to overcome them" (2002, p. 27). These assertions are important in considering the implications for teaching chemistry and the learning of chemistry which are the focus of the next section.

2.4 Constructivism, Conceptual Change, and Student Learning

Over the past two decades, there has been an increasingly major focus on developing student understanding of chemical phenomena through teaching. This mirrors Eisner's assertion that curriculum should focus on "the development of intellectual power rather than the simple dissemination of a body of ideas or information" (1979, p. 53). To be able to focus on student thinking, teachers must be aware of students' pre-instructional knowledge base which is often incongruent with normal scientific convention. Being aware of the students' misconceptions, the teacher can focus on assisting learning to overcome these barriers to student learning and "foster the development of the student's cognitive processes" (Eisner, 1979, p. 51). If this reconciliation was actually to take place in Chemistry classrooms, the instruction would possess pedagogical elements consistent with constructivist teaching methodologies including teaching for conceptual change (Hewson, Beeth, & Thorley, 1998), and focus on the integration and correlation of the three levels of Chemistry representation endorsed by Chemistry educators today (Johnstone, 1991). The purpose of this section is to examine how constructivist views on learning, pedagogical approaches congruent with conceptual change and Johnstone's views on the three levels of Chemistry representation can assist students in moving towards the understanding of chemical phenomena. This analysis will be developed especially within the context of electrochemistry and electrolysis.

2.4.1 Traditional Pedagogy

One of the major changes in the Manitoba curricula over the past 40 years has been the explicit goal of promoting learning in Chemistry. This is evident in the present transitional curriculum where the focus is on developing student understanding through discussions and experimental explorations (Province of Manitoba, 1998). Traditionally, the focus has been on preparation of students for post-secondary education with little emphasis on student understanding. As Shulman stated, "A teacher knows something not understood by others, presumably the students" (1987, p. 7). Therefore, the teacher as expert used the method of transmission for teaching the content of the Chemistry curricula in Manitoba. In theory, this would allow for the "mastery of traditional school subjects through traditional teaching methods, particularly textbook learning" (Miller & Seller, 1985, p. 5) where the students would work closely with the textbook to perform skills outlined by chapter questions. The teacher was the centre of the classroom and any learning that was done was strongly influenced by how hard the student works and how effectively they can repeat the lessons on tests due to the fact that "the learning itself ultimately remains the responsibility of the students" (Shulman, 1987, p. 7).

Many of the early Chemistry curricula in Manitoba outlined the appropriate textbooks that were to be used by the classroom teacher. For example, in the 1972 Province of Manitoba Chemistry curriculum, it listed four different textbooks that were suggested for use by the teacher. Much of the textbook language was foreign to students and consequently "if the language, the vehicle for communication, is suspect, no wonder science is hard to learn" (Johnstone, 1991, p. 81). This didactic method of teaching through textbook work and teacher prepared lessons were propagated not only by what the teachers thought was appropriate but also by the resources developed by the Manitoba Chemistry curricula despite the curricular foundational premise of promoting understanding. Learning was to be done solely by the students as the teacher already possessed the necessary knowledge and it was the responsibility of the students to demonstrate their capabilities to regurgitate the knowledge through rote learning passed on by the teacher and the textbook. In other words, "[e]verything came in well designed, closed boxes and the exams explore the contents of each box and never asked the pupils to look in two boxes at once" (Johnstone, 1991, p. 75). It also assumed that there was not a need for deeper understanding or the creation of connections between the chemical phenomena and the theory. There was no push for the students to understand how the particles moved or acted in any aspect of the Chemistry curricula. However, there was a need for a cursory knowledge of Chemistry and the visualization of chemical processes at the macroscopic level through laboratory work.

The students were required to perform several laboratory activities throughout the length of the course that were verifications of previously discovered chemical phenomena. This allowed the students to visualize the chemical phenomena but if the students were asked to explain the phenomena, they would explain using only symbols and balanced chemical equations largely ignoring the particulate level. In essence, Chemistry was "taught at a macrolevel only, with 'explanation' available on demand"

(Johnstone, 1991, p. 82). The students were not trained nor were they given the opportunity to look deeper at the processes that were occurring at the microscopic or unseen level of Chemistry. They were merely given the opportunity to respond to the teacher rhetoric in such a manner that would demonstrate their knowledge based on the restatement of facts learned.

2.4.2 Recent Developments in Teaching

Recent developments in the Chemistry curricula of Manitoba have moved beyond teacher-centered learning environments, allowing for more attention to students and their learning. Descriptive words in recent curricula give evidence that opportunity for deeper understanding by the student is being encouraged. The Manitoba Chemistry curricula now included such words as discuss, examine, explain, and describe (Province of Manitoba, 1984, p. 7). This change in language used by the curriculum documents gave the teachers a chance to move away from the chalkboards and allowed them the freedom to ascertain what their students were thinking and to teach accordingly. Increased emphasis was being placed on students as active and engaged learners. Now, the teachers were being encouraged to explore student thinking and become aware of student thoughts regarding Chemistry that would help lead the students to reconstruct their knowledge base to include the topics learned in the Chemistry classroom. These developments are consistent with recent international research in learning in Science education. For example, as Osborne and Wittrock stated "the brain is not a passive consumer of information. Instead it actively constructs its own interpretations of information, and draws inferences from them" (1983, p. 492).

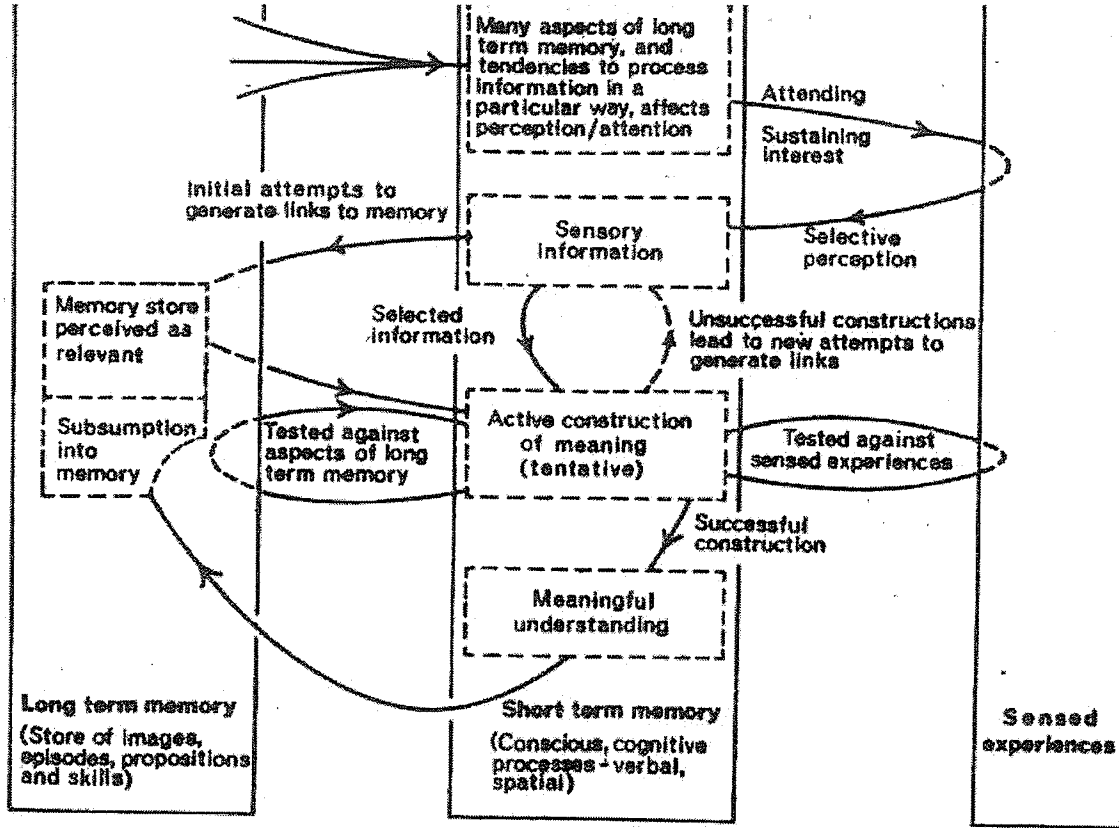


Figure 1. Schematic representation of the Generative Learning Model.

Learning in Science as illustrated by Osborne and Wittrock in their Generative Learning Model helps to explain how teachers should consider how learners learn. Research into cognition was their starting point, from which they generated a model that described for effective learning, the "learner must actively construct meaning" (1983, p. 493) through a series of steps. This model represents the steps necessary to comprehend a topic. There are three levels through which an idea or topic must pass: the sensed experience, the short-term memory, and the long-term memory (Osborne & Wittrock, 1983). Much of the generative learning model occurs in the short-term memory bank, as this is the working and conscious part of the students' brain. However, all students have experiences and memories stored in their long-term memory banks which they draw upon to make sense of new phenomena.

When students as active learners encounter new phenomena, they call up any knowledge from their long-term memory that seems related to the topic. They then perceive the new information or experience selectively by making links to their pre-existing knowledge framework. Smith, diSessa, and Roschelle state "that all learning involves the interpretation of phenomena, situation, and events, including classroom instruction, through the perspective of the learner's existing knowledge" (1993, p. 116). The students then store this experience in both their short and long-term memory from which they will move on to actively construct a meaning from the experience. The students will then test the new meaning against real-life experiences and their long-term memory bank. This new meaning is very tentative as any experience or memory that goes against the new meaning will potentially destroy it. However, if the meaning proves to be acceptable, the generative model has been successfully negotiated and meaningful learning has occurred. To be successful, the meaning of the experience for the student must be "intelligible, plausible and useful" (Osborne & Wittrock, 1983, p. 495). Once this meaningful understanding has taken place, the new knowledge is stored in the long-term memory where it can be called upon at a later time.

The students will actively try to make sense of their experience in their short-term memory bank by going back to their sensory information gathered by their experience with the topic. This is done through "conscious, cognitive processes" (Osborne & Wittrock, 1983, p. 493) where the students make meaning through verbalizations and spatial reconstructions. This may lead to the construction of misconceptions or alternative frameworks that can hamper the success of the student in future endeavours. A misconception in this vein is defined as "observed differences between student ideas and corresponding expert concepts" (Smith et. al, 1993, p. 119). These misconceptions are hard to overcome for the students because they have constructed these meanings and have taken some ownership over the meanings. Therefore, there must be convincing evidence for the students to reconstruct their misconceptions to allow for the rearrangement of their knowledge bank to accommodate the new phenomena.

In order to allow for generation of ideas and meanings of scientific theories, both the students and teacher must take an active role in learning and teaching. Osborne and Wittrock (1985) stated in Ritchie and Volkl that "teachers need to provide opportunities for students to construct their own knowledge and reflect on their freshly generated views" (2000, p. 83). Therefore, the students need to be allowed the opportunities to move through the generative model to construct knowledge regarding experienced chemical phenomena. If the students are not given the opportunities to construct knowledge and to connect it to prior knowledge, there would be no opportunities for deeper understanding of Chemistry, and thus we are back to the traditional pedagogy of teacher as expert and students as passive learners.

2.4.3 Conceptual Change Model

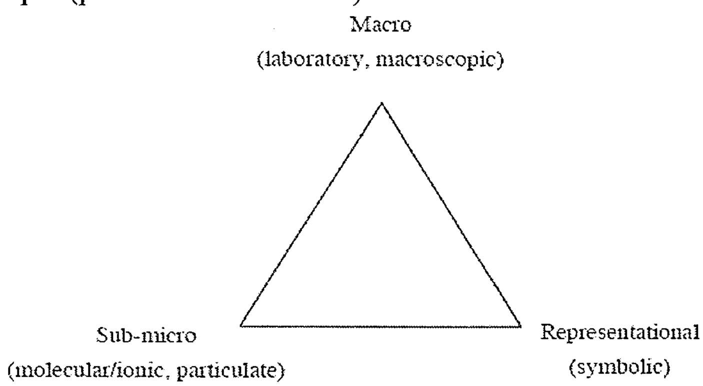
Osborne and Wittrock's Generative Learning Model has strong parallels to the Conceptual Change Model endorsed by Hewson, Beeth, and Thorley (1998). The important aspect regarding the acceptance of new knowledge construction in the Generative Learning Model was whether the new information is plausible, intelligible, and useful (Osborne & Wittrock, 1983, p. 495). This is consistent with teaching for Conceptual Change Model presented by Hewson et al. in which they assert that the degree to which a student accepts new knowledge has to do with how plausible and fruitful an idea is (1998, p. 200). They state that the variety of ideas that students hold vary in "status" (Hewson et. al, 1998, p. 199) from most plausible to least. This hierarchy of ideas is in constant flux as students create and recreate knowledge based on their experiences with chemical phenomena.

Providing opportunities for students to experience chemical phenomena will increase the possibilities for them to create deeper meanings of their knowledge base which will result in the flux in Hewson et. al's status hierarchy of ideas. These researchers do not mean to imply that all deeper learning occurs in experiential classrooms but rather, if the opportunities are there, the students will take advantage of them (Hewson et al., 1998). By taking advantage of the opportunities to experience chemical phenomena, the students will have the chance to construct knowledge that makes sense to them. In other words, the students will be allowed the freedom to create intelligible and plausible meanings for the sensed chemical phenomena.

Apart from giving the students the opportunity to experience chemical phenomena, Hewson et. al suggests that student cognition should be explicit. In other words, students should be given the tools necessary for metacognition, or thinking about their thinking, to occur. They should be given the space and the opportunity to think about their thinking and how they came to understand a concept or what is preventing them from understanding. Hewson et. al assert that allowing students to think about their thinking "recognizes that existing knowledge plays an important role in people's learning" (1998, p. 203). Therefore, students can bring their own knowledge to their consciousness; they can also consider the knowledge and thinking of their peers. In this, the teacher as expert becomes less dominant, and the students take on more of the responsibility for their learning. Although the approach of teacher as expert lessens, by monitoring the student's metacognition, the teacher can examine the learning of their students and watch out for possible misconceptions.

2.4.4 Learning and Teaching in Chemistry

In order to teach for conceptual change, one should negotiate between two related schools of thought proposed by Johnstone (1991) and Stinner (1993). Johnstone developed three levels of Chemistry representations (see figure 2) which involved the macroscopic (observed phenomena), symbolic (abstract representations), and the microscopic (particulate/molecular).



(Johnstone, 1991)

Stinner's LEP model also involved three levels; the evidential, the psychological, and the logical. To promote student learning, effort in teaching must be made to promote congruency among what is evidenced and the theory this evidence supports through the psychological plane (observed phenomena). It is this psychological plane that strategies are used to promote learning. In order for fruitful, intelligible, and plausible learning in Chemistry, it is essential that the students be exposed to teaching that emphasizes Johnstone's particulate level congruent to Stinner's psychological level of Chemistry learning. This will allow the student a greater chance for conceptual change as they will be able to bridge the practical (macroscopic) level with the algorithmic (symbolic) level of Chemistry. In reconciling the macroscopic and symbolic planes of learning, teachers may choose to employ a variety of teaching strategies to help their students. The variety of teaching strategies can assist the teacher to bridge the three levels of Chemistry education as outlined by Johnstone and the learning levels of Stinner's LEP model.

In teaching a unit in Chemistry, teachers can employ a variety of teaching strategies to enhance understanding by touching on Johnstone's three levels of Chemistry education. The first level is the macroscopic level in which the students can make meaning from directly observed or manipulated phenomena. The most common form of macroscopic learning is through laboratory experiences. An example related to the electrochemistry unit is a demonstration of an electrolytic cell. This electrolytic phenomenon could be represented by the observed demonstration involving the electrolysis of potassium iodide at two inert electrodes; this is the macroscopic level (yellow-brown colour at one electrode and bubbles at the other electrode). This then can be explained at the particulate/atomic level (visual representations and physical manipulations of molecular formation and gas generation); and finally, expressed at the most abstract, the electrolytic cell (balanced chemical half-reactions).

Traditionally, students have been trained to make a cognitive leap from observed macroscopic phenomena to symbolic representation. This does not allow for a conceptual change to occur as the students have missed the important particulate level of representation. Therefore, pre-existing misconceptions are fostered and as a result many students lack success. Many students believe they can write balanced chemical equations based on what they observed by using basic Chemistry knowledge. Students continue to fall back on mathematical or abstract approaches to explain chemical phenomena. Rarely can the students make intelligible connections between observed chemical phenomena and their mathematical and symbolic approach to Chemistry. As Johnstone stated, "the pupil can be stranded at the 'macro'" (1991, p. 78). Therefore, many misconceptions may arise.

To make the observed phenomena and the symbolic representations congruent, the students would have to look deeper into what is occurring inside the reaction. This is the microscopic or particulate level of Johnstone's model of Chemistry representation. Traditionally, this is the level at which students have the most difficulty both articulating and understanding. This is the level at which "the behaviour of substances is interpreted in terms of the unseen and molecular and recorded in some representational language and notation" (Johnstone, 2000, p. 39).

It is important to note that although Johnstone represented his three levels of Chemistry learning as a triangle, "the instructional sequence is likely to be best addressed in a more linear sequence involving, first, macroscopic experiences, ..., second, sub-microscopic, ..., and third, introduce symbolic" (Lewthwaite, 2003). This would allow for the integration and connection with Stinner's LEP model, which is also represented in a linear format. It is likely that Johnstone's three levels can be integrated with Stinner's three stages in such a manner that would facilitate more plausible, fruitful, and intelligible student understanding of chemical phenomena.

2.4.5 Pedagogical Shift

Traditional pedagogy has been very teacher centred with much of the language used in the Chemistry classrooms being highly technical and scientific. Students were able to regurgitate the knowledge passed on by the teacher as expert on formative assessments in a manner that would have demonstrated the memorization of theory. The textbook also played a significant role in this transmission style of teaching and learning. As a result, "the transmission position is linked with rote learning" (Miller & Seller, 1985, p. 6), and the acquisition of knowledge was through textbook work and the memorization of teacher taught knowledge.

Chemistry education has moved away from the didactic teaching styles of the past to a more modern, generative process for teaching and learning. In this generative model, the student is an active participant in their knowledge acquisition through which they juggle the plausibility of an idea within their short and long-term memories. A major point in this model is the logistics of the chemical topic and how well the student can make sense of the topic. To make sense of an idea, the student must be presented with not only the symbolic and macroscopic evidence but they must also be required to explore the particulate level pertaining to the phenomena. If the topic is not feasible or if it does not connect with any prior knowledge held by the student, the student will likely dismiss the topic or go back to the experience to try to make more sense of the topic (Osborne & Wittrock, 1983). Therefore, students' prior knowledge is a key component to student learning especially in Chemistry where many misconceptions or alternative frameworks may arise due to misplaced or ill-constructed cognitive connections.

Equally important to the awareness of student's prior knowledge in Chemistry is the awareness by the teacher and the students of the three levels of representation in Chemistry. Johnstone (2000) asserts that although much of the teaching and learning in Chemistry occurs at one or both of the macroscopic and symbolic levels, many teachers do not make the connections with the particulate level of learning. As a result, what the students observe is disjointed with their symbolic and abstract representations of the topic. With the introduction of the particulate level, students may be more likely to make the connections between what is observed and the theory presented symbolically. They can imagine and manipulate the topic with the use of models that represent the particulate nature of reacting species. Therefore, the students can draw symbolic connections to the observed phenomena by using the manipulations of the particulate elements of the model or analogy as a foundation for their thinking.

2.5 Summary

The historical review of the Manitoba Chemistry curricula over the past 40 years indicates the importance of developing the students as active learners who are engaged in their studies. This is mirrored in Eisner's (1994) curriculum orientation of the "Development of Cognitive Processes" in which the students must have an active role in their education through such activities as observations, predictions, and extrapolations. In more recent years, the underpinning curricular orientation has evolved to include "Social Adaptation and Social Reconstruction" (Eisner, 1994). The Science-Technology-Society-Environment (STSE) aspect of the curriculum allows for the development of socially conscious and technologically aware students within the area of Chemistry.

In order to foster students who not only understand Chemistry theory, the teacher must also work with the students to become aware of their pre- and misconceptions. Armed with the knowledge of any misconceptions, teachers and students can venture into the exciting yet abstract subject of Chemistry. Not only must teachers be aware of any misconceptions, they too must be conscious of the language they use while describing the chemical phenomena and theories. One must approach the language with caution and great care as to not overwhelm the students enrolled in our Chemistry courses.

Some methods teachers may employ are derived from the evolution of Johnstone's (1991) three levels of Chemistry education. This progression is supported by Osborne and Wittrock's (1983) Generative Learning Model and the Conceptual Change Model described by Hewson, Beeth, and Thorley (1998). To significantly enhance students' learning in Chemistry, Johnstone firmly believes that the students must experience Chemistry on the macroscopic, the microscopic, and the symbolic levels.

The three levels of Chemistry education and learning will not only assist students to understand Chemistry, they will also allow students to make meaning of the abstract nature of the observed chemical phenomena presented to them. By first understanding student preconceptions, teachers will be able to provide more opportunities for the students to experience Chemistry at the three levels of understanding. The purpose of the next chapter is to outline the methodology that will be used to answer research questions based on the three level approach to Chemistry learning and understanding. This study will focus primarily on the effectiveness of a treatment program at the particulate level in the unit of electrolysis and electrochemistry.

Chapter 3 – Methodology

3.1 Research Questions

The purpose of the study was to develop a treatment program designed to improve the understanding of electrochemistry in Grade 12 Chemistry classes within two high schools. In order to address that purpose, three research hypotheses were generated:

a) Will there be a difference in understanding of electrolytic and galvanic processes between the experimental treatment and control group students over time?

b) Will there be a significant difference between the pre- and post- test scores for both the experimental treatment and control groups students?

c) Will there be a difference between school/instructor treatment interaction over time?

3.2 Participants

The subjects of this study were enrolled in Grade 12 Chemistry classes within the Winnipeg Public School system. A convenient sample consisting of 68 grade 12 students enrolled in two different high schools located within one school division were used. The number of subjects was not different by their race, gender, and ability level. The schools were representative of middle class suburban areas of Winnipeg. The typical student was 17 years of age, low to middle socio-economic class, and will have passed Grade 11 Chemistry.

The research was a pre-test/post-test design focused on independent student growth over a time period. Classes were classified as either treatment or control group, with one of each group at each of the two schools. The classifications were randomly drawn as to which class is treatment or control but the students were drawn as convenient samples as they were scheduled into pre-determined classes.

3.3 Materials

The basis for subject matter content was derived from the interim Chemistry 40S (Grade 12) Manitoba Chemistry Curriculum. That is students were expected to learn the processes involved in the operation of both galvanic and electrolytic cells. Knowledge acquisition was measured by an identical pre-test/post-test design that will include twenty-five multiple-choice items and two free drawing questions. The teacher-researcher conducted the classes at School 1 and another teacher conducted the classes at School 2. Each teacher administered the pre-test, the delivery of the treatment or control lessons, and the post-test for their respective classes.

3.4 Treatment and Procedure

The entire Electrochemistry unit took approximately three weeks. The unit progressed in a manner consistent with the expectations of the Transitional Curriculum which included: writing redox reactions, assigning oxidation numbers, balancing redox reactions, solving redox reactions using Faraday's Law, determining spontaneity, galvanic cells, electrolytic cells, and real life redox reactions. The focus of this study is centered on the galvanic and electrolytic cells section of the Electrochemistry unit. Therefore, this research controlled only for the treatments during these two sections of the unit.

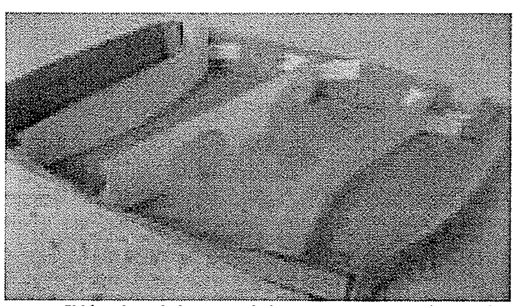
At the beginning of the unit, all four groups took the pre-test to assess prior knowledge about electrolysis (Appendix 1).

Each classroom participated in a parallel instruction program by their respective teacher with the same instructional activities including notes for the galvanic and electrolytic cells section. At the end of the teaching segment, students in the treatment groups manipulated a model of a galvanic and an electrolytic cell and derived the balance chemical equations based on their manipulation of the model in the laboratory setting. This allowed the students to manipulate individual particles as they react within each system. Students in the control groups were given an assignment to complete combining the theoretical knowledge from the notes and their prior knowledge of balancing and predicting equations.

3.4.1 Electrochemical Model

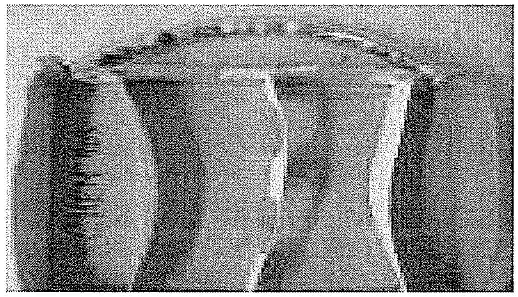
This model is a low cost atomic/ionic manipulative that uses a shallow cardboard box, manilla tag, marbles, plastic tubing, and coloured plasticine. The cardboard box will be sectioned off into 3 areas using strips of manilla tag. The two end sections represent the electrodes while the middle two sections represent the electrolytic solutions. The middle strip of manilla tag has two half moons cut into it to allow ion transfer as it represents the salt bridge, see Figure 3.1.

Figure 3.1



The plastic tube was filled with marbles representing the electrons and was placed outside of the box with one end attached at the left electrode section and the other end placed at the right electrode section, see Figure 3.2.

Figure 3.2



There are 3 colours of plasticine to represent the different chemicals in the reaction, red is for the copper, blue is for zinc and yellow represents the sulfate ions. The students gathered 8 yellow balls and place 2 electrons in each ball. The students then placed 3 red and 3 blue plasticine balls, the complete "ions," in the center sections. Then, the students gathered 4 red plasticine balls with two marbles and 4 blue plasticine balls with two marbles. They then placed the complete "atoms" in the electrodes with the red atoms on the left and the blue atoms on the right as pictured in Figure 3.3.

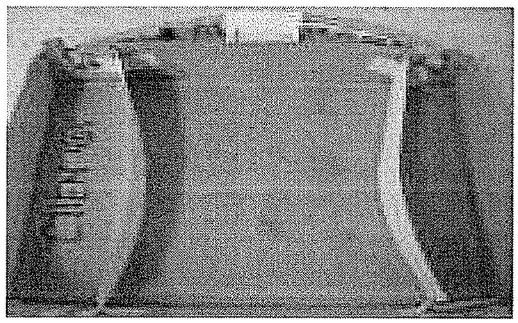
Figure 3.3

This placement of the plasticine balls represented ions in the electrolytic solution and atoms at the electrodes. From this point, the student worked through the electron transfer and ion movement within the electrochemical cell as per the lab script (Appendix 2 – Electrochemical Cell – Microscopic Level).

3.4.2 Electrolytic Model

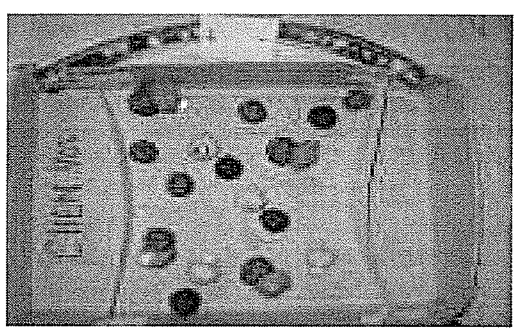
The model is similar to the electrochemical model in that it uses the same basic materials. The only major difference is that it needs 4 colours of plasticine as opposed to 3. Also, the cardboard box need only be fit with the two end manilla tag pieces and not the middle piece, since there is no salt bridge in an electrolytic cell. Over the curve of the plastic tube, a card is placed with a positive and negative sign representing the power source required for the push and pull of electrons respectively shown in Figure 3.4.

Figure 3.4



The students need to have 4 red balls, the hydride ions, and 4 blue balls, the potassium ions, in the center section. Then, they must place one marble between a fresh red and an orange ball four times and place these hydroxide ions in the electrolyte. Finally, the students also needed to place 4 yellow balls with 1 marble in each ball representing the iodide ions in the solution. The electrodes, the end sections, are left empty because they represent inert carbon electrodes. This is shown in Figure 3.5 below.

Figure 3.5



Once the plasticine particles are placed in the electrolytic center of the cell, the students worked through the function of the electrolytic cell as per their lab script (Appendix 2 – Electrolytic Cells – Microscopic Level).

3.4.3 Control Groups

Students in the control groups were given an assignment to complete combining the theoretical knowledge from the notes and their prior knowledge of balancing and predicting equations. All students, whether in the experimental or control groups, were allowed to work in groups of two or three students. In addition to their groups, all students were allowed to use their notes and reactivity charts as support materials. At the conclusion of the chapter, all four groups completed the post-test to assess the knowledge acquisition throughout the unit.

3.5 Treatment Variables

Within the context of this study, there will be three independent variables: the treatment (experimental and control) and the school. As stated previously, there will be two treatment groups and two control groups, that is one treatment and one control classroom at each of the two schools. The school will also have two levels in that there will be instructor one and instructor two.

3.6 Dependent Variables

The major dependent variable in this study was the test scores that assess student understanding between the pre-test and the post-test. These scores were further broken down into and examined by treatment group versus control group, and also school one versus school two.

The pre-test consists of multiple-choice questions that assessed the prior knowledge of the students. The questions were based on major misconceptions identified by Garnett, Garnett, and Treagust (1995) and Sanger and Greenbowe (1997a, 1997b). For example, question seven on the pre/post-test is reflective of misconception number six (Table 3.1) which states that many students believe that water is unreactive in an electrolytic cell. Further examples include question two, which tested misconception number five, and question nine, which will test misconception number eight. The post-test was administered at the end of the electrochemistry unit. The pre- and post-tests were identical forms where every question will be marked out of one, correct answers worth one and incorrect answers worth zero. This marking scheme allowed for a scale measure of pre- to post-test growth. In each question, there was at least one answer that is a distracter. Distracters are answers that correspond to the major misconception for the content area which are listed in Table 3.1 and 3.2 (paraphrased from Garnett, Garnett, & Treagust, 1995, and Sanger & Greenbowe, 1997a and 1997b). The scores on both the pre- and post-tests were gathered and compared between the treatment and control groups.

Table 3.1
Common Student Misconceptions: Electrolytic Cells

1. Electric current is due to the flow of positive charge through metal
2. Electric current is due to the flow of electrons in the electrolytic solution
3. The polarity of the battery terminals does not determine the situation of the anode or cathode
4. No reactions occur with inert electrodes
5. Water is unreactive in electrolytic cells
6. The cell potential of electrolytic cells can be positive
7. Identical reactions will occur if identical electrodes are used in electrolytic cells
8. When there are more than two redox reactions, it is impossible to tell which reactions will occur

Table 3.2
Common Student Misconceptions: Electrochemical/Galvanic Cells

1. The flow of positive charge, notably protons, constitutes the electric current in metallic conductors.
2. The flow of electrons constitute the electric current in electrolytes
3. In an electrochemical cell, the salt bridge supplies the electrons to complete the circuit
4. In Standard Reduction Potential tables, the species with the highest reduction potential is the anode
5. The anions and cations move until their concentrations in both half cells are equal
6. The anode is positively charged because it loses electrons, while the cathode is negatively charged because it gains electrons
7. Electrons move through the electrolyte to complete the circuit
8. Half cells need not be electrically neutral. One half cell can be positive with cations and the other negative with an equal number of anions
9. The identity of the anode and cathode depends on the physical placement of the half cells

3.7 Instrumentation

The focus of this study was on determining whether a teaching intervention had any influence on student understanding of galvanic and electrolytic cells, in particular in enhancing their understanding of what was occurring in the cell at the molecular level as the reaction progressed. For this reason, this study used a pre-test and post-test approach to assessing learning chemistry as a result of a teaching intervention. The tests were identical and were given at the beginning of the unit prior to instruction and then again at the end of the unit once the instructional sequence had ended. Both the experimental and control groups were given the same tests. The pre- and post-tests were split into two sections, an open-ended section with two questions and a second section that included 25 multiple-choice type questions. In hopes of waylaying student test anxiety, a statement was included at the top of the first section of the test. This statement read that the student's answers would not count in their term marks but would be marked by the researcher for analytical purposes only. See Appendix 1 for a copy of both portions of the pre-and post-test.

3.7.1 The Open-Ended Questions

This section of the pre-and post-test was made of two questions that asked the students to draw a visual representation of both the electrochemical and electrolytic cell. Each question included a list of the parts that the students were required to label in their drawings. It was these required parts of the cell that the assessment rubric was based upon (Appendix 3). The inclusion of these two questions was to provide an insight into students' understanding of the operation of electrochemical cells, in particular at the particulate level. Although quantitative data would be gathered from the assessment of student answers, the illustrations were anticipated to provide a qualitative understanding of student conceptions of the components and operation of these cells. The rubric, a scoring system, was designed to provide insight into students' understanding of the electrochemical and electrolytic cells by scoring the inclusion of pertinent objects within the drawing of the two cells. This will be discussed in section 3.7.3. Once the students were done this section of the test, they were to hand it in and get the second section of the test, the multiple-choice section.

3.7.2 The Rubric

The rubric (Appendix 3) for the open-ended questions was the same for each question and was a score out of four. Zero represented an answer that was completely incorrect or was unanswered. One represented a drawing with one of the four listed requirements correct. Two represented a drawing with two of the four listed requirements correct. Three represented a drawing with three of the four listed requirements correct. A score of four represented a perfect drawing with all the listed requirements included. A total score of eight was possible in this section of the test.

The rubric for the multiple-choice section of the test was a correct or incorrect mark. If the student chose the correct answer, they received a mark of one, and if the student chose any of the three incorrect answers, they received a mark of zero for that question. A total of 26 was possible for this section of the test.

3.7.3 The Multiple-Choice Section

This portion of the pre- and post-test consisted of 25 questions encompassing the three levels of Johnstone's learning of Chemistry. That is, some questions focused on macroscopic observable changes as well as particulate changes and symbolic representations of changes occurring within the cells as the reactions proceeded. The 24 questions had four options, one correct answer, one incorrect distracter that tied in to the misconceptions reflected in the tables in section 3.6, and the final two answers were also incorrect but did not tie into a reported misconception. One question, number 22, was a two-tiered multiple-choice question in which the students had to choose an answer in both sections of the question. Of the 25 questions, nine had to do specifically with the particulate level of Chemistry learning and understanding. Those nine questions were questions 3, 4, 9, 11, 13, 14, 22, 24, and 25. These questions were further broken down to six questions that were directly addressed by the use of the model used by the students in the experimental groups. These questions were 3, 9, 11, 13, 14, and 22. This multiple choice section, once assessed, would provide quantitative data to determine whether the intervention statistically had any influence on student learning. As well, the patterns of responses were anticipated to provide some indication of the resiliency of student misconceptions.

3.8 Statistical Analysis

The data was analyzed using a 3-way (time x treatment x school) analysis of variance (ANOVA) with testing time (pre-test and post-test) as the repeated measure. This analysis will be done for the full test, then again for the nine multiple-choice questions relating to the particulate level of Chemistry learning and understanding, and then again for the six multiple-choice questions relating to the use of the model by the experimental groups.

Chapter 4 – Analysis of Data

4.1 Introduction

In Chapter Four, results are presented from the analysis of the data obtained from the pre- and post-tests taken by the subjects of this study. The analysis sequence has been organized to address the five levels of analysis that have been used to answer the research questions listed below. The five levels of analysis are the full test 25 multiple choice questions, open-ended question 1, open-ended question 2, nine multiple choice questions (from the original 25), and six multiple choice questions (from the nine chosen from the original 25 multiple choice questions). Once again, the three research questions were as follows:

a) Will there be a difference in understanding of electrolytic and galvanic processes between the experimental treatment and control group students over time?

b) Will there be a significant difference between the pre- and post- test scores in both the experimental treatment and control groups students?

c) Will there be a difference between school/instructor treatment interactions over time?

4.2 Research Groups

The test subjects were comprised of four separate participant groups broken down by school/instructor and treatment. There were two schools each with their own instructor. School one employed the instructor/researcher, and school two employed a second instructor. Each instructor taught one control group and one treatment group.

4.3 Methodology

Each instructor taught the electrochemistry unit of Grade 12 Chemistry as per the working curriculum guide in Manitoba. Both the control and treatment groups performed a laboratory experiment designed by the researcher. The one major difference between the treatments was that the treatment group had to do a model manipulation for both the galvanic and electrolytic cell in addition to the regular laboratory experiment. The model, described in Chapter Three, focused on the particulate level of Chemistry understanding and learning.

At the beginning of the unit, both treatment groups took a pre-test consisting of two open-ended questions and 25 multiple-choice questions. Upon completion of the unit, the subjects took a post-test of identical design and make-up as the pre-test. These tests contained questions that addressed all three levels of Chemistry learning and understanding stated by Johnstone (1991). These three levels were the macroscopic, the symbolic, and the particulate. The macroscopic level includes the chemistry that is observable and seen with the naked eye. The symbolic level includes algorithmic chemistry like balanced equations. The particulate level includes the molecular/sub-microscopic aspects of chemistry such as the activity of molecules, ions, and particles within a cell or system.

4.4 Presentation of the Results

The results of the pre- and post-tests were graded by the researcher for total scores and then broken down into more focused groups of questions. The multiple-choice questions were assessed out of one or zero depending on the correctness, one being a correct answer and zero being an incorrect answer. The open-ended questions were assessed using a rubric of zero through four. A response was assessed a mark based on the number of correct attributes the drawing had as per the instructions for the question, zero being an incorrect or missing response and four being a completely correct response. Once assessed, the tests were given a total score made up of the sum of the number of multiple-choice questions correct and the number received on the open-ended question.

The analysis used was a three-way ANOVA, analysis of variance, with time, treatment, and instructor as the variables.

Five different analyses were carried out: one on the 25 multiple choice questions, open-ended question 1, open-ended question 2, the nine multiple choice questions relating to the particulate nature of chemistry learning and understanding, and the six multiple-choice questions most directly related to the model manipulation.

4.5 Results

This section is divided into five sections based on the dependent measures previously stated. Each sub-section will include the results for the different sources, namely time, time x treatment, time x instructor, and time x treatment x instructor interactions. Each section will contain a table of results reporting the mean and the standard deviation. The results will then be discussed in terms of statistical significance supported by corresponding graphs. The discussion of each research question will appear in Chapter 5.

4.5.1 The 25 Multiple-Choice Questions

The interactions will be presented for the full 25 multiple-choice questions that included macroscopic/visual questions, symbolic/chemical representation questions, and particulate/atom/ion/electron questions. This section of the test was scored question by question for correct answers, one mark, or incorrect answers, zero marks.

4.5.1a –ANOVA Table for the full test 25 Multiple-Choice Questions

Table 4.1 reports the analysis of variance for the 25 multiple-choice questions for both the between-subject effects and the within-subject effects. The table will include the sum of squares, the degrees of freedom, the mean squared value, the F value, and the significance level.

Table 4.1 ANOVA of 25-point Multiple-Choice Questions

Analysis of Variance of 25-point Multiple Choice Measure					
Source	**S/S**	**d/f**	**Mean Squared**	**F**	**Sig.**
Between Subject Variables					
Treatment	34.44	1	34.44	2.94	0.091
Instructor	38.99	1	38.99	3.33	0.073
Treatment X Instructor	69.88	1	69.88	5.97	0.017*
Error	760.98	65	11.71		
Within Subject Variables					
Time	984.99	1	984.99	103.62	<.001*
Time X Treatment	5.65	1	5.65	0.59	0.44
Time X Instructor	107.46	1	107.46	11.3	0.001*
Time X Treatment X Instructor	54.54	1	54.54	5.74	0.02*
Error	617.88	65	9.51		

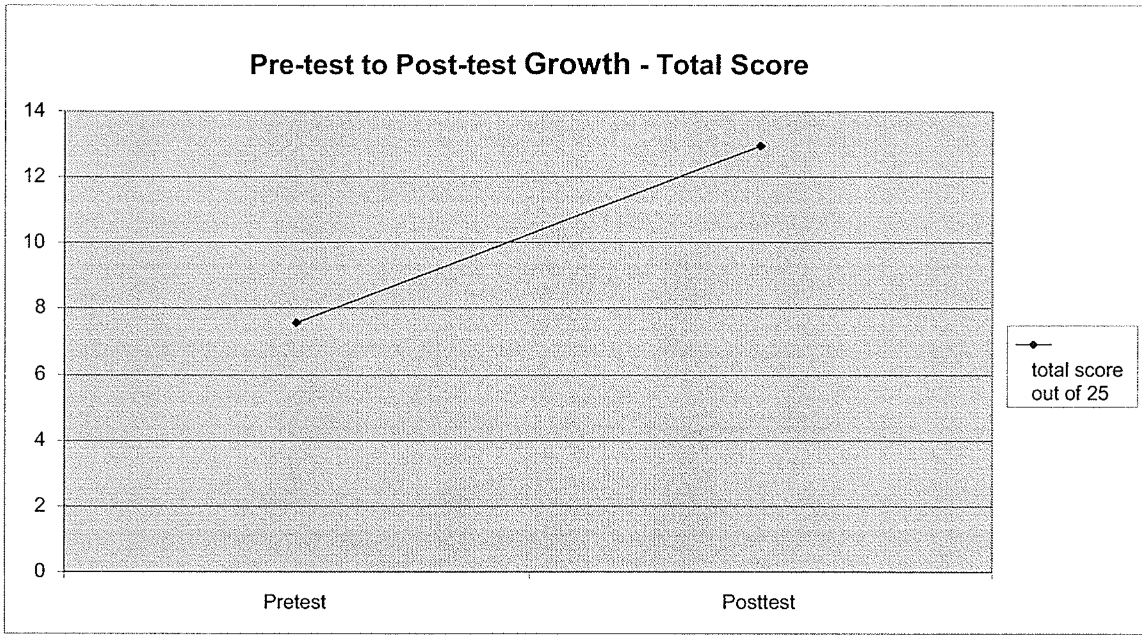
4.5.1b – The Time variable for the 25 Multiple-Choice Questions

Table 4.2 and Figure 4.2 will present the mean total scores on the pre-test and post-test measure and will show the means and standard deviations (in brackets).

Table 4.2 – Time Analysis Chart for the Full 25 Multiple-Choice Questions

The Full 25 Multiple-Choice Questions	Pre-test	Post-test
Total Score	7.55 (2.77)	12.94 (4.12)

Figure 4.2 – Time Analysis Graph for the Full 25 Multiple-Choice Questions



. Not surprisingly, these data show a significant growth in total scores from pre- to post-test, $F_{(1,65)} = 103.62, p < 0.001$. This is to be expected as the students had very little understanding or previous learning on the subject of electrochemical and electrolytic cells.

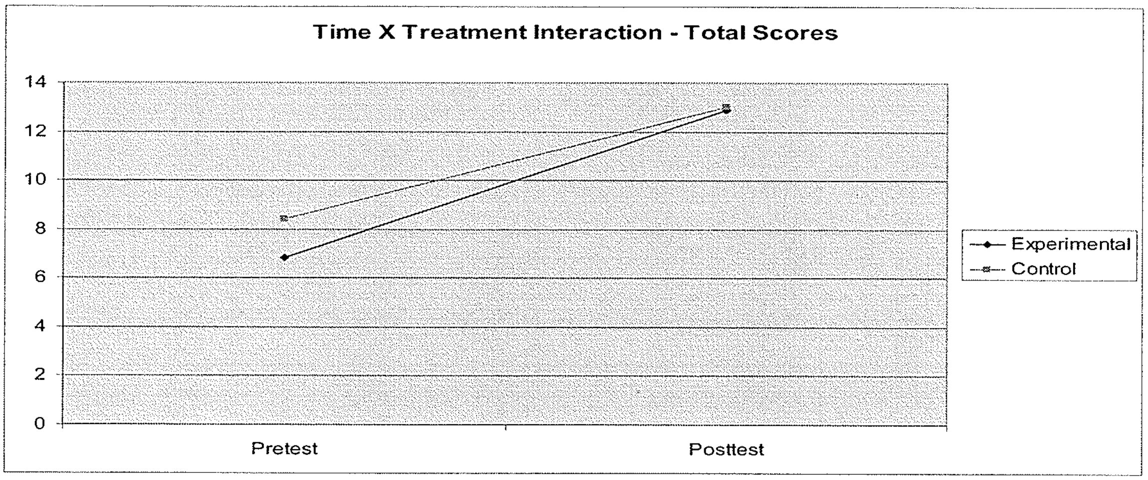
4.5.1c – The Time by Treatment Interaction for the 25 Multiple-Choice Questions

Table 4.3 and Figure 4.3 will present the time by treatment interaction for the full 25 multiple-choice questions.

Table 4.3 – Time by Treatment Interaction Chart for the 25 Multiple-Choice Questions

The Full Test Multiple-Choice Questions	Pre-test	Post-test
Control Group	8.44 (2.78)	13.02 (4.16)
Experimental Group	6.83 (2.57)	12.88 (4.14)

Figure 4.3 – Time by Treatment Interaction Graph for the 25 Multiple-Choice Questions



Both groups (experimental and control) increased their mean scores over time: there was no significant difference between the two groups, $F_{(1, 65)} = 0.59, p > 0.05$ over time.

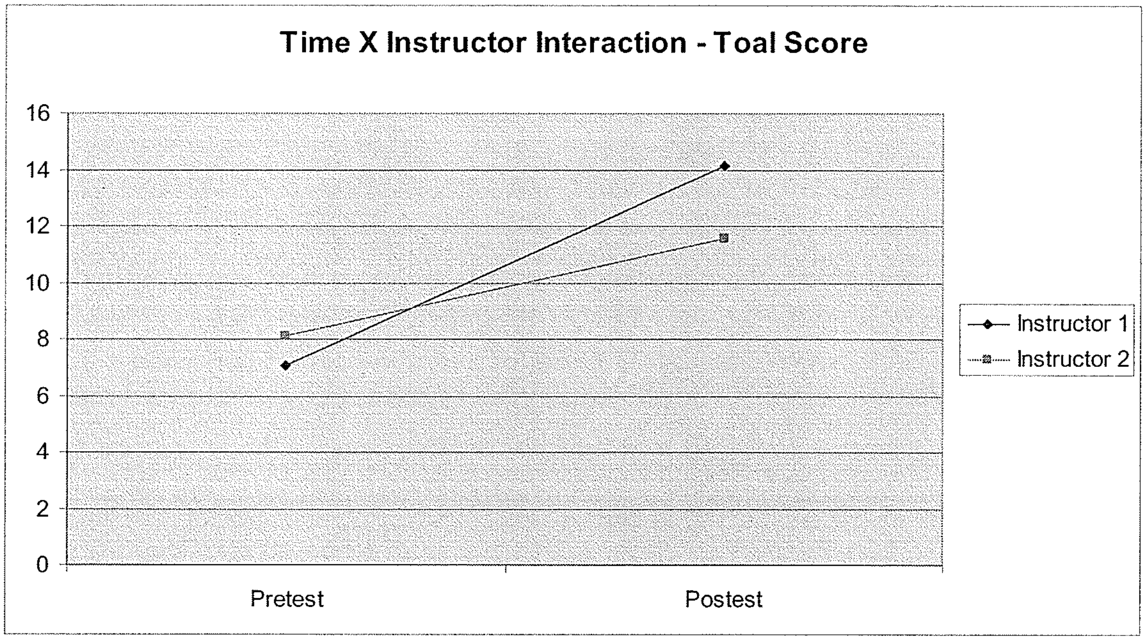
4.5.1d – The Time by Instructor Interaction for the 25 Multiple-Choice Questions

The time by instructor interaction will be presented in Table 4.4 and Figure 4.4

Table 4.4 – Time by Instructor Interaction Chart for the 25 Multiple-Choice Questions

The Full Test Multiple-Choice Questions	Pre-test	Post-test
Instructor 1	7.07 (2.68)	14.12 (4.52)
Instructor 2	8.11 (2.80)	11.58 (3.15)

Figure 4.4 – Time by Treatment Interaction Graph for the 25 Multiple-Choice Questions



The difference in growth was significant for this interaction, $F(1,65) = 11.304$, $p=0.001$. That is to say that there was a significant difference in the total scores on the pre-test to post-test between the two instructors

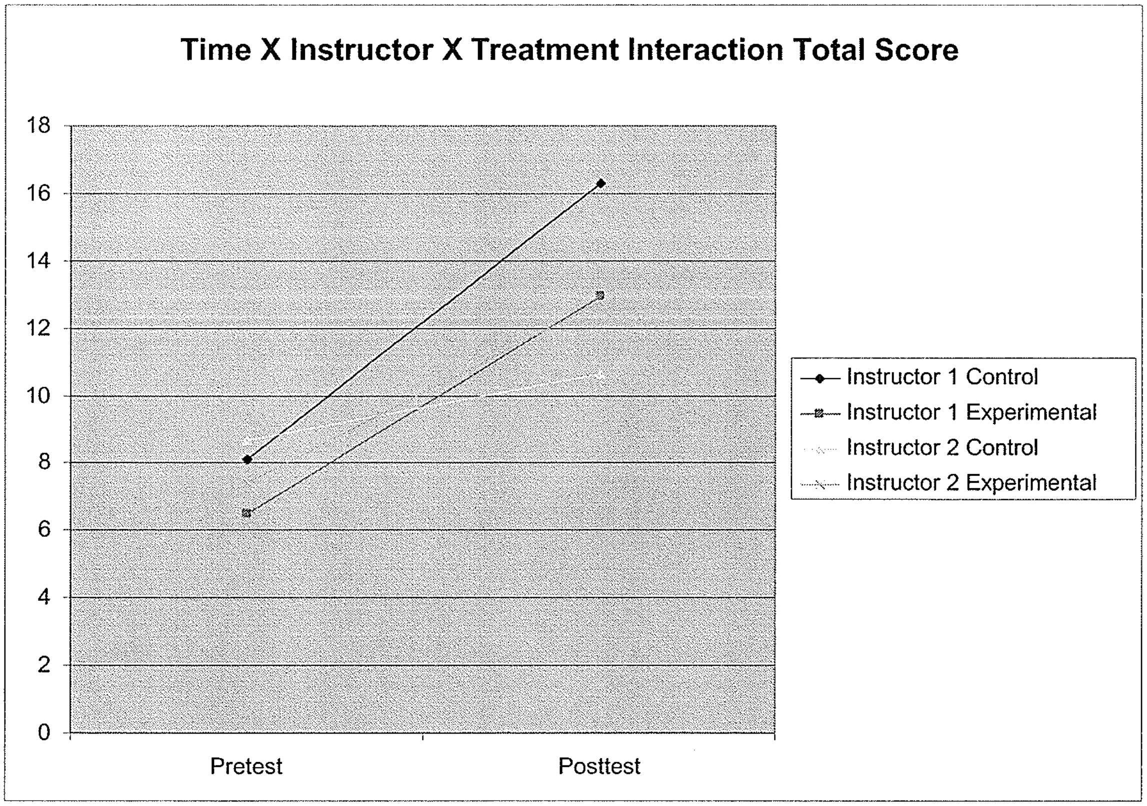
4.5.1e – The Time by Treatment by Instructor Interaction for the 25 Multiple-Choice Questions

The interaction between the treatment, instructor, and time variables are presented in the following chart and graph. Instructor 1 was the teacher-researcher and instructor 2 was a teacher colleague of similar academic background and experience but not involved in the research analysis. The control group was taught the Electrochemistry Unit without the model while the experimental group was taught the unit with the assistance of the model manipulation. The time by treatment by instructor interaction will be shown in Table 4.5 and Figure 4.5.

Table 4.5 – Time by Treatment by Instructor Interaction Chart for the Full 25 Multiple-Choice Questions

The Full 25 Multiple-Choice Questions		Pre-Test	Post-Test
Control Group	Instructor 1	8.12 (2.29)	16.31 (3.13)
	Instructor 2	8.67 (3.13)	10.64 (3.06)
Experimental Group	Instructor 1	6.50 (2.74)	12.94 (4.77)
	Instructor 2	7.39 (2.22)	12.79 (2.93)

Figure 4.5 - Time by Treatment by Instructor Interaction Graph for the Full 25 Multiple-Choice Questions



On the full test multiple-choice questions, a significant interaction result was found, $F_{(1,65)} = 5.74, p = 0.02$. This is likely attributable to the difference between instructor 1 and instructor 2. In fact, upon further analysis, when the within-subjects analysis was done for only Instructor 2, there was a significant result for the time by treatment interaction.

Table 4.6 Analysis of Variance of the 25 Multiple-Choice Questions for Instructor 2

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	236.234	1	236.234	25.661	.000
Time * Treatment	39.477	1	39.477	4.288	.047*
Error	285.387	31	9.206		

4.5.2 – Open – Ended Question 1

This sub-section will look first at the open-ended question that asked the students to draw an electrolytic cell with four distinct parts. The question was scored using a rubric from zero to four (Appendix 3).

4.5.2a –ANOVA Table for Open-Ended Question 1

The following table will illustrate the between-subject effects and the within-subject effects for open-ended question 1. The table will include the sum of squares, the degrees of freedom, the mean squared value, the F value, and the significance level.

Table 4.7 ANOVA of Open-Ended Question 1

ANALYSIS OF VARIANCE OF OPEN-ENDED QUESTION 1 MEASURE					
Source	**S/S**	**d/f**	**Mean Squared**	**F**	**Sig.**
Between Subject Variables					
Treatment	2.51	1	2.51	3.93	0.05
Instructor	0.27	1	0.27	0.42	0.52
Treatment X Instructor	0.32	1	0.32	0.51	0.48
Error	41.46	65	0.64		
Within Subject Variables					
Time	331.93	1	331.93	544.06	<.001*
Time X Treatment	0.2	1	0.2	0.33	0.57
Time X Instructor	4.87	1	4.87	7.98	0.006*
Time X Treatment X Instructor	0.44	1	0.44	0.71	0.4
Error	39.66	65	0.61		

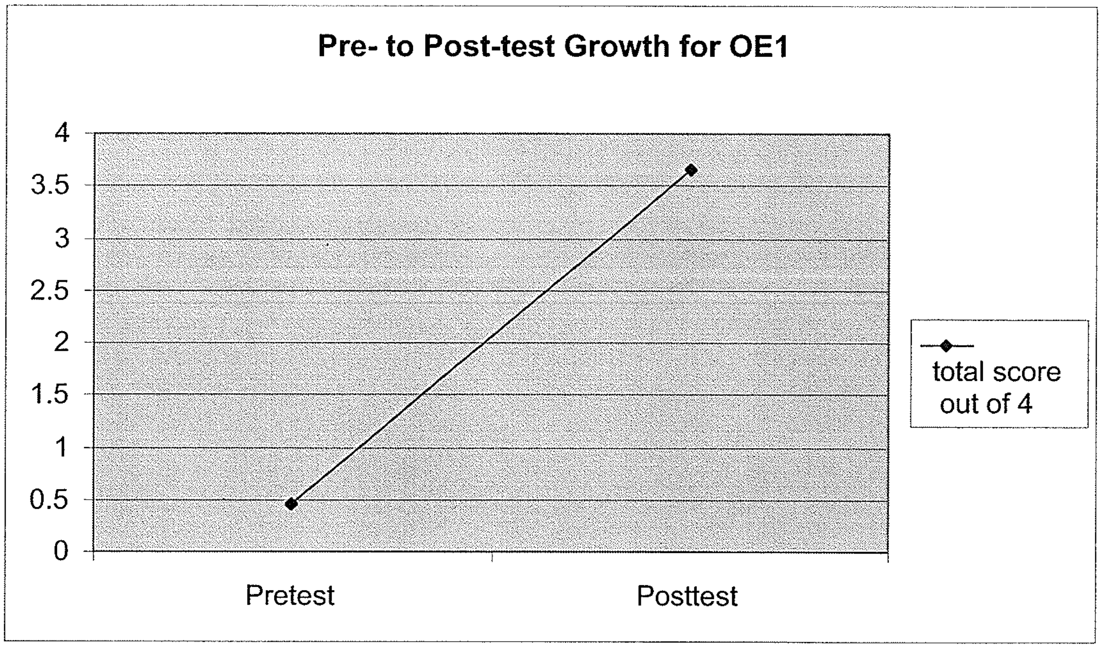
4.5.2b – The Time variable for Open-Ended Question 1

The mean total scores over time are reported in Table 4.8 along with the standard deviations in brackets and the same data is graphically displayed in Figure 4.8.

Table 4.8 - Time Analysis Chart for Open-Ended Question 1

Open-Ended Question 1	Pre-test	Post-test
Total Score	0.46 (0.90)	3.67 (0.72)

Figure 4.8 – Time Analysis Graph for Open-Ended Question 1



Again, these data showed a significant result for the total score over time, $F_{(1, 65)} =$ 544.06, $p < 0.001$. Students had very little exposure to electrochemical cells prior to the Electrochemistry Unit and therefore scored low on the pre-test (M= 0.46). However, with the instruction of the electrochemical cell section of the unit, student scores significantly increased on the post-test (M= 3.67).

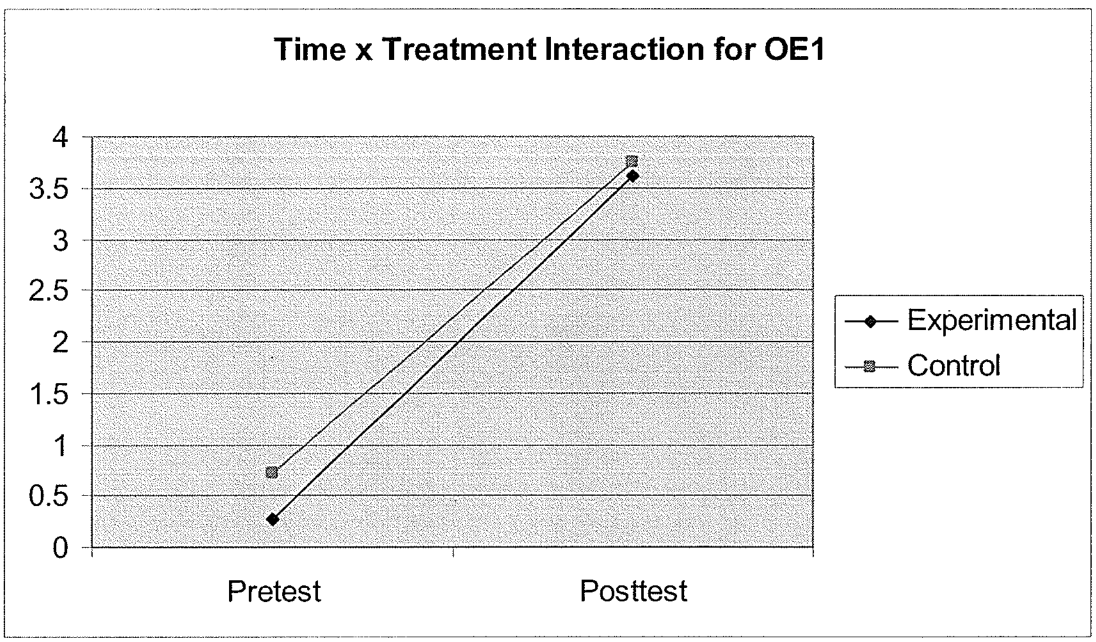
4.5.2c – The Time by Treatment Interaction for Open-Ended Question 1

Again the means are reported along with the standard deviations in brackets in Table 4.9. Figure 4.9 follows with a graphical representation of the differences in means over time.

Table 4.9 - Time by Treatment Interaction Chart for Open-Ended Question 1

Open-Ended Question 1	Pre-test	Post-test
Control Group	0.71 (0.94)	3.74 (0.77)
Experimental Group	0.26 (0.83)	3.61 (0.68)

Figure 4.9 - Time by Treatment Interaction Graph for Open-Ended Question 1



Similar to the multiple-choice questions, the two groups had increased their understanding of electrochemical and electrolytic cells over time but their mean-score differences were not significant, $F_{(1, 65)} = 0.33, p > 0.05$.

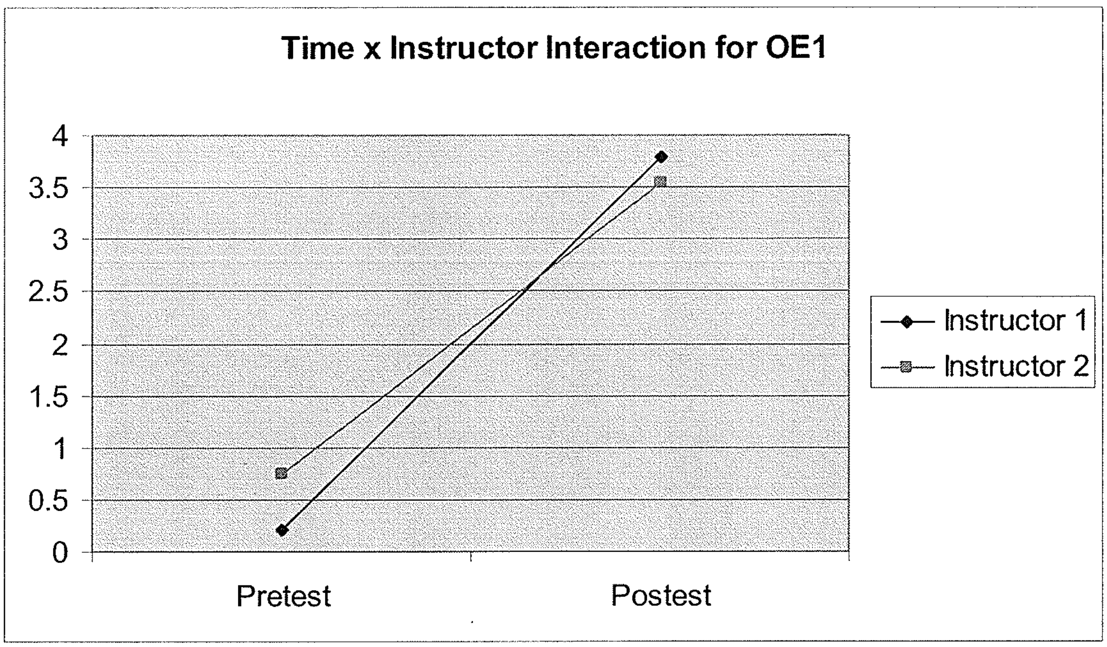
4.5.2d – The Time by Instructor Interaction for Open-Ended Question 1

There were two instructors for this study so their interaction over time will be analyzed in this section. Table 4.10 and Figure 4.10 will display this interaction.

Table 4.10 - Time by Instructor Interaction Chart for Open-Ended Question 1

Open-Ended Question 1	Pre-test	Post-test
Instructor 1	0.22 (0.63)	3.78 (0.42)
Instructor 2	0.75 (1.08)	3.53 (0.95)

Figure 4.10 - Time by Instructor Interaction Graph for Open-Ended Question 1



There was a significant interaction between the instructor and time variables for open-ended question 1, $F_{(1, 65)} = 7.98$, p=0.006. This is due to the fact that the students taught by instructor 1 had a greater change in pre-to post-test scores than the students taught by instructor 2. Although the scores for all four groups seem similar, there was enough of a mean-score increase difference between the two instructors from pre- to post-test to provide a significant result in that respect.

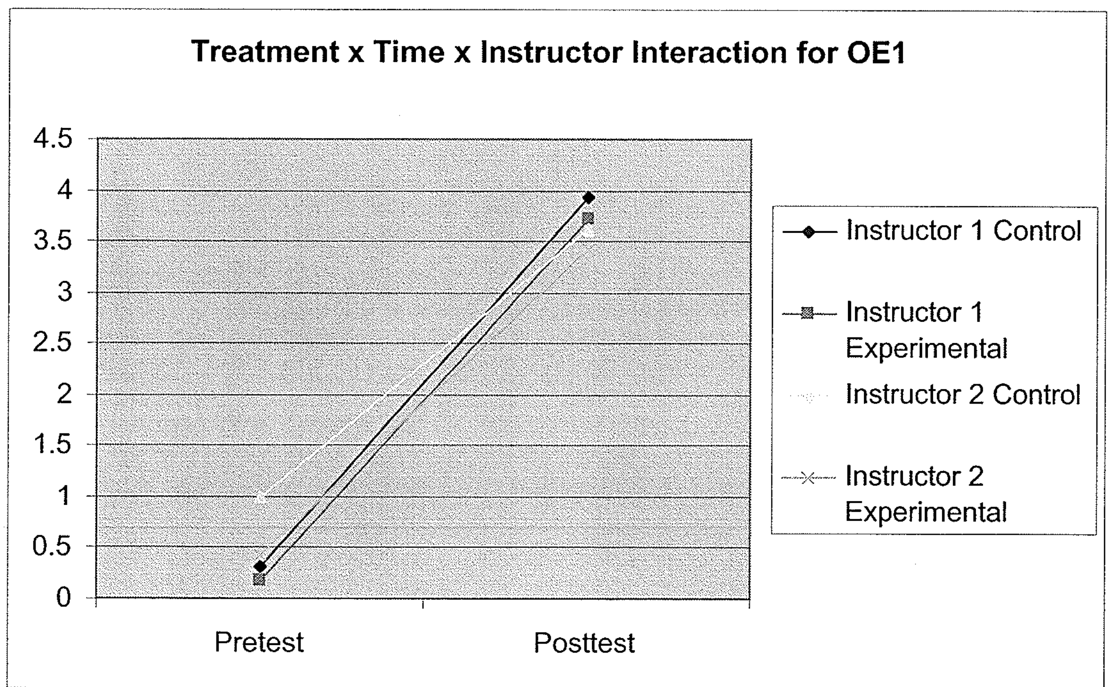
4.5.2e – The Time by Treatment by Instructor Interaction for Open-Ended Question 1

Students in all groups would have had very little experience with the drawing of electrochemical cells prior to the Electrochemistry Unit. Therefore, it would be expected that the mean scores on the pre-test would be low for all four groups in this analysis. The means and standard deviations for the three-way analysis of open-ended question 1 are displayed in Table 4.11 and then plotted out in Figure 4.11.

Table 4.11 – Time by Treatment by Instructor Interaction Chart for Open-Ended Question 1

Open-Ended Question 1		Pre-Test	Post-Test
Control Group	Instructor 1	0.31 (0.63)	3.92 (0.28)
	Instructor 2	1.00 (1.03)	3.61 (0.98)
Experimental Group	Instructor 1	0.17 (0.64)	3.71 (0.46)
	Instructor 2	0.43 (1.09)	3.43 (0.94)

Figure 4.11- Time by Treatment by Instructor Interaction Graph for Open-Ended Question 1



The analysis of the time by treatment by instructor interaction for open-ended question 1 did not have a significant difference, $F_{(1,65)} = 0.74, p > 0.05$. That is, the mean scores for all four groups increased at a similar rate whether or not the students used the model or not.

4.5.3 – Open – Ended Question 2

This question asked the students to draw an electrolytic cell with four distinct parts. Again, this section was marked using a rubric out of four (Appendix 3).

4.5.3a –ANOVA Table for Open-Ended Question 2

Table 4.12 presents the results for open-ended question 2 of both the between-subject effects and within-subject effects. The sum of squares, degrees of freedom, mean square, F value, and significance have been included.

Table 4.12 ANOVA of Open-Ended Question 2

ANALYSIS OF VARIANCE OF OPEN-ENDED QUESTION 2 MEASURE					
Source	**S/S**	**d/f**	**Mean Squared**	**F**	**Sig.**
Between Subject Variables					
Treatment	0.56	1	0.56	1.1	0.3
Instructor	11.07	1	11.07	21.58	<.001*
Treatment X Instructor	3.05	1	3.05	5.95	0.02*
Error	33.33	65	0.51		
Within Subject Variables					
Time	200.44	1	200.44	460.83	<.001*
Time X Treatment	0.05	1	0.05	0.12	0.73
Time X Instructor	5.88	1	5.88	13.52	<.001*
Time X Treatment X Instructor	0.3	1	0.3	0.69	0.41
Error	28.27	65	0.43		

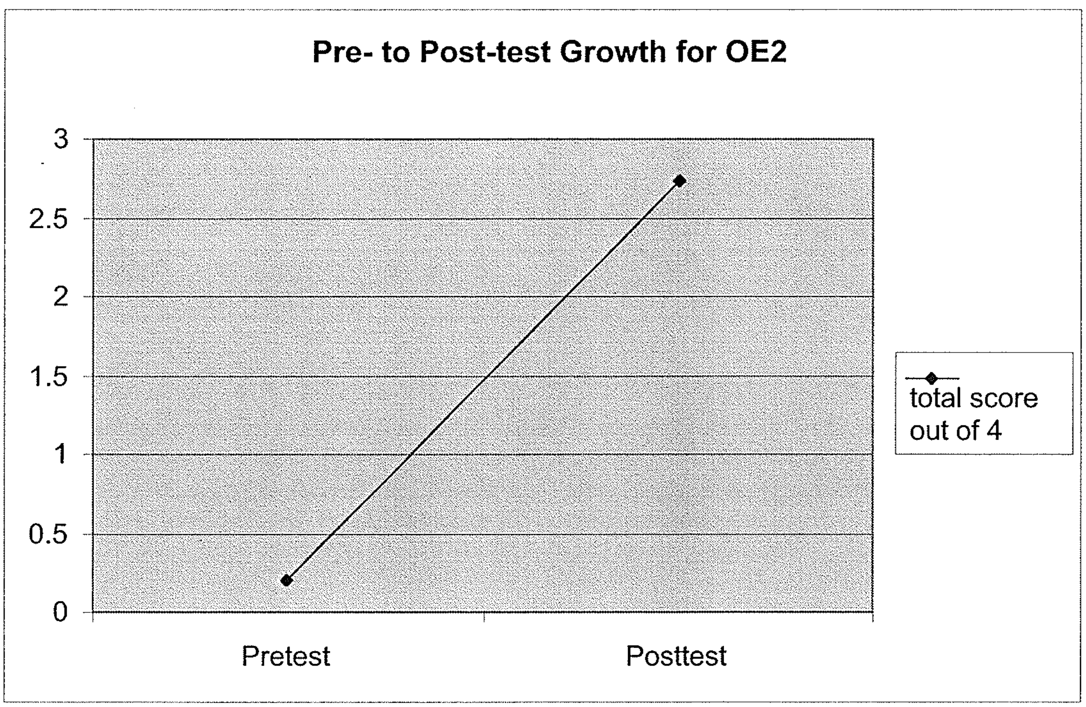
4.5.3b – The Time variable for Open-Ended Question 2

Open-ended question 2 had the students draw an electrolytic cell with four distinct components. The drawing was scored using a rubric from zero to four based on the number of correct components (Appendix 3). Table 4.13 reports the total score means and standard deviations over time for open-ended question two and Figure 4.13 displays this data graphically.

Table 4.13 - Time Analysis Chart for Open-Ended Question 2

Open-Ended Question 2	Pre-test	Post-test
Total Score	0.20 (0.50)	2.74 (0.98)

Figure 4.13 – Time Analysis Graph for Open-Ended Question 2



The data from this section of the pre-and post-tests also showed a significant mean effect, $F_{(1, 65)} = 460.83, p < 0.001$. That is to say, the students had little understanding of electrolytic cells prior to the unit (M= 0.20), but after the instructional sequence all students showed increased understanding by answering the question more correctly (*M*= 2.74).

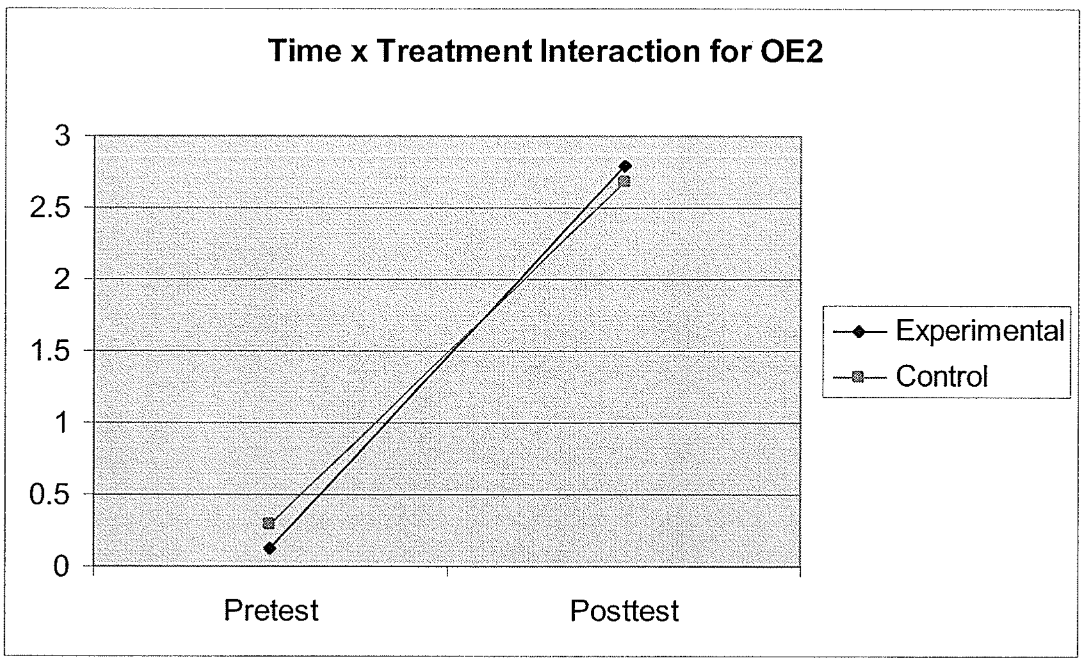
4.5.3c – The Time by Treatment Interaction for Open-Ended Question 2

Table 4.14 reports the means and standard deviations over time for open-ended question two and Figure 4.14 represents this data graphically.

Table 4.14 - Time by Treatment Interaction Chart for Open-Ended Question 2

Open-Ended Question 2	Pre-test	Post-test
Control Group	0.29 (0.59)	2.68 (0.97)
Experimental Group	0.13 (0.41)	2.79 (0.99)

Figure 4.14 - Time by Treatment Interaction Graph for Open-Ended Question 2



Open-ended question 2 showed no significant difference between the two groups over time, $F_{(1,65)} = 0.12, p > 0.05$. Even though the students in both groups increased in their mean scores from pre-test to post-test, there was no significant difference in growth patterns whether the students were in the control or experimental groups.

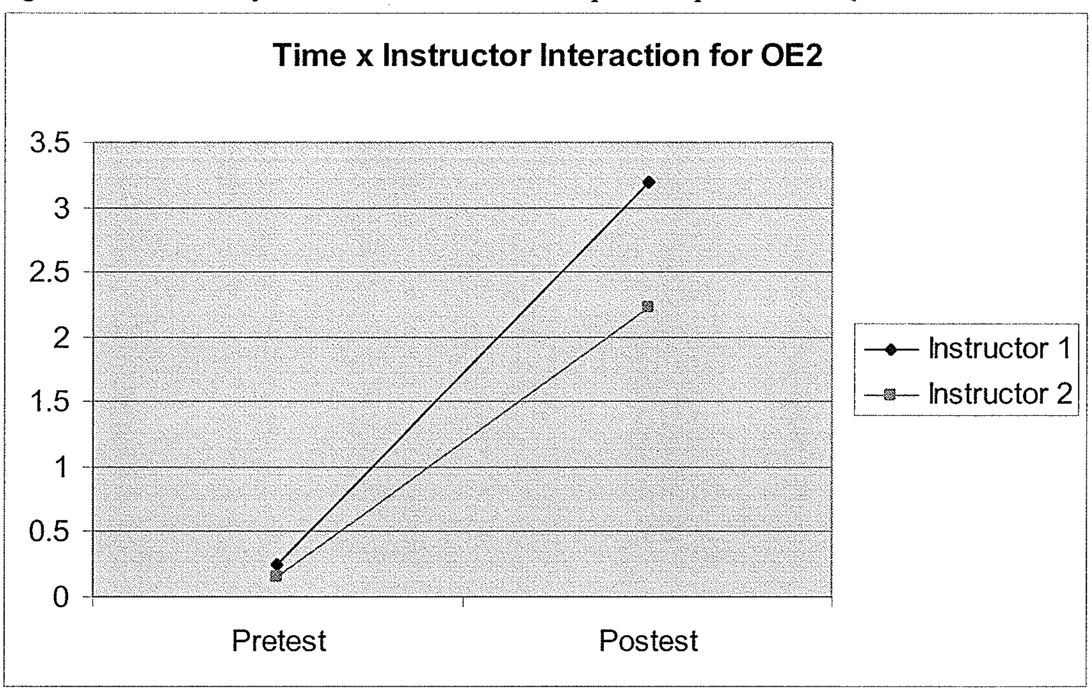
4.5.3d – The Time by Instructor Interaction for Open-Ended Question 2

Again, the time by instructor interaction will be evaluated using Table 4.15 and Figure 4.15. Please note that the standard deviations are in brackets under the mean scores.

Table 4.15 - Time by Instructor Interaction Chart for Open-Ended Question 2

Open-Ended Question 2	Pre-test	Post-test
Instructor 1	0.24 (0.55)	3.19 (0.69)
Instructor 2	0.16 (0.45)	2.22 (1.01)

Figure 4.15 - Time by Instructor Interaction Graph for Open-Ended Question 2



The students taught by instructor 1 did better on the post-test than the students taught by instructor 2. Upon further analysis it was found that there was a significant difference between the instructor and time variables, $F_{(1, 65)} = 13.52, p < 0.001$.

4.5.3e – The Time by Treatment by Instructor Interaction for Open-Ended Question 2

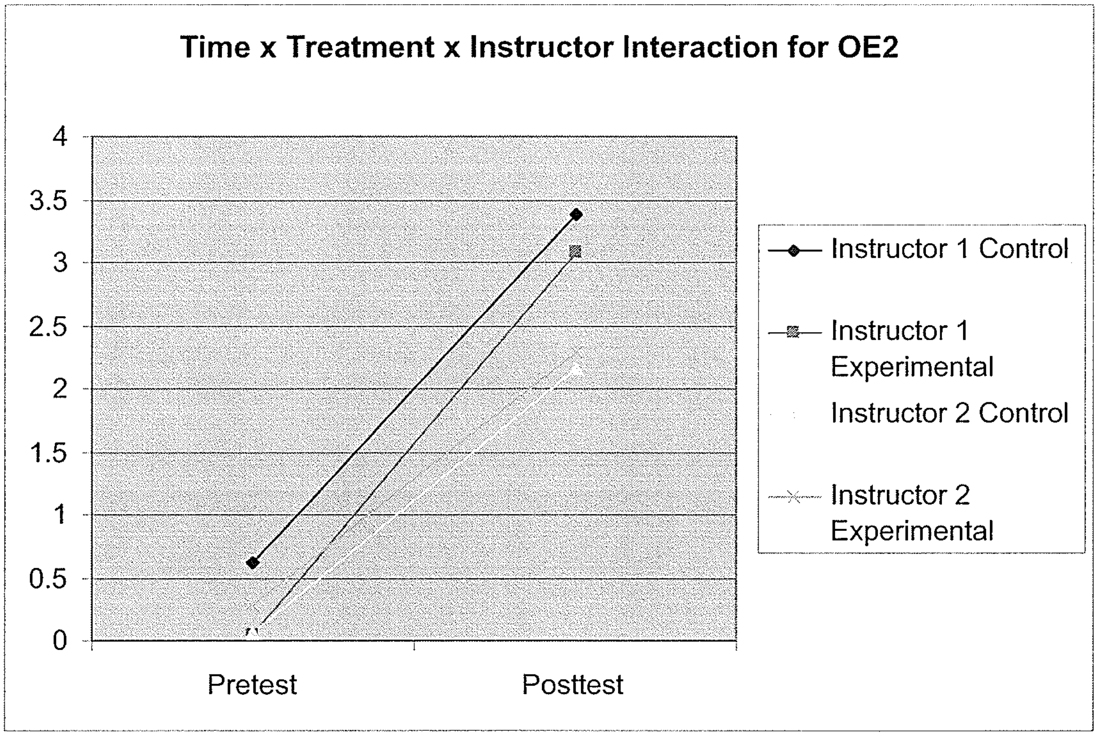
Open-ended question 2 had the students draw an electrolytic cell with four distinct components. As expected, the pre-test mean scores were low due to students' lack of understanding of the topic. However, it was expected that the post-test results would be significantly different for the experimental group who had the opportunity to manipulate the model of an electrolytic cell. The means and standard deviations for open-ended question 2 are reported in Table 4.16 and then drawn out in Figure 4.16.

Table 4.16 – Time by Treatment by Instructor Interaction Chart for Open-Ended Question 2

Open-Ended Question 2		Pre-Test	Post-Test
Control Group	Instructor 1	0.62 (0.77)	3.38 (0.46)
	Instructor 2	0.06 (0.24)	2.17 (0.92)
Experimental Group	Instructor 1	0.04 (0.20)	3.08 (0.78)
	Instructor 2	0.29 (0.61)	2.29 (1.14)

Like the results for the open-ended question 1, the analysis of open-ended question 2 did not show a significant interaction between the three variables of time, treatment, and instructor, $F_{(1, 65)} = 0.69, p > 0.05$. All students did poorly on the pre-test drawing, and they all did approximately the same as each other on the post-test drawing.

Figure 4.16 - Time by Treatment by Instructor Interaction Graph for Open-Ended Question 2



4.5.4 – The Nine Multiple-Choice Questions

From the 25 multiple-choice questions, nine were chosen that best represented the particulate level of Chemistry learning and understanding addressed by the model used in the intervention. These nine questions were 3, 4, 9, 11, 13, 14, 22, 24, and 25. These questions focused on the molecules, ions, and electrons in electrochemical and electrolytic cells.

4.5.4a –ANOVA Table for the Nine Multiple-Choice Questions

Table 4.17 presents the results for open-ended question 2 of both the between-subject effects and within-subject effects. The sum of squares, degrees of freedom, mean square, F value, and significance have been included.

Table 4.17 – ANOVA of the Nine Multiple-Choice Questions

ANALYSIS OF VARIANCE OF THE NINE MULTIPLE CHOICE QUESTIONS MEASURE					
Source	**S/S**	**d/f**	**Mean Squared**	**F**	**Sig.**
Between Subject Variables					
Treatment	2.61	1	2.61	0.75	<.001*
Instructor	24.07	1	24.07	6.87	0.011*
Treatment X Instructor	0.03	1	0.03	0.008	0.93
Error	227.8	65	3.51		
Within Subject Variables					
Time	205.93	1	205.93	104.95	<.001*
Time X Treatment	0.01	1	0.01	0.006	0.94
Time X Instructor	30.94	1	30.94	15.77	<.001*
Time X Treatment X Instructor	2.91	1	2.91	1.48	0.23
Error	127.55	65	1.96		

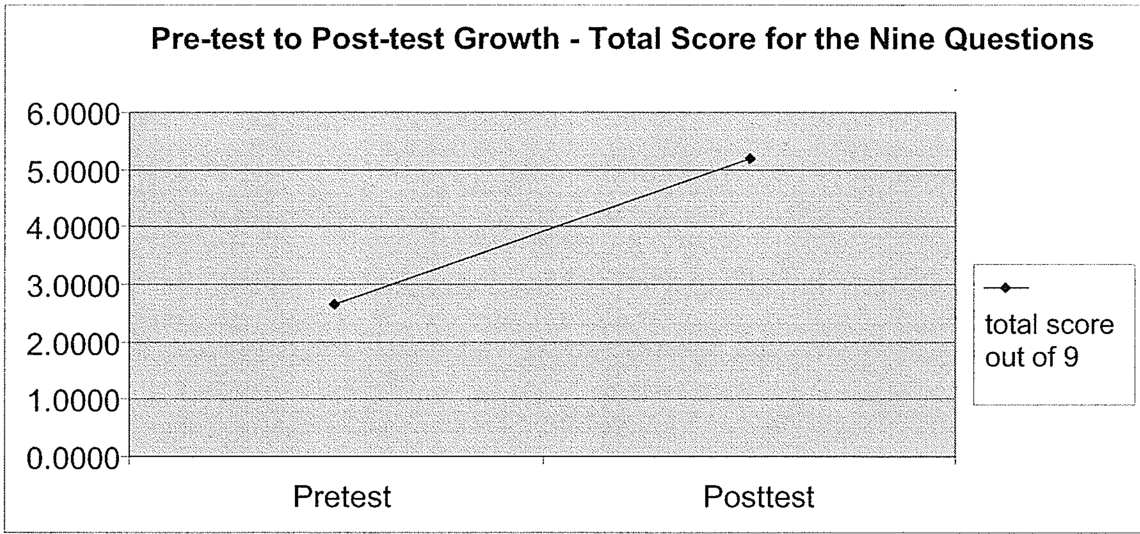
4.5.2b – The Time variable for the Nine Multiple-Choice Questions

As mentioned, from the full test of 25 multiple-choice questions, nine questions focused more closely on the particulate nature of Chemistry learning and understanding. These nine questions were 3, 4, 9, 11, 13, 14, 22, 24, and 25. They were tallied and the total scores are reported as means with standard deviations followed in brackets in Table 4.18. The data are presented graphically in Figure 4.18.

Table 4.18 - Time Analysis Chart for the Nine Multiple-Choice Questions

The Nine Multiple-Choice Questions	Pre-test	Post-test
Total Score	2.67 (1.52)	5.19 (1.94)

Figure 4.18 – Time Analysis Graph for the Nine Multiple-Choice Questions



For the questions that focused on the particulate nature of Chemistry learning and understanding there was a significant difference between pre-and post-test scores, $F_{(1, 65)} = 104.95$, $p < 0.001$. In other words, student understanding increased significantly from pre-test, $M = 2.67$, to post-test, $M = 5.19$ on questions 3, 4, 9, 11, 13, 14, 22, 24, and 25.

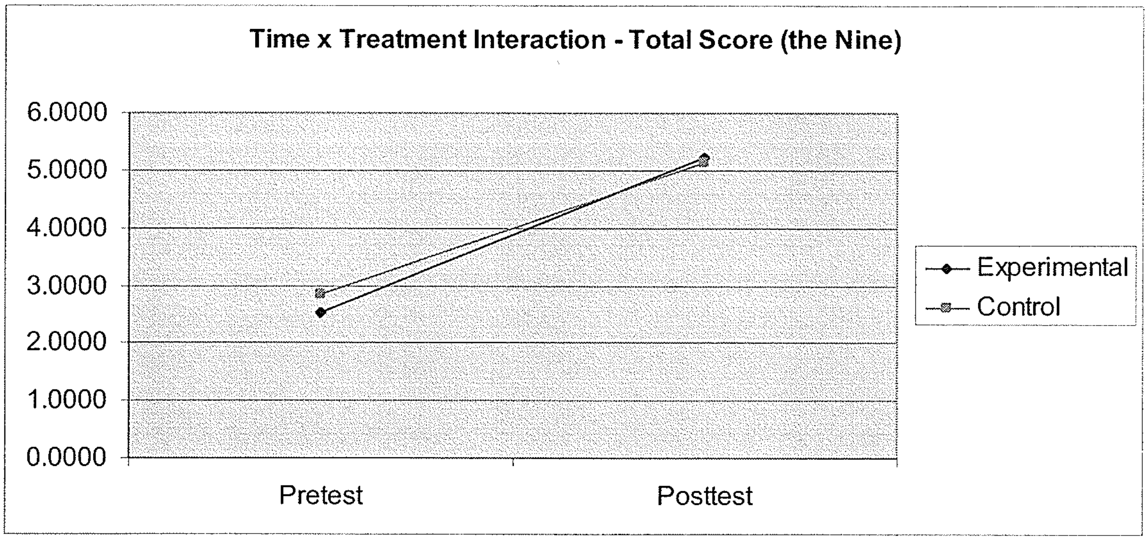
4.5.4c – The Time by Treatment Interaction for the Nine Multiple-Choice Questions

Table 4.19 and Figure 4.19 represent the mean scores of the two groups over time.

Table 4.19 - Time by Treatment Interaction Chart for the Nine Multiple-Choice Questions

The Nine Multiple-Choice Questions	Pre-test	Post-test
Control Group	2.84 (1.53)	5.13 (2.14)
Experimental Group	2.53 (1.52)	5.24 (1.79)

Figure 4.19 - Time by Treatment Interaction Graph for the Nine Multiple-Choice Questions



The data for the nine multiple-choice questions mirror that of the full 25 multiple-choice questions in that while student understanding increased from pre-to post-test, the increase was not significant for the control versus experimental groups, $F_{(1, 65)} = 0.006$, $p > 0.05$. So, with the use of the model, the experimental group of students did not significantly increase their mean scores over the mean scores of the students in the control group who did not manipulate a model.

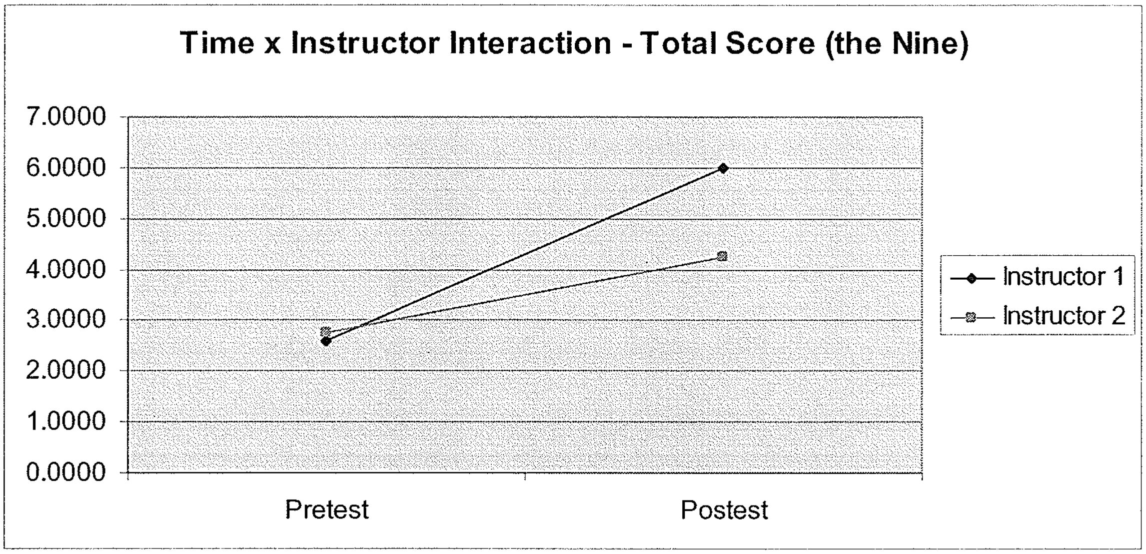
4.5.4d – The Time by Instructor Interaction for the Nine Multiple-Choice Questions

The time by instructor interaction will be detailed in Table 4.20 and Figure 4.20.

Table 4.20 - Time by Instructor Interaction Chart for the Nine Multiple-Choice Questions

The Nine Multiple-Choice Questions	Pre-test	Post-test
Instructor 1	2.59 (1.50)	6.00 (1.56)
Instructor 2	2.75 (1.57)	4.25 (1.93)

Figure 4.20 - Time by Instructor Interaction Graph for the Nine Multiple-Choice Questions



There is a significant interaction between time and instructor, $F_{(1, 65)} = 15.77, p < 0.001$. This is explained by the fact that although the students in all four groups had similar pre-test scores, the students taught by instructor 1 had significantly higher scores on the post-test than those students taught by instructor 2.

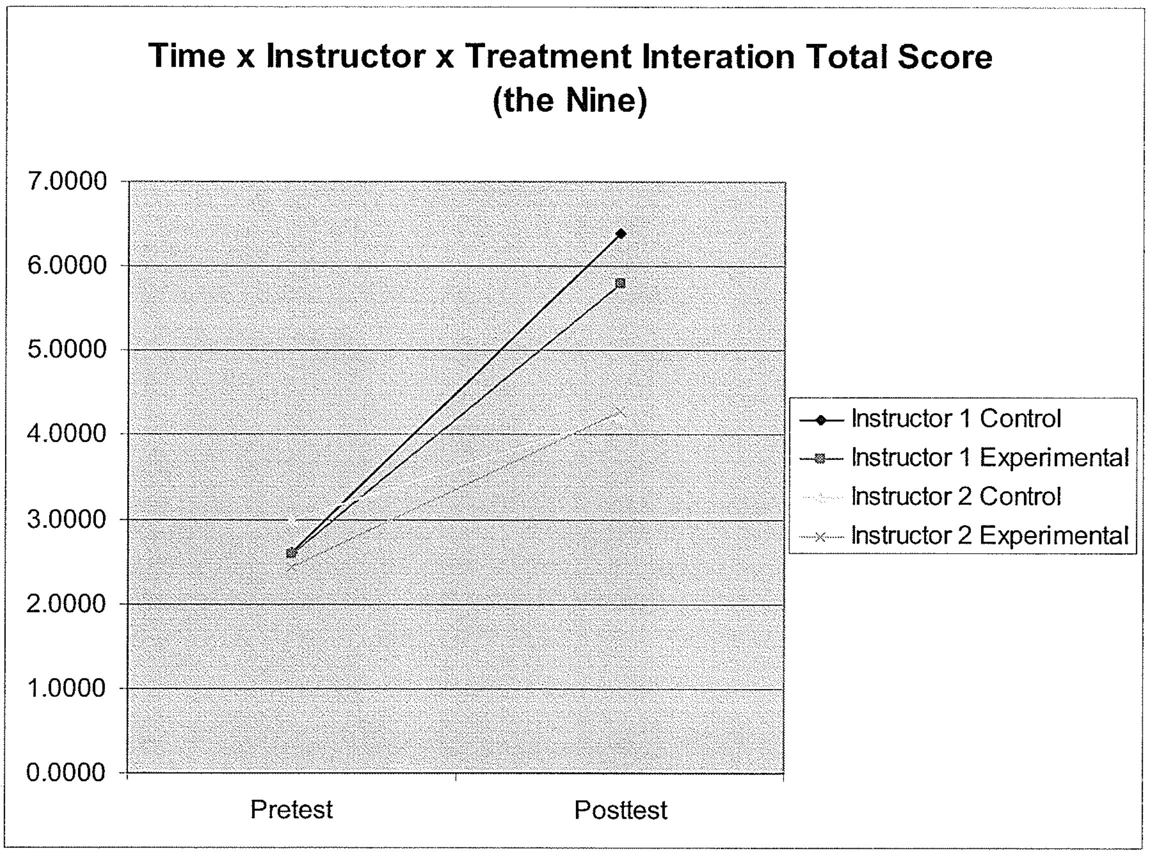
4.5.4e – The Time by Treatment by Instructor Interaction for the Nine Multiple-Choice Questions

From the full test of 25 multiple-choice questions, nine were further analyzed for significant interaction between the three variables of time, treatment and instructor. Since these nine questions had to do with the focus on the particulate nature of learning of Chemistry and the full test multiple-choice questions had significant results, it was expected that the same would occur for this sub-category of multiple-choice questions. As was done for the full test 25 multiple-choice questions, the means and standard deviations for the nine questions will be detailed in Table 4.21 and Figure 4.21 will show the graph that corresponds to this data.

Table 4.21 – Time by Treatment by Instructor Interaction Chart for the Nine Multiple-Choice Questions

The Nine Multiple-Choice Questions		Pre-Test	Post-Test
Control Group	Instructor 1	2.62 (1.61)	6.38 (1.39)
	Instructor 2	3.00 (1.50)	4.22 (2.16)
Experimental Group	Instructor 1	2.58 (1.47)	5.79 (1.64)
	Instructor 2	2.43 (1.65)	4.29 (1.68)

Figure 4.21 - Time by Treatment by Instructor Interaction Graph for the Nine Multiple-Choice Questions



It is interesting to note that although the mean scores for the pre- and post-test scores 25 multiple-choice questions were significantly different, for the nine multiple-choice questions the pre- and post-test scores were not, $F_{(1, 65)} = 1.48, p > 0.05$.

4.5.5 – The Six Multiple-Choice Questions

From the original 25 multiple-questions, the nine multiple-choice questions were further reduced to six multiple-choice questions for analysis. The six questions were the questions in the test that were most closely related to the model manipulation. That is to say the six questions were directly addressed by the model manipulation lab script (Appendix 2).

4.5.5a –ANOVA Table for the Six Multiple-Choice Questions

Table 4.22 presents the results for open-ended question 2 of both the between-subject effects and within-subject effects. The sum of squares, degrees of freedom, mean square, F value, and significance have been included.

Table 4.22 – ANOVA of the Nine Multiple-Choice Questions

ANALYSIS OF VARIANCE OF THE SIX MULIPLE CHOICE QUESTIONS MEASURE					
Source	**S/S**	**d/f**	**Mean Squared**	**F**	**Sig.**
Between Subject Variables					
Treatment	2.73	1	2.73	1.38	0.25
Instructor	11.41	1	11.41	5.74	0.02*
Treatment X Instructor	0.007	1	0.007	0.004	0.95
Error	127.25	64	1.99		
Within Subject Variables					
Time	81.73	1	81.73	67.86	<.001*
Time X Treatment	1.45	1	1.45	1.2	0.28
Time X Instructor	6.81	1	6.81	5.65	0.02*
Time X Treatment X Instructor	0.24	1	0.24	0.2	0.66
Error	77.08	64	1.2		

4.5.5b – The Time variable for the Six Multiple-Choice Questions

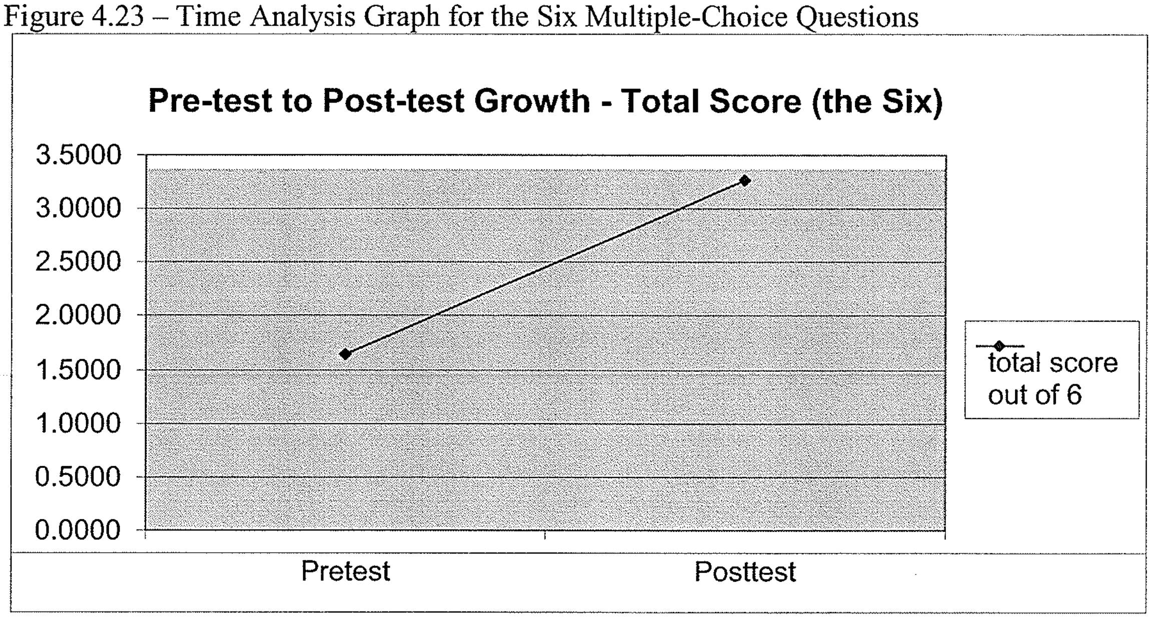
Using further analysis, the nine questions from the previous sub-section were broken down into six questions that were directly taught using the model manipulation. Although the treatment variable was not part of the time main effect, the researcher performed the analysis on the six questions for the sake of consistency. The means and standard deviations for questions 3, 9, 11, 13, 14, and 22 are reported in Table 4.23 and the graph of total score versus time follows in Figure 4.23.

Table 4.23 - Time Analysis Chart for the Six Multiple-Choice Questions

The Six Multiple-Choice Questions	Pre-test	Post-test
Total Score	1.65 (1.08)	3.26 (1.49)

It follows since the full test 25 multiple-choice questions and the nine multiple-choice questions yielded significant results so would the six multiple-choice questions, $F_{(1,64)} = 67.86, p < 0.001$. That is to say that the students significantly increased their understanding of electrochemical and electrolytic cell from pre-test, $M = 1.65$, to post-test, $M = 3.26$.

Figure 4.23 – Time Analysis Graph for the Six Multiple-Choice Questions



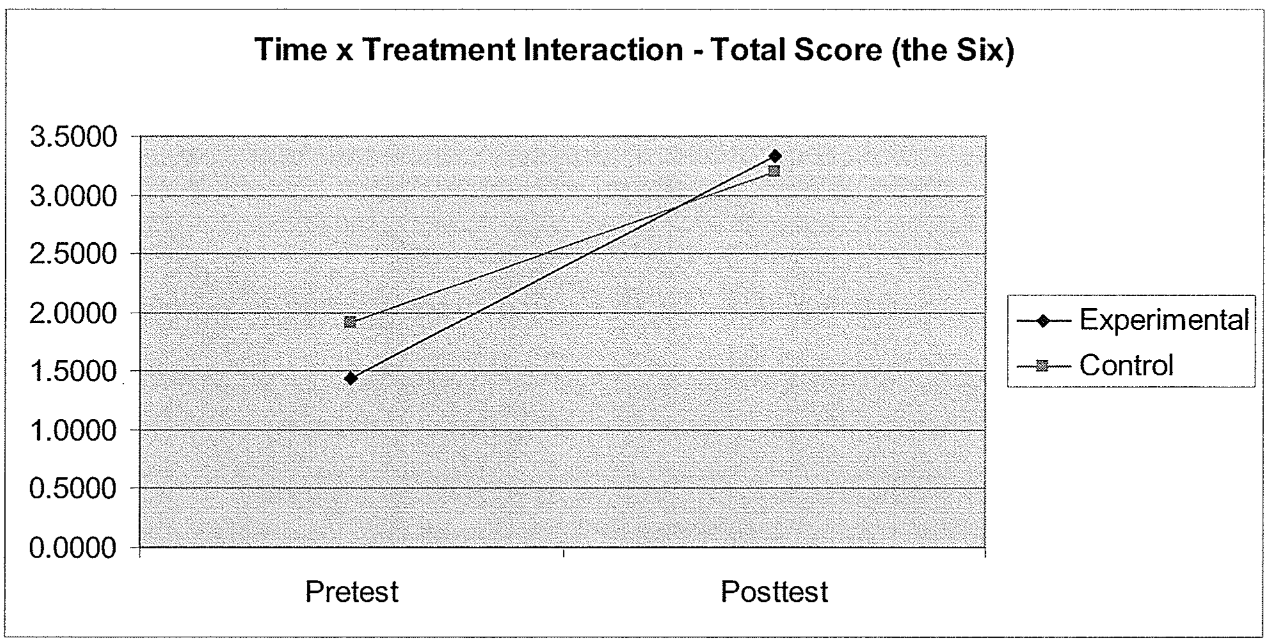
4.5.5c – The Time by Treatment Interaction for the Six Multiple-Choice Questions

Table 4.24 and Figure 4.24 display the changes over time in mean scores of the experimental and control groups for the six multiple-choice questions directly relating to the model manipulation.

Table 4.24 - Time by Treatment Interaction Chart for the Six Multiple-Choice Questions

The Six Multiple-Choice Questions	Pre-test	Post-test
Control Group	1.90 (1.14)	3.19 (1.68)
Experimental Group	1.43 (0.99)	3.32 (1.33)

Figure 4.24 - Time by Treatment Interaction Graph for the Six Multiple-Choice Questions



Although this graph shows that the experimental group finished with a higher mean than the control group, the growth differences from pre-test to post-test was not statistically significant result, $F_{(1,64)} = 1.20, p > 0.05$. So, while the experimental group had a higher end mean, both groups main similar gains in their understanding in the six multiple-choice questions.

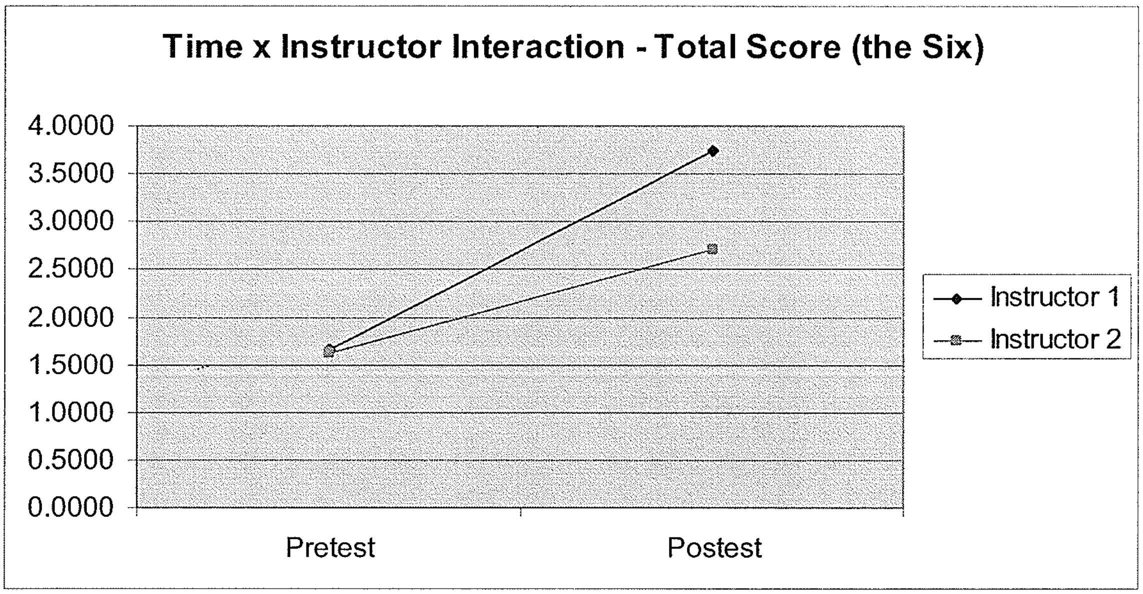
4.5.5d – The Time by Instructor Interaction for the Six Multiple-Choice Questions

The time by instructor interaction will be detailed in Table 4.25 and Figure 4.25.

Table 4.25 - Time by Instructor Interaction Chart for the Nine Multiple-Choice Questions

The Six Multiple-Choice Questions	Pre-test	Post-test
Instructor 1	1.67 (0.99)	3.75 (1.30)
Instructor 2	1.63 (1.18)	2.72 (1.53)

Figure 4.25 - Time by Instructor Interaction Graph for the Nine Multiple-Choice Questions



The students taught by instructor 1 obtained higher grades than the students taught by instructor 2. In other words, a significant difference was found between the time by instructor variables for total scores, $F_{(1.64)} = 5.65, p = 0.02$.

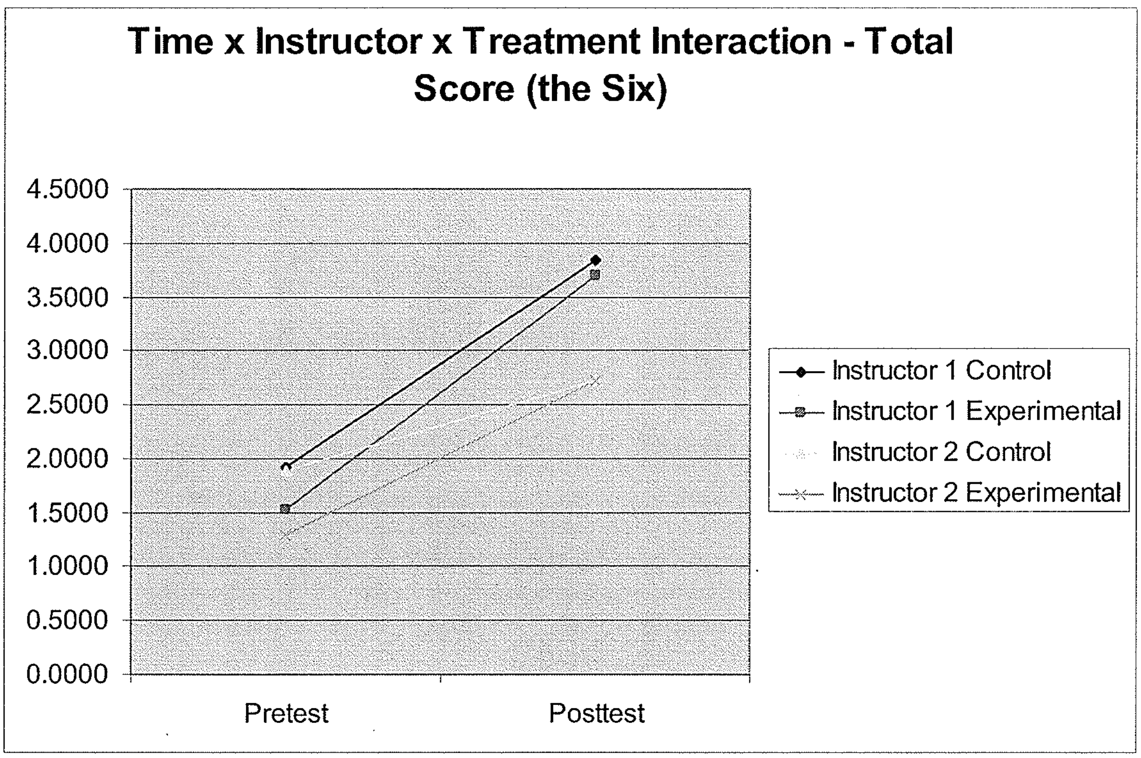
4.5.5e – The Time by Treatment by Instructor Interaction for the Six Multiple-Choice Questions

The six multiple-choice questions that were separated from the full 25 multiple choice questions had to do specifically with the model manipulation that the experimental groups performed. The means and standard deviations for the time by treatment by instructor interaction for the six multiple-choice questions are shown in Table 4.26. The same data are shown as a graph in Figure 4.26.

Table 4.26 – Time by Treatment by Instructor Interaction Chart for the Six Multiple-Choice Questions

The Six Multiple-Choice Questions		Pre-Test	Post-Test
Control Group	Instructor 1	1.92 (1.04)	3.85 (1.41)
	Instructor 2	1.89 (1.23)	2.72 (1.74)
Experimental Group	Instructor 1	1.52 (0.95)	3.70 (1.26)
	Instructor 2	1.29 (1.07)	2.71 (1.27)

Figure 4.26 - Time by Treatment by Instructor Interaction Graph for the Six Multiple-Choice Questions



There was a similar change in the pre-to post-test mean scores by all groups, in other words a significant result did not occur, $F_{(1,64)} = 0.199, p > 0.05$. Again, all students started with low mean scores and ended with higher mean scores.

4.6 Summary of Results

Of the five dependent variables, only the time variable and the time by instructor measures, proved to have significant interactions. That is to say, for the time interaction, there was a significant difference between the pre- and post- test scores in both the experimental treatment and control groups. This was not unexpected as the students in Chemistry 40S (Grade 12) have had little to no formal instruction on electrochemical and electrolytic cells. Therefore, it would follow that the pre-test scores would have been low on all parts of the test and, because of instruction there would be a significant increase in understanding on all parts of the post-test.

There was also a significant interaction between the instructor and time variables. That is, the students taught by instructor 1 and those taught by instructor 2 had significantly different results as a whole from pre-to post-test. This result will be discussed further in Chapter 5. When Instructor 2 was isolated for the time by treatment interaction, there was a significant difference. Again, this will be discussed in Chapter 5.

There were no significant different in student understanding of electrolytic and galvanic processes between the experimental treatment and control group students over time. As well, there was no significant difference between school/instructor treatment interactions over time.

The statistical results will now be discussed further in Chapter 5 that follows.

Chapter 5 – Conclusion

5.1 Introduction

Conclusions drawn from the statistical analysis of interactions between time, a treatment, and two instructors will be discussed in Chapter 5. As well, the chapter will conclude by providing an overview of the study by discussing the results of the study through a restatement of purpose and research questions, observations and limitations of the study, a summary of results by research question, implications for further research and teaching, and a final conclusion.

5.2 Restatement of Purpose

In order to have success in Chemistry, students need to have experience with the three levels of Chemistry learning and understanding, the macroscopic, the symbolic, and the particulate (Johnstone, 1991). Although Jonstone's assertion has been voiced for the past 20 years, the focus of Manitoba curricula until most recently has been on the macroscopic, which emphasizes laboratory activities, and the symbolic, which emphasizes chemical formulae and calculations. To have a full understanding of Chemistry, there should be a bridge between these two levels of instruction. This is suggested to be at the particulate level of Chemistry where the interactions of molecules, ions, and electrons can be visualized. In response to this relatively unsubstantiated by research claim by Johnstone, the purpose of this study was to investigate the effectiveness of a treatment strategy; a laboratory experiment involving model manipulation emphasizing the particulate level.

5.3 Restatement of Research Questions

Three research questions focused the analysis of the effectiveness of the treatment variable for this study:

a) Will there be a difference in understanding of electrolytic and galvanic processes between the experimental treatment and control group students over time?

b) Will there be a significant difference between the pre- and post- test scores in both the experimental treatment and control groups students?

c) Will there be a difference between school/instructor treatment interactions over time?

5.4 Summary of Results by Research Question

The effectiveness of this study was evaluated using a pre- and post-test analysis that was comprised of two open-ended questions and a 25 question multiple-choice section. These questions were evaluated by total score on five levels. The first was the full test 25 question multiple choice section, open-ended question 1, open-ended question 2, nine multiple choice questions pulled out of the full test, and six multiple choice questions pulled out of the nine multiple-choice questions. Two of the research questions showed no significant difference in the variables and one research question did have a positive result.

Research question 1, "will there be a difference in understanding of electrolytic and galvanic processes between the experimental treatment and control group students over time?" had no significant differences in the interaction of time and treatment. This was found for the entire test and again when smaller groups of questions were examined.

Therefore, it can be concluded that manipulating a model of electrochemical and electrolytic cells did not improve student understanding significantly more than a standard procedure. In all sections of analysis, students in the control group achieved approximately the same mean total score on the post-test as the students who were in the treatment group (Tables 4.3, 4.9, 4.14, 4.19, and 4.24).

Research question 2, "will there be a significant difference between the pre- and post- test scores in both the experimental treatment and control group students?" had statistically significant results across all 5 levels of analysis. This was not unexpected as students in both the control and treatment groups had very little knowledge or experience with electrochemical and electrolytic cells prior to the Electrochemistry Unit of Grade 12 Chemistry. For example, on the open-ended question section of the pre-test, scores (OE1, $M = 0.46$ and OE2, $M = 0.20$) showed very little knowledge of electrochemical and electrolytic cells (Table 4.8 and Table 4.13). Scores on the pre-test were very low in all 5 sections of analysis. As a result, scores on the post-tests of all 5 levels of analysis yielded statistically significant differences. One specific example was open-ended question 1 had a mean total score on the pre-test of 0.46 which improved to a mean score on the post-test of 3.67.

Research question 3, "will there be a difference between school/instructor treatment interaction over time?" yielded one statistically significant interaction but the other four levels resulted in no statistically significant differences. When examining the full test 25 question multiple-choice section, a statistically significant result ($p=0.02$) was found. The significance was due to a difference in the patterns between the four research groups. There was very little growth in understanding from pre- to post-test by this group while two other groups scored similar on both pre- and post-tests. It was interesting to note that Instructor 1's control group had the highest post-test score (M= 16.31). Reasons for this anomaly will be discussed in the next section but at this stage of the discussion it is suggested that researcher bias was a possibility for this result.

With the other four levels of analysis for research question 3, there were no statistically significant results. Interestingly, the scores for the students taught by Instructor 1 were much higher on the post-test than the scores of the students taught by Instructor 2. An example of this was shown in the analysis of open-ended question 2 in which Instructor 1's students mean scores on the post-test were 3.38 (control) and 3.08 (treatment) while Instructor 2's students mean scores on the post-test were 2.17 (control) and 2.29 (treatment), see table 4.13. Therefore, when the time by instructor interaction was explored it showed a statistically significant result across all five levels of analysis. That is to say that there was a significant difference in the total scores over time for the two instructors. So, although the model manipulation treatment had no significant effect on understanding of electrochemical and electrolytic cells, there was a difference in the results of the two instructors over time. Again, it is inferred that this difference can be attributed to researcher bias which will be discussed further in the next section.

5.5 Observations and Limitations of the Study

During the course of the study and after the analysis of results was completed, several limitations became evident. First, this study took place over a two-week period in which the students took the pre-test, completed the electrochemistry unit, and completed the post-test. This unit is one that the students have never been exposed to in their academic careers. This is a complex topic to address in only two weeks and therefore, the results of this study may have been affected by the short time period of the overall unit and the even shorter time devotion to the intervention strategy. The focus of this research project was to support students in their learning of conceptually complex chemistry concepts, but unfortunately this instruction occurred within an abbreviated instructional time allowance. In all, it is suggested that the model manipulation accounted for as little as 90 minutes of instructional time during the two to three week entire unit. Simply put, the intervention was likely under-developed in its ability to cause meaningful learning to occur. There is little evidence gathered through the use of pre- and post-test scores that students were actually learning during and through the manipulation of the model. Perhaps, if the students had had more time to interact with the model of electrochemical and electrolytic cells, the results might have been more positive for supporting greater comprehension of this electrochemical unit of grade 12 Chemistry. As well, perhaps if the procedure for data collection allowed me as a researcher to interact with students as they were manipulating of the model I would have been a position to determine of the efficacy of the model for supporting learning as it was being manipulated.

Secondly, there were only two weeks between the pre-test and the post-test. It is possible that there may have been some test recall that occurred. This may have been an important bias especially for the open-ended questions. Although the pre-tests were not given back to the students, they may have recalled that they needed to draw a cell and, therefore, remembered the appropriate diagrams for an electrochemical and electrolytic cell thereby increasing their pre- to post-test score significantly. To alleviate this possible effect, I would suggest that a further delayed test might have been conducted. This would not only minimize test recall, but, also assist in determining if student understanding of electrochemistry over long term is fostered by focusing on a particulate manipulative.

Third, the selection of participants was not random. The researcher chose groups based on the school time-table and students make choices for enrolling in classes on mass for different reasons. Students may choose to study because their friends have chosen a particular section or because chemistry is in the same selection block as another preferred class. It is possible that students in either the experimental or control groups were attitudinally or intellectually different. The groups may not have been balanced in terms of willingness to manipulate a model for a deeper understanding of electrochemical and electrolytic cells. It is suggested that the researcher may have examined students' Chemistry related attitudes to gauge the similarity of the classes in terms of their attitudes to chemistry and the learning of chemistry. This could have been done using the Test of Science Related Attitudes, which is a questionnaire that ranks students' responses regarding science attitudes using a Likert-type scale. The social importance of science, openness to new ideas, interest in science classes, preference for experimentation, science careers, and science leisure are the six broad categories assessed with the questionnaire (Smist, Archambault, & Owen, 1994). By using this questionnaire, the researcher could have assessed the students participating in the study to see if one group was more vested in doing well in Chemistry than another group. If one group showed more interest in the subject, they may have had more motivation for doing well and improving significantly from pre- to post-test.

Most importantly it is suggested by the researcher that there was researcher bias displayed in her instructional protocols. One control class and one experimental class were taught by the researcher. In reflection of my teaching, I believe there was carry-over from experimental to control in which the teacher-researcher put extra emphasis on the drawing and understanding of the electrochemical and electrolytic cells. In other words, there was a greater focus on electron movement and ionic movement than perhaps was discussed in Instructor 2's control class. It is important to note that Instructor 2 was taught about the use of the model *after* he had instructed the electrochemical sequence to his control class. Prior to this he had had little exposure to or encouragement for teaching with emphasis on the molecular level. Therefore, this may explain why the time x treatment x instructor analysis was not statistically significant for Instructor 1, whereas it was for Instructor 2 (Table 4.6).

5.6 Recommendations and Implications for Future Research and Teaching

Although results of this study were not conducive to the promotion of teaching with model manipulations, it is my opinion based upon my observations of students learning chemistry from a 'three-modes' of representation' approach that the particulate level of Chemistry learning and understanding must play a major role in the instruction of Grade 12 Chemistry. I make this claim even though my own research and the research literature, as yet, show little benefit of using the particulate nature for promoting Chemistry learning and understanding for high school students. The findings of this study do offer a few recommendations for future research and teaching for integrating the particulate level in high school Chemistry instruction.

First more research needs to be completed on the use of the three modes of representation in the teaching of chemistry. Especially important is the need for other researchers to take consideration of the limitation of study mentioned in the previous section in developing their research methodology. Further, the research should potentially address different concepts where a particulate emphasis is not usually considered by teachers.

Second, teachers need specific curricula including examples, diagrams and teaching suggestions using the particulate nature of Chemistry. Perhaps if teachers had a document that outlined examples of the particulate level of different chemical phenomena, they would be more likely to understand their chemistry better and be able to use it in their instruction sequence. Also, the more comfortable the teachers become at instructing using the particulate level, the more comfortable the students will become at thinking at the particulate level. It would follow that students would have a better understanding of Chemistry, because they would be exposed to not only the macroscopic and symbolic levels but also the particulate level, therefore making their experience with Chemistry rounded and complete.

Third, not only is there a need for the particulate level in Chemistry curricula but also in Chemistry texts. If textbooks had activities and visual aids that focused on the particulate nature, students would be exposed yet again to the third level of Chemistry learning and understanding. Therefore, a text enhanced by illustrations and activities focusing on the particulate level would aid in bridging the gap between the macroscopic and symbolic levels prevalent in Chemistry textbooks of the past.

Forth, this study focused on the use of one particulate strategy. Perhaps if multiple strategies had been employed, a statistically significant observation may have resulted. The multiple strategies could have included a model, computer animations, drawings, interaction with text, and interaction with the class notes. The researcher recognizes that in this study students used a script in following a procedure in using the manipulative. Possibly this script prevented students from working at a meaningful cognitive level when using the manipulative. In this research intervention only one scripted strategy was used to support learning. In Chapter Two, Osborne and Wittrock's (1983) Generative Learning Model was discussed. This model emphasizes that learning is best fostered by repeating cycles of instruction using varying representations to assist students in their learning. Obviously, this claim suggests that time must be taken to assist students in their learning. As I look at my model intervention I realize that the intervention to support learning was likely compromised by how quickly the instruction model was used and how little opportunity there was to support students in their learning. I realize the importance of wanting to know if and what students actually learned from the model and their response to the model as an instructional tool. If it was helpful, how was it helpful? If not, why not? These questions did not enter into my research activity, and in reflection, I believe they were questions that should have been addressed through my research agenda.

The researcher touched briefly on the connection between the short-term memory and sensed experience called "Tested against sensed experience" (Fig. 2.1). In order for the students to actively construct acceptable meaning, Osborne and Wittrock suggest that learners must be able to test the new knowledge against real-life experiences and their long-term memories. Electrochemistry was a new topic for the majority of students, and, therefore, they probably needed many opportunities to construct meaning by way of sensed experiences. This study allowed the experimental groups one such opportunity. Had there been numerous opportunities using multiple strategies, the chance for "intelligible, plausible and useful" (Osborne & Wittrock, 1983, p. 495) learning might have occurred.

Finally, there needs to be research done on what is effective professional development for teachers of Chemistry. What processes assist teachers in implementing the three modes of representation into their teaching? Without professional development, will teachers be able to make sense of or appropriately use the particulate level in their classrooms? Additionally, it must be asked: what constitutes good professional development? Does it need to be at the macroscopic level, the symbolic level, or the particulate level? Or, does professional development need to show how to incorporate all three levels in the instruction of high school Chemistry? As well, how do students respond to the strategies teachers are using in their teaching? Are there particular particulate strategies that assist students in their learning? If there are, what characteristics of these strategies promote learning?

5.7 Conclusions

This study looked at the use of a model interaction within the topic of electrochemistry in the Grade 12 Manitoba Chemistry Curriculum. The *Grade 12 Chemistry – A Foundation for Implementation* states that "[l]earning involves the process of linking newly constructed understandings *with* prior knowledge, and then adding new contexts and experiences to current understandings" (p. 3). The facilitation of this type of learning was the goal of this study. I believed that the use of the electrochemical and electrolytic models would have promoted a deeper understanding of the processes and therefore significant learning would have occurred. According to the data analysis, these results were not achieved.

I am still optimistically positive that the use of particulate strategies will enhance the learning for students, especially in topics like electrochemistry where the students have had very limited exposure. For learning to occur, the students need to be exposed not only to the macroscopic teaching of notes and diagrams, and to the symbolic representations of the balanced chemical equations of electrochemistry, but also to the particulate level of Chemistry learning. Perhaps the use of particulate level interactions throughout the Chemistry course across all units of study would facilitate learning and understanding. Possibly students need to be assisted in developing an appreciation that understanding about what molecules and atoms actually do can assist them in developing a better understanding of chemistry phenomena in general. If they can see the importance of knowing what molecules are doing, they have a stronger inclination to learn when teachers are addressing the molecular level. I am pleased to see that the new 2008 draft copy of the Grade 12 Chemistry curriculum states specific learning outcomes of "explain the operation of a voltaic (galvanic) cell at the visual, particulate and symbolic levels" and "explain the operation of an electrolytic cell at the visual, particulate and symbolic levels" (http://www.edu.gov.mb.ca/k12/cur/science/scicurr.html). This includes the interaction of the students with multiple particulate examples such as models, computer animations, and other hands-on strategies focusing on the ions, electrons and molecules within the electrochemical and electrolytic cells.

When students interact with Chemistry on all three of Johnstone's levels (1991), the macroscopic, the symbolic and the particulate, they may develop a greater understanding of the most difficult topics in Chemistry. With more exposure to the three levels the students might be able to interact with the chemical phenomena and explore them in greater depth by asking questions and hypothesizing potential results in very much the same way that many famous scientists of our past had. As Galileo Galilei stated, "[y]ou cannot teach a man anything; you can only help him find it within himself." It is our goal as educators to help our students construct an understanding of Chemistry through experiences with the chemical phenomena that surrounds them everyday. It is still my belief as evidenced in my ongoing teaching practice that incorporating the particulate mode of representation in my teaching assists students in their journey of learning. I look forward to watching the ongoing research development in this area. Potentially this study can assist others in further addressing this important area in chemistry education.

References

Brandt, L., Elen J., Hellemans, J., Heerman, L., Couwenberg, I., Volckaert, L., & Morisse, H. (2001). The impact of concept mapping and visualization on the learning of secondary school chemistry students. *International Journal of Science Education, 23*(12), 1303 – 1313.

Eisner, E. W. (1979). Five basic orientations to the curriculum. Chapter 4 in *The Educational Imagination.* New York: Macmillan, pp. 50 – 70.

Eisner, E. W. (1994). Curriculum Ideologies. In *The Educational Imagination: On the Design and Evaluation of School Programs* (3rd ed.) (pp. 47-83). New York: Macmillan.

Gabel, D. (1999). Improving Teaching and learning through chemistry education research: A look to the future. *Journal of Chemical Education, 76*(4), 548 – 554.

Garnett, P.J., Garnett, P.J., & Hackling, M.W. (1995). Students' alternative conceptions in Chemistry: A review of research and implications for teaching and learning. *Studies in Science Education, 25*, 69 – 95.

Garnet, P.J., & Treagust, D.F. (1992). Conceptual difficulties experienced by senior high school students of electrochemistry: Electrochemical (galvanic) and electrolytic cells. *Journal of Research in Science Teaching, 29,* 1079 – 1099.

Hewson, P.W., Beeth, M.E., & Thorley, N.R. (1998). Teaching for Conceptual Change. *International Handbook of Science Education*, 199 – 218.

Johnstone, A.H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning, 7*, 75 – 83.

Johnstone, A.H. (2000). Teaching of chemistry – logical or psychological? *Chemistry Education: Research and Practice in Europe, 1*(1), 9 – 15.

Jonassen, D.H., Peck, K.L., & Wilson, B.G. (1999). *Learning with technology: A constructivist perspective.* Columbus: Merrill, pp. 164 – 180.

Lewthwaite, B. (2003). Improving teaching and learning in chemistry.

McGraw-Hill (2005). Chemistry: Matter and Change. New York, pp. 971-972.

Miller, J.P., & Seller, W. (1985). The Curriculum Process. In *Curriculum Perspectives and Practice.* New York: Longman, pp. 3 – 16.

Osborne, R.J. & Wittrock, M.C. (1983). Learning science: A generative process. *Science Education, 67*(4), 489 – 508.

Özkaya, A.R. (2002). Conceptual difficulties experienced by prospective teachers in electrochemistry: Half-cell potential, cell potential, and chemical and electrochemical equilibrium in galvanic cells. *Journal of Chemical Education, 79*(6), 735 – 738.

Province of Manitoba. (1966). *University Entrance Course Chemistry 300 Grade XII.* Winnipeg: Department of Education Curriculum Branch.

Province of Manitoba. (1972). Chemistry *200- 300 (Teaching Guide).* Winnipeg: Department of Education Curriculum Branch.

Province of Manitoba. (1984). *Chemistry 200, 300 Interim Guide.* Winnipeg: Department of Education Curriculum Branch.

Province of Manitoba. (1990 reprinted). *Chemistry 200, 300.* Winnipeg: Department of Education Curriculum Branch.

Province of Manitoba. (1998). *Senior 4 Chemistry (40S) Topic 6.4 Electrolytic Cells Prescribed* Outcomes. Retrieved October 11th, 2004 from http://www.edu.gov.mb.ca/ks4/cur/science/ch40s/main/ch40s64.html

Province of Manitoba. (1998). Senior *4 Chemistry (40S) Units.* Retrieved October 11th, 2004, from http://www.edu.gov.mb.ca/ks4/cur/science/ch40s/main/ch40s.html

Province of Manitoba. (2007). Grade *12 Chemistry – A Foundation for Implementation.* Retrieved April 4, 2008, from http://www.edu.gov.mb.ca/k12/cur/science/found/gr12_chem/intro.pdf

Ritchie, D., & Volkl, C. (2000). Effectiveness of two generative learning strategies in the science classroom. *School Science and Mathematics, 100*(2), p. 83 – 89.

Sanger, M.J. (2004). Computer animations in chemistry: What we have learned. *Review of Computer Animation Research.* Retrieved October 18th, 2004, from http://faculty.cns.uni.edu/~sanger/Review.htm.

Sanger, M.J., & Greenbowe, T.J. (1997a). Student's misconceptions in electrochemistry: Current flow in electrolyte solutions and the salt bridge. *Journal of Chemical Education, 74*(7), 819 – 823.

Sanger, M.J., & Greenbowe, T.J. (1997b). Common student misconceptions in electrochemistry: Galvanic, electrolytic, and concentration cells. *Journal of Research in Science Teaching, 34*(4), 377 – 398.

Sanger, M.J., & Greenbowe, T.J. (2000). Addressing student misconceptions concerning electron flow in aqueous solutions with instruction including computer animations and conceptual change strategies. *International Journal of Science Education, 22*(5), 521 – 537.

Sewell, A. (2002). Constructivism and student misconceptions: Why every teacher needs to know about them. *Australian Science Teachers' Journal, 48*(4), 24 – 28.

Shulman, L.S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1 – 22.

Smith, J.P., diSessa, A.A., & Roschelle, J. (1993). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *The Journal of the Learning Sciences, 3*(2), 115 – 163.

Stinner, A. (1993). The LEP model – A heuristic model for the teaching of science. University Press: University of Manitoba.

Appendix 1 - Pre/Post-Test

Please answer the following questions to the best of your ability. You will not be marked on your answers; it is only for informational purposes only.

Part 1: Draw

1) Draw a copper/zinc electrochemical cell. Label all the necessary parts including the solution in the beakers, the voltmeter/potentiometer, the salt bridge, and the metal electrodes

2) Draw an electrolytic cell showing the electrolysis of potassium iodide. Label all the necessary parts including the solution in the U-tube, the electrical leads, the power source, and the carbon electrodes

*****Please hand this sheet in and get Part 2*****

Part 2: Multiple Choice

1) Which best describes the contents of a beaker containing water and zinc sulfate?
   a) $ZnSO_4$ and water
   b) Zn^{2+} and water
   c) SO_4^{2-} and water
   d) Zn^{2+} and SO_4^{2-} and water

2) Which best describes the contents of a beaker containing water and copper (II) sulfate?
   a) $CuSO_4$ and water
   b) Cu^{2+} and water
   c) SO_4^{2-} and water
   d) Cu^{2+} and SO_4^{2-} and water

3) In the electrolysis of potassium iodide:
   a) potassium ions gain electron to form potassium atoms
   b) iodide ions lose electrons to form iodine atoms
   c) iodide ions gain electrons to form iodine molecules
   d) water molecules lose electrons to form hydroxide ions

4) Which of the following is a contributor to an electric circuit?
   a) flow of positive charge through a metallic medium
   b) flow of negative charge through the electrolytic solution
   c) flow of negative charge through a metallic medium
   d) flow of positive charge throughout the entire system

5) In electrochemical cells, oxidation occurs at the ____________ and reduction occurs at the _________________
   a) cathode/anode
   b) cathode/cathode
   c) anode/cathode
   d) anode/anode

6) The cathode in electrochemical cells always go:
   a) on the left
   b) on the right
   c) with the reducing reaction
   d) with the oxidizing reaction

7) What will occur at the surface of inert electrodes?
   a) nothing
   b) an oxidation
   c) a reduction
   d) either oxidation or reduction

8) The ____________ terminal of the battery is attached to the _____________
   a) negative/anode
   b) positive/anode
   c) positive/cathode
   d) doesn't matter

9) What is the purpose of the salt bridge?
   a) to close the circuit
   b) to allow ion transfer
   c) to allow electron transfer
   d) to make the voltmeter work

10) To make an electrolytic cell work, it need a(n):
   a) salt bridge
   b) electron
   c) power source
   d) nothing, it's spontaneous

11) In an electrochemical cell involving zinc metal in a zinc sulfate solution and copper metal in a copper (II) sulfate solution, which of the following occurs on the surface of the cathode?
a) zinc atoms are reduced to form zinc ions
b) zinc ions are oxidized to form zinc atoms
c) copper atoms are reduced to form copper ions
d) copper ions are reduced to form copper atoms

12) Which of the following is true about electrochemical cells?
a) cations and anions move until their concentrations are uniform
b) half cells must be electrically neutral
c) one half cell has positive ions and the other has an equal number of negative ions
d) half cells don't have to be electrically neutral

13) In the electrolysis of potassium iodide, a series of steps occur and hydrogen gas is produced at one of the electrodes. This occurs because:
a) water is decomposed by the electrical input source
b) hydrogen ions gain electrons from the electrode and then bond covalently to form a hydrogen molecule
c) electrons attach to water molecules to form hydrogen gas and hydroxide ions
d) potassium iodide reacts with water to form hydrogen gas and potassium iodate

14) The function of the salt bridge is to:
a) allow electron flow
b) allow proton flow
c) complete the circuit by providing electrons
d) complete the circuit by providing ions

15) How do electrons flow through the electrolytic system?
a) from anode to cathode through the wires
b) from anode to cathode through the solutions without ionic assistance
c) through the solution from the cathode to the anode
d) through the solution be being attracted from one ion to the other

16) In electrolytic cells, oxidation occurs at the __________ and reduction occurs at the_________.

a) cathode/anode	b) anode/cathode
c) cathode/cathode	d) anode/anode

17) In an electrolytic cell made by passing a current through a solution of potassium bromide and water, which species remains unreactive?

a) potassium ions	b) bromide ions
c) water	d) none of the above

18) In electrolysis, reactions only occur because:
   a) one of the reacting species is a strong oxidant
   b) stable ions and molecules are made unstable by energy input from the power source
   c) one of the species is a strong reductant
   d) the reactants combine spontaneously

19) The calculated cell potential in electrolytic cells can be making the cell:
   a) positive therefore, spontaneous
   b) negative therefore, non-spontaneous
   c) either positive or negative
   d) none of the above

20) In electrolytic cells with identical electrodes (ie, 2 carbon electrodes) connected to a battery, what will occur?
   a) nothing will occur
   b) the same reaction at both electrodes
   c) oxidation at one electrode and reduction at the other electrode
   d) an oxidation at both electrodes

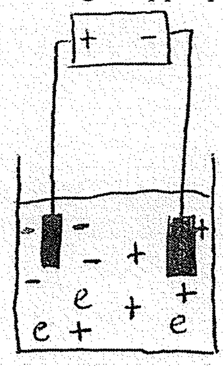
21) In an electrochemical cell, the anode always goes:
   a) on the left
   b) on the right
   c) with the reducing reaction
   d) with the oxidizing reaction

22) How do electrons move through an electrochemical cell?
   a) throughout the entire system
   b) from one electrode to another through the wire
   c) from one electrode to another through the salt bridge
   d) they are not moving
   because: i) they must have a metal medium to travel
   ii) they must have a liquid medium to travel
   iii) they are the only moving sub-atomic particle so they must be all over the system
   iv) they are sub-atomic and contained within the nucleus of each atom

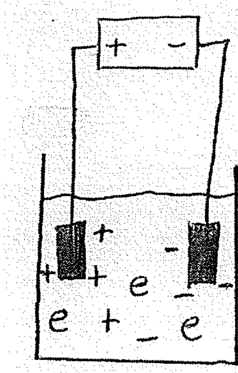
23) In electrochemical cells:
   a) one metal has to be more reactive than the other
   b) a power source is necessary
   c) the metals are connected through a salt bridge
   d) water becomes an electron donor

24) Which drawing is appropriate for an electrolytic cell?

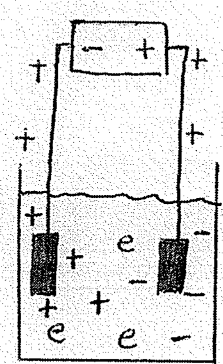
a)



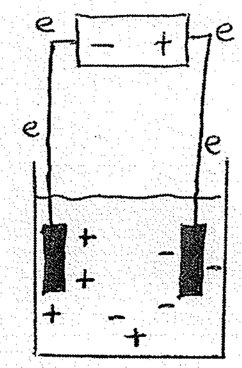
b)



c)

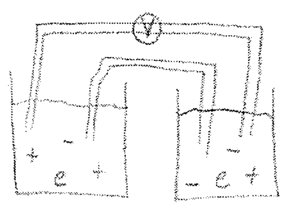


d)

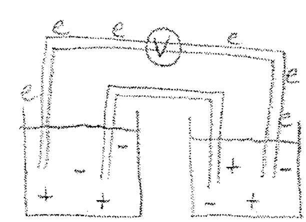


25) Which drawing best represents an electrochemical cell?

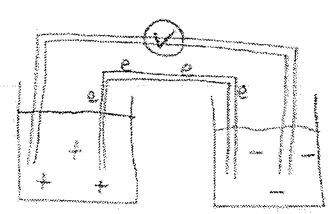
a)



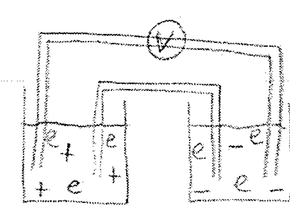
b)



c)



d)



Appendix 2 – Lab Scripts

Electrolysis

MACRO

Day 1 – Prelab Exercise:

In the diagram below, the apparatus used in the electrolysis of a solution of potassium iodide is presented. With teacher instruction, your apparatus as a group will be set up in a similar manner. **At this stage only, connect one lead to the battery.**

Label the: (1) solution in the U-tube
(2) electrical leads
(3) power source
(4) carbon electrodes

Day 2 Laboratory Level – Instructional Sequence:

(1) We will begin by describing and clarifying the role of the equipment in the experimental setup **with special emphasis on the stability of the species in the U-tube.** Use the space below to document aspects of this discussion that are important to you in the development of your understanding.

(2) Now connect the final lead to the battery. On the basis of your observations, begin by describing all **evidence** that suggests a chemical reaction is occurring. You may wish to illustrate this on the diagram. This evidence, especially the chemical tests performed, should assist you in identifying the products formed at each electrode. **List these products alongside the evidence observed.**

COLORS:	
Red = hydrogen	Yellow = iodine
Orange = oxygen	Blue = potassium

MICRO

****Intervention ONLY****

(3) Using the model of the electrolytic cell described and illustrated in class, fully explain (you may wish to illustrate as well):

(a) If one blue ball plus one yellow ball equals potassium iodide (KI), what would:

i. when the KI is put into the water, what happens to the KI? Will it make K atoms and I atoms? Will it make K^+ ions and I^- ions?

ii. the yellow ball be if it were separate? An iodine atom? An iodide ion? How do we represent the yellow ball in chemical symbols?

iii. The blue ball be if it were separate? A potassium atom? A potassium ion? How do we represent the blue ball in chemical symbols?

(b) If two red balls and one orange ball equals water (HOH), what would:

i. one red ball be if it were separate? A hydrogen atom? A hydrogen ion? How would we represent the one red ball in chemical symbols?

ii. One red and one orange be if they were separated from the other red ball? An oxygen atom? A hydroxide ion? How would we represent the red and orange balls in chemical symbols?

(c) How reactive are the species in the solution? Are the K^+ ions reactive or unreactive? Are the I^- ions reactive or unreactive? Are the water molecules reactive or unreactive? If they are all unreactive, what would make them become reactive?

(d) Where are the individual electrons (not attached to plasticine) in the system? Are they ever alone in the box?

(e) Remove 2 electrons from two iodide ions and push them through the tube.

i. What should the two new, different atoms do to ensure a stable octet?

ii. Which of the following equations represent what just happened?

$$2I^- \rightarrow I_2 + 2e^-$$
$$2I_2 + 2e^- \rightarrow 2I^-$$

(f) What happens in the electron tube (wire) when you pushed the two electrons through in the above question? Where did they come out?

(g) Water will dissociate into one red ball and one red and orange ball. How would we represent this? H^+ and OH^-? H and OH? H and O?

(h) Place the two "new" electrons into two hydrogen ions formed from the dissociated water.

i. What should the new, different atoms do to ensure a full valence shell?

ii. Place the following reactions in order of what just happened:

$2H_2O + 2e^- \rightarrow 2OH^- + H_2$ (overall reaction)

$H_2O \rightarrow H^+ + OH^-$ (water dissociating)

$H^+ + e^- \rightarrow H$ (hydrogen ions forming hydrogen atoms)

$H + H \rightarrow H_2$ (hydrogen atoms forming molecular hydrogen)

(i) Which of the ions were not used at all in the cell?

SYMBOLIC

Closure – For all students.

(4) Using the demonstration model of the electrolytic cell described and illustrated in class, fully explain (and/or draw):

(a) the role of the power source
(b) the role of the electrical leads
(c) the role of the carbon electrodes
(d) the movement of electrons through the circuit
(e) the movement of anions and cations in the solution

(5) At the symbolic level, use chemical formulae to represent:

(a) what is happening at the anode (loss of electrons)
(b) what is happening at the cathode (gain of electrons)
(c) the overall cell reaction including overall cell potential

(6) At the sub-microscopic level, explain why this reaction:

(a) does not result in the formation of potassium at the cathode
(b) does not occur spontaneously
(c) makes the iodide ions lose electrons, and the water molecules gain electrons.

Electrochemical Cells

MACRO

Day 1 - Pre-lab Exercise:

In the diagram below, the apparatus used in the setup fro the copper-zinc voltaic cell is presented. With teacher instruction , your apparatus as a group will be set up in a similar manner. **At this stage only, place only one end of the salt bridge into the electrolyte solution.**

Label the: (1) solution in the beakers
(2) voltmeter/potentiometer
(3) salt bridge
(4) the metal electrodes

Day 2 Laboratory Level – Instructional Sequence:

(1) We will begin by describing and clarifying the role of the equipment in the experimental setup. Use the space below to document aspects of this discussion that are important to you in the development of your understanding.

(2) **Now you may place the other end of the salt bridge into the electrolyte solution.** On the basis of your observations, begin by describing all evidence that suggests a chemical reaction is occurring. You may wish to illustrate this on the diagram. This evidence, especially the chemical test performed, should assist you in identifying the products formed at each electrode. List these products alongside the evidence observed.

COLORS:	
Red = copper	Yellow = sulfate ions
Blue = zinc	

MICRO

****Intervention ONLY****

(3) Using the model of the electrochemical cell described and illustrated in class, fully explain (you may wish to illustrate as well):

(a) If the red balls represent copper and the marbles are electrons, what does:

i. a red ball without marbles represent? A copper atom? A copper ion? How would we represent this in chemical symbols? Where in the system would these go?

ii. a red ball with marbles represent? A copper atom? A copper ion? How would we represent this in chemical symbols? Where in the system would these go?

(b) If the blue balls represent zinc and the marbles are electrons, what does:

i. a blue ball without marbles represent? A zinc atom? A zinc ion? How would we represent this in chemical symbols? Where in the system would these go?

ii. a blue ball with marbles represent? A zinc atom? A zinc ion? How would we represent this in chemical symbols? Where in the system would these go?

(c) In the electrolyte solution (the center part), balance the number of red and blue balls on either side of the bridge with yellow balls which represent sulfate ions.

i. what does one red + one yellow make? How would we represent this in chemical symbols?

ii. what does one blue + one yellow make? How would we represent this in chemical symbols?

(d) Where are the individual electrons (not attached to plasticine) in the system? Are they ever alone in the box?

(e) Remove 2 electrons from one zinc atom and push them through the tube.

i. Where should the new zinc ion go?

ii. Which of the following equations represent what just happened?

$$Zn \rightarrow Zn^{2+} + 2e^-$$

$$Zn^{2+} + 2e^- \rightarrow Zn$$

(f) What happens in the electron tube (wire) when you pushed the two electrons through in the above question? Where did they come out?

(g) Place the two "new" electrons into a copper ion from the solution.

i. Where should the new copper atom go?

ii. Which of the following equations represent what just happened?

$Cu \rightarrow Cu^{2+} + 2e^-$

$Cu^{2+} + 2e^- \rightarrow Cu$

SYMBOLIC

Closure – For all students.

(4) Using the demonstration model of the galvanic cell described in class, fully explain (and/or draw):

(a) What is happening at the particle level in terms of ions, atoms, and electrons to cause the changes at one of the electrodes. You should be able to explain, as well, precisely where this is occurring.

(b) What is happening at the particle level in terms of ions, atoms, and electrons to cause the changes at the *other* electrode. Again, you should be able to explain, precisely where this process is occurring.

(c) The role of the metallic electrodes.

(d) The role of the wire

(e) The role of the salt bridge

(f) The movement of electrons through the circuit.

(g) The movement of anions and cations in the solution

(5) At the symbolic level, use chemical formulae to represent:

(a) what is happening at the anode (loss of electrons)

(b) what is happening at the cathode (gain of electrons)

(c) the overall cell reaction

(6) Furthermore, explain, at the particle level, why this reaction occurs spontaneously.

Appendix 3 – Rubric for the Open-Ended Questions

CATEGORY	4	3	2	1	0
Electrochemical Cells	All assigned details have been added. These are the solutions, the voltmeter, the salt bridge, and the electrodes.	Three of the assigned details have been added.	Two of the assigned details have been added.	One of the assigned details has been added.	Zero assigned details have been added. No Response.
Electrolytic Cells	All assigned details have been added. These are the solutions, the voltmeter, the salt bridge, and the electrodes.	Three of the assigned details have been added.	Two of the assigned details have been added.	One of the assigned details has been added.	Zero assigned details have been added. No Response.

Appendix 4 – Letters to Principal and Superintendents of the School Division

Letter to Principals

Research Project Title: Demystifying Misconceptions in Senior 4 Electrochemistry.
Researcher: Mrs. T. Romu

Dear Principal,

As part of my Masters' Thesis for my Masters' of Education through the University of Manitoba, I need to implement an activity requiring data collection from some of your students. This letter outlines the study intent and what is being requested of students. If you have any concerns associated with this activity occurring in your school and including the participation of two Chemistry 40S classes, please contact me.

The focus of my study is outlined below:

Typically, Chemistry teaching has focused on abstract and theoretical approaches requiring students to make the leap from observable qualities of chemical phenomena to abstract yet logical balanced chemical equations. Throughout years of theoretical teaching pedagogy, there has been a key link that has been absent for the student to be able to make intelligible and meaningful connections between the observable phenomena and the logical algorithms of Chemistry.

My primary research is based on the following hypotheses:
(a) there will be a difference in understanding of electrolysis between the experimental treatment and comparable control group students over time
(b) there will be a significant difference between the pre- and post- test scores in both the experimental treatment and control groups students
(c) there will be no difference between school 1 and school 2 in terms of understanding of electrolysis and student scores over time.

In order to complete my research, data from four Chemistry classes will be compared. Two classes will be the control classes, being taught standard lesson plans that coincide with the Manitoba Chemistry curriculum. The other two classes will also be taught standard lesson plans but will be given an opportunity to manipulate two models that represent electrochemical and electrolytic cells. The new information introduced will not cause any more stress on students than that already associated with learning Chemistry. Participants will not be tested for marks on the treatment presented.

The four classes will be asked to complete a pre-test at the beginning of the unit and a post-test at the end of the unit. The pre-and post-tests will consist of mainly multiple-choice questions along with two drawing questions. Any information collected from the pre/post-tests will be analytical purposes only. There will be no extra time required, outside of the regularly scheduled Chemistry classes. All data obtained in this study will be kept by a third party teacher until the end of the semester and then destroyed after completion of my thesis. Participation in the study is entirely voluntary and anonymous. Any students participating in

the study may have a summary of the research results mailed out to them by completing the attached portion on their consent form.
The research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact the Human Ethics Secretariat at 474-7122, or e-mail margaret_bowman@umanitoba.ca.

Thank-you for your continued support of my Masters' Thesis work.

Sincerely,

Mrs. Tracy Romu

Letter to Superintendents

Research Project Title: Demystifying Misconceptions in Senior 4 Electrochemistry.
Researcher: Mrs. T. Romu

Dear Superintendent,

Thank-you for your consideration of my Masters' Thesis application for a Masters' of Education from the University of Manitoba. The application has been successful and an initiative is being actioned, pending your approval, in two of the. This letter outlines the study intent and what is being requested of students. If you have any concerns with this research activity please contact me.

The initiative for my study is outlined below:

Typically, Chemistry teaching has focused on abstract and theoretical approaches requiring students to make the leap from observable qualities of chemical phenomena to abstract yet logical balanced chemical equations. Throughout years of theoretical teaching pedagogy, there has been a key link that has been absent for the student to be able to make intelligible and meaningful connections between the observable phenomena and the logical algorithms of Chemistry.

My primary research is based on the following hypotheses:
(a) there will be a difference in understanding of electrolysis between the experimental treatment and comparable control group students over time
(b) there will be a significant difference between the pre- and post- test scores in both the experimental treatment and control groups students
(c) there will be no difference between school 1 and school 2 in terms of understanding of electrolysis and student scores over time.

In order to complete my research, data from four Chemistry classes will be compared. Two classes will be the control classes, being taught standard lesson plans that coincide with the Manitoba Chemistry curriculum. The other two classes will also be taught standard lesson plans but will be given an opportunity to manipulate two models that represent electrochemical and electrolytic cells. The new information introduced will not cause any more stress on students than that already associated with learning Chemistry. Participants will not be tested for marks on the treatment presented.

The four classes will be asked to complete a pre-test at the beginning of the unit and a post-test at the end of the unit. The pre-and post-tests will consist of mainly multiple-choice questions along with two drawing questions. Any information collected from the pre/post-tests will be analytical purposes only. There will be no extra time required, outside of the regularly scheduled Chemistry classes. All data obtained in this study will be kept by a third party teacher until the end of the semester and then destroyed after completion of my thesis. Participation in the study is entirely voluntary and anonymous. Any students participating in the study may have a summary of the research results mailed out to them by completing the attached portion on their consent form.

The research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact the Human Ethics Secretariat at 474-7122, or e-mail margaret_bowman@umanitoba.ca.

Again, thank-you for your continued support of my Masters' Thesis work.

Sincerely,

Mrs. Tracy Romu

Appendix 5 – Student Assent Form

Assent Form for Students

Research Project Title: Demystifying Misconceptions in Senior 4 Electrochemistry.
Researcher: Mrs. T. Romu

This assent 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 not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Dear Student,

Typically, Chemistry teaching has focused on abstract and theoretical approaches requiring students to make the leap from observable qualities of chemical phenomena to abstract yet logical balanced chemical equations. Throughout years of theoretical teaching pedagogy, there has been a key link that has been absent for the student to be able to make intelligible and meaningful connections between the observable phenomena and the logical algorithms of Chemistry. My research aim for my Master of Education thesis for the Faculty of Education at the University of Manitoba, is to investigate how the inclusion of the sub-microscopic level of Chemistry learning will affect how students view and learn electrochemistry.

In order to complete my research, data from four Chemistry classes will be compared. To keep student identities anonymous, a third party will collect all information. Two classes will be the control classes, being taught standard lesson plans that coincide with the Mantioba Chemistry curriculum. The other two classes will also be taught standard lesson plans but will be given an opportunity to manipulate two models that represent electrochemical and electrolytic cells. The new information introduced will not cause any more stress on students than that already associated with learning Chemistry. Participants will not be tested for marks on the treatment presented. Any information collected from the pre/post-tests will be analytical purposes only. There will be no extra time required, outside of your regularly scheduled Chemistry class. All data obtained in this study will be destroyed after completion of my thesis. Participation in the study is entirely voluntary and anonymous. Any students participating in the study may have a summary of the research results mailed out to them by completing the attached portion on the consent form.

Your signature on this form indicated that you have understood to your satisfaction the information regarding participation in the research project, and agree to participate as a subject. You are free to withdraw from the study at any time without prejudice or consequence. To withdraw, simply inform the third party teacher that you wish to withdraw. 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.

Thank you for your consideration. Please feel free to contact me, through the neutral third party teacher, if you have any questions.

Sincerely,

Mrs. T. Romu

Date: _______________

I, ________________, agree to participate in the research project. I will take the pre-test at the beginning of the unit and the post-test at the end of the unit. I understand that my pre/post-test scores will be looked at and kept anonymous.

If you are interested in a copy of the project summary once it is available, please provide your full name and mailing address below:

Appendix 6 – Parental Consent Form

Consent Form for Parents or Students of Age

Research Project Title: Demystifying Misconceptions in Senior 4 Electrochemistry.
Researcher: Mrs. T. Romu

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 not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Dear Parent/Guardian,

Your son/daughter has expressed an interest in participating in a research study to be conducted at the school. This study, which is part of my Masters of Education thesis for the Faculty of Education at the University of Manitoba, focuses on how models affect student learning in the Electrochemistry unit of Chemistry 40S. The research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact the Human Ethics Secretariat at 474-7122, or e-mail margaret_bowman@umanitoba.ca.

Typically, Chemistry teaching has focused on abstract and theoretical approaches requiring students to make the leap from observable qualities of chemical phenomena to abstract yet logical balanced chemical equations. Throughout years of theoretical teaching pedagogy, there has been a key link that has been absent for the student to be able to make intelligible and meaningful connections between the observable phenomena and the logical algorithms of Chemistry.

In order to complete my research, data from four Chemistry classes will be compared. To keep student identities anonymous, all information will be collected by a third party.

Two classes will be the control classes, being taught standard lesson plans that coincide with the Manitoba Chemistry curriculum. The other two classes will also be taught standard lesson plans but will be given an opportunity to manipulate two models that represent electrochemical and electrolytic cells. The new information introduced will not cause any more stress on students than that already associated with learning Chemistry. Participants will not be tested for marks on the treatment presented.

The four classes will be asked to complete a pre-test at the beginning of the unit and a post-test at the end of the unit. The pre-and post-tests will consist of mainly multiple-choice questions along with two drawing questions. Any information collected from the pre/post-tests will be analytical purposes only. There will be no extra time required, outside of the regularly scheduled Chemistry classes. All data obtained in this study will be kept by a third party teacher until the end of the semester and then destroyed after completion of my thesis.

Participation in the study is entirely voluntary and anonymous. Any students participating in the study may have a summary of the research results mailed out to them by completing the attached portion on the assent form.

Your signature on this form indicates that you have understood to your satisfaction the information regarding your son's/daughter's participation in the research project, and agree to allow him/her to participate as a subject. In no way does this waive your legal rights nor release the researcher from their legal and professional responsibilities. Your son/daughter is free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. To withdraw, your son/daughter must inform the third party teacher. His/her continued participation should be as informed as his/her initial consent, so you should feel free to ask for clarification or new information throughout his/her participation.

Thank you for your consideration. Please fell free to contact me.

Sincerely,

Mrs. T. Romu

Date: ________________

I, _______________, agree to having my son/daughter _____________________ participate in the research project. I understand that a copy of his/her pre/post-tests will be kept anonymously for analysis.